Role of biomass in achieving net zero: call for evidence

Response from UCL Institute for Sustainable Resources

15 June 2021

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Response to Consultation

THE BARTLETT
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Preface & summary of key messages

Preface

This response is the combined effort of members of UCL Institute for Sustainable Resources. It builds on diverse and complementary backgrounds and varied perspectives in relation to biomass and bioenergy in the UK and Global contexts. Across the team of authors, our areas of expertise cover LCA analysis of bioenergy supply chains; techno-economic modelling for long-term energy systems planning; land-use modelling; linking the global and local scale impacts of energy policy and governance; economics in relation to international trade and natural capital accounting; industrial symbiosis; circularity and waste management; sustainable agriculture and the links between resources, water, and food.

The editorial team would like to highlight two points with regards to the consultation. First, the shear breadth of the topics included in this consultation is positive, reflecting the large amount of work done by BEIS to understand key issues related to biomass and formulate vital questions around key topics. However, certain questions were difficult to answer because they include several inter-locking elements; or because they assume a given focus 'a-priori' which we challenge. Second, this area of research and political and financial interest is evolving fast but remains complex. It is not always well understood, and significant uncertainty remains in some areas. We highlight these issues in our responses where they arise.

Key messages

1. Land is the primary resource. Understanding "the best use of biomass" should then better focus on understanding "the best use of land". This hinges on its applications for carbon sequestration and environmental services. Bioenergy should not be viewed in isolation from other uses of land or crops.
2. Our strong view is that a coherent approach to land-use can only be developed collaboratively across government, involving DEFRA, the Forestry Commission, and the Treasury. This will help mitigate risk, overcome barriers to deployment and ensure long-term environmental, social and economic sustainability.
3. Focus on land-use options where there are significant co-benefits in terms of biodiversity, socio-economic impacts and ecosystem services as well as carbon removal.
4. Sustainable biomass feedstocks are and will be in limited supply with significant supply-chain risks. Strategies that reduce the size of the overall energy system by rationalising, shifting, and reducing demands – for energy, materials, and specific transport modes – should be pursued in order to reduce the carbon pressure on the energy system and thus the pressure on biomass supply options.
5. Incentives to upscale biomass production should recognise land-owners' and farmers' custodial role of land and offer reliable, long lasting, and appropriate funding to support good practices that enhance soil health, carbon balance, biodiversity, ecosystem services, livelihoods etc.
6. The social priorities of vulnerable communities – including health, safety, labour conditions of people involved in growing, harvesting and processing feedstocks – should be considered when developing biomass supply chains.
7. Biomass deployment should be limited to those sectors and specific applications which are harder to decarbonise using other routes such as electrification and hydrogen.
8. Biomass should only be used in power generation and hydrogen production if CCS is available. If CCS is delayed, biomass should not be used for these applications, as renewables are better options.
9. As context of land and biomass use is so important, careful monitoring of the whole bioenergy supply chain, including its end-use, is required to evaluate costs, carbon and other environmental and social implications. Policy and regulations (and priorities for biomass) should be changed as required.
10. The international nature of biomass supply chains, and the inherent imbalances in power that market pressures create, mean that increased biomass imports imply increased risks for human rights in vulnerable communities – particularly in relation to land governance and land rights.

Response to consultation

Biomass Availability – How much biomass can we assume the UK will have access to?

2. What is the potential size, location and makeup of the sustainable domestic biomass resource that could be derived from the a) waste, b) forestry, c) agricultural sectors, and d) from any other sources (including novel biomass feedstocks, such as algae) in the UK? How might this change as we reach 2050?

Assessments of domestic sustainable biomass potential in the UK have been published in academic, industrial, and public sector publications and reports for many years. As our knowledge of how to carry out these assessments has progressed, the total levels of "sustainable" biomass available have changed significantly, see Table 1 for a (non-exhaustive) summary of these publications. It highlights: first, that there can be a wide range between upper and lower bound assumptions suggested by a given analysis; second, that newer assessments tend to suggest lower levels of sustainable biomass are available (see AEA 2011 and 2017 assessments for 2030), especially for energy crops; third, that as our understanding on the difficulties of sustainable energy crop production has increased, assessments have focussed more on the potential for biomass from waste and residues. This has remained relatively stable across the years published in the last 10 years, with regard to the potential for both 2030 and 2050.

Table 1. Focused review of biomass availability for energy uses in the UK. Compilation by Oliver Broad, UCL-ISR, based on Broad et al., 2018[1].

Year	Organisation / Reference	2030 [TWh] Energy Crops	2030 [TWh] Wastes & residues	2050 [TWh] Energy Crops	2050 [TWh] Wastes & residues
2004	RCEP[2]			152.8 – N/A	20.8 – N/A
2007	EEA	171.0 – N/A*	100.0 – N/A		
2007	Fischer[3]	65.3 – N/A	48.3 – N/A		
2008	NNFCC	18.1 – N/A	57.0 – N/A		
2009	de Wit[4]	62.5 – N/A	62.5 – N/A		
2009	E4Tech	154.3 – N/A	146.8 – N/A		
2010	AEA[5]	22.6 - 75.9	94.6 -169.4		
2011	AEA	32.8 - 102.4	125.8 - 219.4		
2011	CCC[6]	18.1 - 24.5	80.7 - 109.4	35.1 - 67.7	72.6 - 140.3
2012	DECC[7]	28.2 - 85.9	81.8 - 110.1		
2017	AEA[8]	15.0 - 46.8	89.9 - 155.8	34.2 -172.9	109.9 – 173.7

[1] O. Broad, I. Butnar, P. Dodds, R. Holland, 2018. Identifying the Optimal Use of Biomass within a Limited Resource Base: a Case Study of the UK. EUBCE 2018 - 26th European Biomass Conference and Exhibition, Copenhagen, Denmark, May 14-17, 2018.

[2] For RCEP, EEA, NNFCC, E4Tech, see UKERC Working Paper (UKERC/WP/TPA/2010/002) The UK bioenergy resource base to 2050: estimates, assumptions and uncertainties. 31 March 2010. https://d2e1qxpsswcpgz.cloudfront.net/uploads/2020/03/the-uk-bio-energy-resource-base-to-2050-estimates-assumptions-and-uncertainties.pdf

[3] Fischer, G., Hizsnyik, E., PRIELER, S., Van Velthuizen, H., (2007) Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results.IIASA. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/refuel_assessment_of_biomass_potentials.pdf

[4] de Wit, M., Faaij, A. European biomass resource potential and costs. Biomass and Bioenergy, Volume 34, Issue 2, 2010, Pages 188-202, ISSN 0961-9534

[5] AEA. UK and Global Bioenergy Resource – Final report. ED56029. March 2011

[6] The CCC Bioenergy Review – Global and UK Bioenergy scenarios. December 2011. https://www.theccc.org.uk/publication/bioenergy-review/

[7] DECC. Bioenergy Strategy Analytical Annex. URN: 12D/078. April2012. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48338/5136-bioenergy-strategy-analytical-annex.pdf

[8] Results obtained from AEA 2017 model runs parametrising for maximum and minimum available biomass. AEA Ricarbo model available here: https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model

2017	Cadent[9]	1.6 – 5.7	73.1 – 108.6	13.9 – 117.7	83.9 – 121.5
2018	CCC Bioenergy[10]			0.0 – 79.8	95.8 – 115.1
2021	CCC CB6			18.5 -91.6	133.9 – 175.7

*N/A denotes no information on the maximum potential.

A key reason for the differences between these estimates is the difficulty of assessing levels of "sustainable" resource. This requires a comprehensive approach to defining what is, and what is not, sustainable, along with confidence that this definition would be implemented in practice. Currently, there is no agreed definition of what "sustainable biomass" means, and there is no internationally agreed Monitoring, Reporting and Verification (MRV) structure in place to support this (Broad et al, 2021[11], see also answers to Q9), so studies seeking to estimate sustainable resource potentials employ a range of different sustainability criteria and assumptions. For energy crops especially, recent studies estimate *lower* total sustainable potentials, and consideration of social factors in the sustainability criteria are generally weak (See Q.15 and 19).

Another source of uncertainty in these assessments comes from the need to apply insights from individual case studies more broadly. Increased amounts of data are now available from case studies of energy crop cultivation, forestry and waste streams. The details of the case studies vary widely across parameters including crop species, the conversion of different land-types, agricultural and forestry management practices, levels of input, location and the period of time studied. It is therefore difficult to infer extrapolated and generalisable insights about crop yields and the potential for waste streams, particularly if production were to be scaled up. Estimating future feedstock availability also requires projections and assumptions about future land availability the impacts of climate change on dedicated energy crops, but also other crops and forestry, as they compete for land. Divergent scenarios of land use (i.e. land competition) and climate change therefore also contributes to the ranges of estimates seen in the literature. More research is needed to "connect the dots" to determine the overall availability of different types of biomass (Welfle et al.2020[12]). A systematic review of existing analyses of technical potential for different biomass feedstocks is lacking. The closest that currently exists was published in 2018 and 2020 in the CCC reports looking at "Biomass in a low-carbon economy" and Carbon Budget 6 advice.

For waste stream feedstocks, while aggregated availability data, is good, more detail on the composition of the biomass and its traceability through the system is required, including how it is used or incorporated into other products. Waste biomass is potentially a valuable resource which can be used to either replace other materials (e.g. bioplastics), or recover nutrients and energy. Ensuring a full utilisation of waste biomass requires harmonised segregated collection of biomass waste and adequate recovery infrastructures. An example of how end of life management impacts the viability of biomass recovery for the case of bio-based plastics and alternatives to plastic packaging can be found in our recent research at the UCL Plastic Innovation Hub[13]. Note that over time the potential of bio-waste will depend on the rates of generation, including trade of biomass resources, effective segregation, collection and treatment. Given the current priorities to reduce food waste in the UK, we expect a reduction in food waste available for energy recovery (e.g. Wrap, 2020[14]), but this is a small fraction of all bio-waste. Most biowaste potential could come from manufacturing industries and agriculture. Currently most of these wastes are not recovered, or only partially recovered. Collecting these

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[9] Cadent. Review of bioenergy potential: Technical Report, September 2017. http://cadentgas.com/getattachment/About-us/The-future-role-of-gas/Renewable-gas-potential/Promo-Downloads/Cadent-Bioenergy-Market-Review-TECHNICAL-Report-FINAL.pdf

[10] CCC references: "Biomass in a low-carbon economy" report, November 2018, https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy; "The Sixth Carbon Budget –The UK's path to Net Zero", December 2020, https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf

[11] Broad O., Butnar I., and Watson J., 2021. The potential role for BECCS in the UK's pathway to net-zero by 2050. Report funded by the European Climate Foundation. https://www.ucl.ac.uk/bartlett/sustainable/files/ecfbeccsfinalreportpdf

[12] Welfle, A., Holland, R., Donnison, I., & Thornley, P. (2020). UK Biomass Availability Modelling: Scoping Report . Supergen Bioenergy Hub.

[13] https://www.plasticwastehub.org.uk/

[14] https://wrap.org.uk/resources/report/food-surplus-and-waste-uk-key-facts

fractions for energy production requires careful consideration to avoid unintended consequences in other dimensions, e.g. soil carbon and nutrient loss and biodiversity loss (Camia et al 2020[15], see also answer to Q3).

Industrial symbiosis and cascading approaches need to be embedded in the analysis of potential uses of bio-waste, so that higher application alternatives (bio-chemicals, high-value products, etc.) are considered, avoiding waste to energy when other options provide lower impacts and higher value.

3. What are the current and potential future costs of supplying these different biomass feedstock types, and the key environmental and land-use impacts (positive or negative) associated with supplying and utilising these different types of biomass, e.g. impacts on GHG emissions, air quality, water quality, soil health, biodiversity, food security, land availability, etc?

The question can be broken into two parts:

1. Financial costs of supplying biomass feedstock types.
    - It is important that production costs or biomass resource are not isolated without accounting for costs along the supply chain and for government economic incentives, including subsidies and support policies for farmers and those involved in processing steps. The financial cost calculations should also account for externalities, noting that these can be direct and indirect (e.g. due to displacement of food production).
    - Financial costs (and environmental impacts) for biomass supply are all highly case-specific, depending on the feedstock, location, the distance transported and processing steps. For energy crops, they are also highly dependent on land-use change conversions, land management practices and species. Therefore, any clear answer to this question should reflect wide cost ranges, as the individual case study results are difficult to generalise. To our knowledge, a recent thorough review of UK case studies, explaining the degree to which findings are generalisable and identifying remaining research gaps has not been done recently and should be commissioned. It is also important to highlight that current and future cost estimates do not provide enough information to inform a decision unless they are accompanied by an understanding of costs associated with alternative pathways (e.g. non-bioenergy) to achieve the desired vision or goals. Environmental impacts will also need to be benchmarked across other alternatives and highlight trade-offs across impact categories.
    - Furthermore, there is an important market consideration, which leads us to warn against taking a cost-benefit approach. For example, if energy crops are cultivated for BECCS, then this supply chain could be competing e.g. against Direct Air Capture and Storage (DACS) which has a very high cost, so very high costs of biomass could be still acceptable. If the market then allows high costs, there could be food displacement, which should be strongly avoided. Thus, the cost (especially the production cost alone) should not be a main criterion for prioritising certain biomass feedstocks over others.

2. Environmental impacts
    - GHG emissions. Richards et al. 2017[16] showed that the net GHG impact of establishing energy crops depends strongly on prior land-use, rather than just the chosen crop itself. Broad et al. (2021)[3] note that expanding cultivation or increasing harvesting of biomass for energy production in the UK and abroad could lead to carbon debt, which could reduce or completely cancel the effectiveness of

[15] Camia, A. et al., (2020). The use of woody biomass for energy production in the EU. JRC report. https://doi.org/10.2760/831621
[16] http://doi.wiley.com/10.1111/gcbb.12360

biomass for climate mitigation. Similar concerns have been voiced by the EU EASAC (2019[17]), and the US National Academies of Sciences Engineering and Medicine (2019[18]).

- Beyond GHG emissions. The report by Broad et al. (2021)[3] also highlights that scaling up biomass use for BECCS in the UK could lead to negative impacts on biodiversity, ecosystem services, and the use of land. See further comments in our response to Q4.
- As potential negative impacts will change as UK and overseas trials are scaled up, there is an urgent need to establish internationally harmonised MRV schemes to inform decision-making (note additional costs related to MRV definition, harmonisation and operationalisation).

4. How do we account for the other (non-GHG) benefits, impacts and issues of increasing our access to, or production of domestic biomass (e.g., air quality, water quality, soil health, flooding, biodiversity)?

We take this question to be asking about the valuation of natural capital impacts related to the production of domestic biomass.

Currently we have a quite good understanding of the potential for certain financial co-benefits (e.g. see studies on benefits of avoided flooding due to planting grasses/SRF/SRC upstream (Rose and Rosolova 2015[19]). As with any financial impact assessment, indirect costs/benefits, for example on health, are less well understood and accounted for. We also have a much less good understanding of other non-GHG environmental impacts such as on biodiversity and soil health. There is a need for basic research, but also for demonstration and monitoring to better understand the soil carbon and biodiversity implications of different options for domestic biomass production in the UK.

Many of the benefits, impacts and issues associated with biomass production will depend on the scale of agricultural changes, and their interactions with other elements of agriculture. In particular, how energy crops are interwoven with other agricultural systems within a landscape approach. Regarding social impacts, assessment of the implications for associated livelihoods should go beyond simple measures such as jobs created (See also Q15-19). This is relevant for production for other countries, but also here in the UK.

Looking forward, we want to strongly emphasise that the way in which economic activities are recorded and reported by governments needs to change to take explicit account of the flows of benefits that societies derive from natural capital (Dasgupta 2021[20]). Natural capital accounting (NCA) provides a framework for accounting for stocks and flows of goods from natural capital, in both biophysical and monetary terms. The UK has one of the most advanced national natural capital accounts in the world (see UK natural capital accounts - Office for National Statistics[21] and biomass would be treated as a commodity asset within these accounts. These accounts would provide a structured approach for reporting on the biophysical stock of biomass in the UK, and the economic value of benefits derived from it.

In areas of biomass production, this provisioning ecosystem service of biomass production may well occur at the expense of other ecosystem services. For example, compared with natural forest or grasslands, biodiversity is unlikely to thrive in areas of monoculture biomass production. In these cases, therefore, the benefits derived from biodiversity, such as pollination, pest regulation, and human enjoyment of nature,

[17] EASAC. (2019). Forest bioenergy, carbon capture and storage, and carbon dioxide removal: an update. https://doi.org/10.1080/14693062.2018.1509044

[18] National Academies of Sciences Engineering and Medicine (2019) Negative Emissions Technologies and Reliable Sequestration, Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. doi: 10.17226/25259.

[19] Rose, S. and Rosolova, Z., 2015. *Energy crops and floodplain flows. UK Environment Agency report no. SC060092/R2*. Skipton, North Yorkshire. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/480799/Energy_crops_and_floodplain_flows_report.pdf (Accessed: 14 June 2021).

[20] Dasgupta, P. (2021), The Economics of Biodiversity: The Dasgupta Review. (London: HM Treasury)

[21] ons.gov.uk

would be lower. When choosing whether to dedicate land to biomass plantations, an assessment is therefore needed of whether the value of the biomass produced outweighs the value potentially lost by changing the goods that can be derived from that natural capital through other ecosystem services.

It may be possible to track such trade-offs in areas where data is collected on the state of natural capital, flows of ecosystem services, goods derived from ecosystem service flows, and the human inputs that are often required to derive benefits from natural capital. Such information will be produced by various sources including, but not limited to, DEFRA, the Environment Agency, the Met Office, the ONS, academic researchers, NGOs and citizen scientists. The UKs NCA will bring together some of this information. Fairbrass et al (2020[22]) offer a structured approach to reporting on natural capital that brings together these disparate sources of information.

Note that some values are harder to capture than others in economic terms as part of the UK's NCA. For example, the outcome of evaluation of cultural ecosystem services, such as the pleasure derived by humans from viewing wildlife, and regulating and maintenance ecosystem services, such as sediment retention, are both difficult to evaluate economically, and tend to suffer from high levels of uncertainty that translate as wide ranges in any values that do arise from studies. The same applies to more complex examples, including quantifying and monetising potential irreversible impacts due to biomass expansion, e.g. associated with biodiversity loss and habitat destruction, or impacts on specific social groups or regions. This must be kept in mind when using the UKs NCA to track the costs and benefits of biomass production.

5. How could the production of domestic biomass support rural employment, farm diversification, circular economy, industrial opportunities, and wider environmental benefits? This can include considerations around competition for land, development of infrastructure, skills, jobs, etc.

Farm diversification has been discussed to support profitable agricultural activities, employment, and other benefits. This discussion is not exclusive to the development of a domestic biomass market and has also been understood as a more traditional increase in ranges of services offered by farming activities to support business.

In the context of biomass production, farmers have previously preferred not to switch to producing energy crops. Looking to understand why, the 2013 study by Glithero et al. (2013)[23] found that reasons included perceived impacts on land quality, lack of appropriate machinery, commitment of land for a long period of time, time to financial return and profitability. (Please see Q6 on barriers to uptake for further detail)

While ISR's work in this area is limited, we highlight the following points:

- <u>Competition for land and the opportunity for revenue</u>: in its recent advice to government on carbon budget 6, the CCC considered reductions in meat and dairy consumption, compensating for calorie intake, of up to 50% against "normal" current consumption. They note that a 35% change has the potential to save up to 10 MtCO2. Garvey et al. (2021[24]) developed similar scenarios, reducing emissions by up to 7MtCO2 but noting, importantly, the corresponding land that is freed up for other uses. While this is a positive spin, it can also imply significant losses for farmers who produce these products. This is where biomass production and nature restoration can provide opportunity for revenue; however, realising this requires sustained and appropriate policy support.

[22] Fairbrass, A., G. Mace, P. Ekins, and B. Milligan. 2020. 'The Natural Capital Indicator Framework (NCIF) for Improved National Natural Capital Reporting'. Ecosystem Services 46 (December): 101198. https://doi.org/10.1016/j.ecoser.2020.101198.
[23] Glithero et al., 2013. Prospects for arable farm uptake of Short Rotation Coppice willow and miscanthus in England. Applied Energy 107, 209-218, https://doi.org/10.1016/j.apenergy.2013.02.032
[24] Garvey, A. et al. (2021) 'Towards net zero nutrition: The contribution of demand-side change to mitigating UK food emissions', Journal of Cleaner Production. 290: 125672. doi:10.1016/j.jclepro.2020.125672.

- Agricultural and forest residues: similar to the point above, these could provide an extra revenue stream for producers. Importantly, investment in collection machinery will only be worthwhile if the sale price is sufficiently high (Ecofys, 2016[25]).
- Environmental Benefits: Energy crops can also bring additional environmental benefits, if managed well. Certain studies note that miscanthus has the potential to improve flood mitigation (Rose and Rosolova 2015[19]), and improve biodiversity due to the crop being largely undisturbed except for harvest and thereby providing leaf litter layer encouraging insects, and providing cover for gamebirds (Shepherd et al. 2020[26]). A recent review and modelling exercise by Donnison et al. (2020[27]) demonstrated the strong importance of location for all these factors, finding that "the impacts of BECCS on ecosystem services are spatially discrete" and that "BECCS can be deployed to generate net welfare gains, but trade-offs and co-benefits between ecosystem services are highly site and context specific, and these landscape-scale, site-specific impacts should be central to future BECCS policy developments".
- Co-location with other infrastructure: focusing on the case of industrial hubs where CCS could be deployed, we note that transport emissions are significantly reduced, and therefore the life-cycle of bioenergy supply chain is significantly improved, when the feedstock is produced close to the power plant. Accounting for this under new incentive schemes may help support farmers close to likely or planned CCS locations to produce energy crops or other feedstocks.
- Industrial Symbiosis: integrated systems and biorefinery projects can provide opportunities for cross-sectoral optimisation of agriculture residues using cascading approaches. This requires consideration of industrial symbiosis approaches which build on the connections between farm systems, manufacturing activities and waste recovery plants to promote better use of biomass products, the prevention of avoidable waste and the utilisation of unavoidable wastes and residues for products and energy solutions. This type of approach should also help to identify new revenue streams, closed-loop production systems and reduction of waste, contributing to the circular economy and generating economic activity and inter-sectoral innovation.

Fundamentally, all these points raise the need for policy consistency and long-term stability across government departments. To switch to unfamiliar crops, farmers need stable market conditions, while ensuring sustainable practices and products relies on industrial strategy and land policy being aligned. Farmers unions should be strongly involved in this conversation, and government should be prepared to remunerate services and farm diversification options that have not previously been considered if all co-benefits of producing biomass crops are to be achieved.

6. What are the main challenges and barriers to increasing our domestic supply of sustainable biomass from different sources?

The question implies that biomass production should be treated as a separate sector. It should be reiterated here that domestic biomass supply (particularly from energy crops and forestry) is interdependent with the agricultural sector, due to their reliance on limited available land. Any transition to a net-zero emissions agricultural sector should then account for changes implied by increases in domestic biomass production. These should not be excluded or treated preferentially: independently of the end use of biomass produced,

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[25] https://ec.europa.eu/energy/sites/ener/files/documents/Ecofys%20-%20Final_%20report_%20EC_max%20yield%20biomass%20residues%2020151214.pdf

[26] Shepherd, A. *et al.* (2020) 'Commercial experience with miscanthus crops: Establishment, yields and environmental observations', *GCB Bioenergy*. Blackwell Publishing Ltd, 12(7), pp. 510–523. doi: 10.1111/gcbb.12690.

[27] Donnison, C. *et al.* (2020) 'Bioenergy with Carbon Capture and Storage (BECCS): Finding the win–wins for energy, negative emissions and ecosystem services—size matters', *GCB Bioenergy*. Blackwell Publishing Ltd, 12(8), pp. 586–604. doi: 10.1111/gcbb.12695.

energy crop production should be net-zero before considering the added benefit of e.g. CO_2 capture at point of use.

Next, we note that financial support schemes for increasing biomass production in the UK have already supported the establishment of new agricultural practices for planting either miscanthus or willow under new short rotation plantations. They have also sought to incentivise the uptake of on farm anaerobic digestion for the production of methane. Examples of case studies that review these two approaches in the UK can be found in Parra-Lopez et al. (2017[28]), Helliwell (2018[29]), and Ackrill et al. (2020[30]), among many others. Overall, the literature identifies a number of important barriers to uptake which, considered together, may fit into the following categories:

- Institutional and political. These relate to the stability of the subsidy scheme, its conditions, its structure, but also to its complexity and its difficulty. This is important for example when considering local planning regulations and their interaction with national government.
- Cultural. These can relate to the existence of negative opinions towards energy crops or new energy practices. These can be exacerbated in cases where local community groups oppose the changes in energy practices, whether directly of for their implications for local living conditions. These can also arise from ignoring farmer motivations – including lifestyle, sense of identity, farming culture or priority of food over fuel – can lead to a lack of uptake of even clearly profitable energy crop practices. One key example here is the widely held assumption that "marginal land" can be "rehabilitated" through producing energy crops – a statement that looks at land from a top-down perspective and did not involve the custodian of that land in defining what "marginal" meant.
- Economic. First, this should attach value to the multifunctionality of the new practices. The cultivation of energy crops, or the establishment of standing forests, provide multifaceted benefits, from flood control through to soil carbon management, biodiversity support, and public health, all of which could be financially recognised by targeted support. Similarly, the inclusion of AD waste treatment facilities provides energy outputs while dealing with difficult waste-streams. Second, support schemes should focus on providing reliable, stable, long-term support. Uncertainty in this area breeds reluctance on the part of important stakeholders to take risk and commit resources to engaging. Policies then should offer security and trust that e.g. convert farm practices to new approaches following different timelines will and producing on emerging markets will be worth it.
- Technical & logistical. First, data gaps will need to be addressed: data gaps in bio-waste mean that we have a poor traceability of waste biomass and this limits the identification for adequate utilisation of bio-waste. (It also means that we have limited understanding of impacts associated with bio-waste management and impact avoidance through bio-waste reutilisation.) Second, related to skills, the 2005 Biomass Task Force[31] highlighted the need for training and skills across the entire biomass sector, which extends to farmers more accustomed to the cultivation and production of food crops. More recent research continues to highlight a general lack of skills in biomass heat, forestry and affiliated sectors (Emmanuel-Yusuf et al. 2017[32]).

[28] Parra-López et al., 2017. Strengthening the development of the short-rotation plantations bioenergy sector: Policy insights from six European countries. Renewable Energy 114, Part B, 781-793, https://doi.org/10.1016/j.renene.2017.07.098
[29] Helliwell, R., 2018. Where did the marginal land go? Farmers perspectives on marginal land and its implications for adoption of dedicated energy crops. Energy Policy 117, 166-172, https://doi.org/10.1016/j.enpol.2018.03.011
[30] Ackrill, R. and Abdo, H. 2020. On-farm anaerobic digestion uptake barriers and required incentives: A case study of the UK East Midlands region, Journal of Cleaner Production 264: 121727, https://doi.org/10.1016/j.jclepro.2020.121727
[31] https://www.forestresearch.gov.uk/documents/2043/BTF_Biomass_Task_Force_Report_to_Government_2005.pdf
[32] Emmanuel-Yusuf, D., Morse, S. and Leach, M. (2017) 'Resilience and livelihoods in supply chains (RELISC): An analytical framework for the development and resilience of the UK wood fuel sector', *Sustainability* 9(4), p. 660. doi: 10.3390/su9040660.

Importantly, we also note that, to date, policy incentives have concentrated on the energy side of biomass. This is particularly true for in the case of bio-waste, but the recovery of the chemical feedstock for other applications and development of bio-based products is something that has not been well addressed in current policy landscape.

The need for stable policy support schemes and the perceived complexity of existing systems calls for a clearer, simpler approach that is consistent across government departments including at least BEIS, Defra, the FC, and the treasury – potentially others on occasion as relevant (e.g. DHSC in relation to health benefits of green leisure spaces). This highlights the need for a coordinated cross-Whitehall bioenergy task force that also engages beyond government to include e.g. representatives from farmer's unions and from academia.

The need to ensure that the increased supply remains sustainable reinforces the barriers raised above, but also highlights that system design and infrastructure will be key.

> On the first, there is a clear need to ensure robust monitoring, verification and reporting is in place to guarantee that, as bioenergy practices become more widespread, they respect robust sustainability criteria. While we need to overcome challenges and barriers to developing domestic supply, we also need safeguards against practices that do more damage than they set out to repair. This includes safeguards against affecting others uses of land – the existence of which is a barrier to increasing domestic production of biomass that we do not always have an interest in removing. This implies the establishment of robust, well connected, yet simple institutional structures across local and national administrations; but also the roll out and correct operation of new and MRV technology.
>
> On the second, there is a need to understand system designs that will be incompatible with, maintaining feedstock sustainability or will otherwise negate the benefit that its use will provide the energy system. This was highlighted for example in Albanito et al. (2019[33]) reviewing what the use of BECCS for power could potentially look like under centralised vs. distributed approaches and showing that the same definition of sustainable biomass use under each scenario results in higher sequestration potential if favouring distributed approaches.

7. What is the potential biomass resource from imports compared to the levels we currently receive? What are the current and potential risks, opportunities and barriers (e.g., sustainability, economic, etc) to increasing the volumes of imported biomass?

Maximum Technical Potential, potential market, and sustainability:

Currently the UK imports 8.8 mt per year of woody biomass (pellets) which represents ~46 TWh (165 PJ) in 2019. [34]

Estimating the total global environmentally and socially sustainable resource availability is complex:

- First, it requires an assessment of the technical potential for each feedstock (e.g. energy crops and forestry residues) on a country-by-country basis. This assessment requires an understanding of land availability, land competition, yields for energy crops, and agricultural and forestry practices.
- Second, (as for the domestic resource assessments), this maximum technical potential (MTP) should be reduced according to environmental and social criteria, restricting it to its "sustainable" fraction. This requires there to be sustainability criteria against which the MTP can be assessed.
- Third, estimating the amount of biomass that the UK might import from this total sustainable potential means making assumptions about each country's future national consumption to understand how

[33] Albanito, F. et al. (2019) 'Mitigation potential and environmental impact of centralized versus distributed BECCS with domestic biomass production in Great Britain', GCB Bioenergy. 11(10), pp. 1234–1252. doi: 10.1111/gcbb.12630

much will be left over for export. Only then can we assess what share of this total international market the UK might be able to access.

Each step is complex.

Assessments of future national production and consumption are influenced by the state of the future market. Using a proxy measure such as the UK's % share of global GDP as an indicator of how much could be accessed is flawed as it does not reflect levels of competition that might exist on this future market, future levels of GDP from competing countries, or changes to how our economy is structured.

Institutional robustness is also important. Recent research at ISR (Butnar et al., 2020[35]) has shown that large shares of the biomass supplied to the international market could come from regions with weaker institutional settings, e.g., Southeast Asia, Central and South America. This is supported by mapping of potential energy crop production areas (Cronin et al 2020[36]). Without clear biomass sustainability criteria, or with criteria that are reinforced across borders, these regions risk seeing further deforestation, which could easily cancel out the mitigation potential of biomass. (See also Q15-19.)

While consensus is emerging in assessing MTP, understanding sustainability globally remains an issue. Looking at global and regional potential biomass resources in the literature, Creutzig et al., 2015[37] shows that there is high consensus in the scientific community that 100 EJ/yr could be attained sustainably, but only a medium level of agreement that 100–300 EJ/yr could be attained. From the IEA 2017 Technology Roadmap[38] (p.58), the estimated sustainable biomass potentials in 2060 are: 10-15EJ from municipal waste, 15-30EJ from forestry waste, 46-95EJ from agricultural wastes and 60-100EJ from dedicated crops. The IPCC Special Report on Climate Change and Land (Chapter 2, Jia et al, 2019[39]) reviewed resource assessments and found that recent studies suggest energy crops could provide 50-244 EJ/yr by 2050 on 0.1-13 Mkm^2 of land. Many factors affect these results however, as shown recently by Cronin et al 2020[35] who highlight the importance of considering the impacts of climate change on agricultural systems, and of reviewing different potential land-use scenarios.

<u>Scenarios Modelling Results</u>

Estimations of biomass trade in different energy decarbonisation scenarios can be drawn out of the integrated assessment model studies and literature. From their review of several modelling studies participating to the 33rd Energy Modelling Forum study (EMF-33), Daioglou et al 2020[40] found that “for a scenario likely to achieve a 2 °C target, 10–45 EJ/year out of a total global bioenergy consumption of 72–214 EJ/year are expected to be traded across nine world regions by 2050. While this projection is greater than the present trade volumes of coal or natural gas, it remains below the present trade of crude oil.” Butnar et al., 2020[34] estimated the size of biomass trade for a 2°C global target but assumed that stringent environmental criteria were implemented to keep global biomass supply to 100 EJ/yr. Their results sit at the lower end of Daioglou’s reports with global trade reaching 15 to 25 EJ/yr.

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[35] Butnar, I. *et al.* (2020) ‘The role of bioenergy for global deep decarbonization: CO2 removal or low-carbon energy?’, *GCB Bioenergy*. Blackwell Publishing Ltd, 12(3), pp. 198–212. doi: 10.1111/gcbb.12666.

[36] Cronin, J. et al. (2020) ‘Land suitability for energy crops under scenarios of climate change and land-use’, GCB Bioenergy, 12(8), pp. 648–665. doi: 10.1111/gcbb.12697.

[37] Creutzig, F. *et al.* (2015) ‘Bioenergy and climate change mitigation: An assessment’, *GCB Bioenergy*, 7(5), pp. 916–944. doi: 10.1111/gcbb.12205.

[38] https://www.ieabioenergy.com/wp-content/uploads/2017/11/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf

[39] Jia, G. et al., 2019: Land–climate interactions. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press. https://www.ipcc.ch/srccl/chapter/chapter-2/

[40] Daioglou, V. *et al.* (2020) ‘Implications of climate change mitigation strategies on international bioenergy trade’, *Climatic Change*. Springer Science and Business Media B.V., 163(3), pp. 1639–1658. doi: 10.1007/s10584-020-02877-1.

(Note that these results are different from assessments of MTP as they show the ranges of resource levels being suggested by global energy system modelling exercises. Note also, importantly, that these results are highly dependent on models' geographical breakdown and that more detailed reviews/studies would be required to understand their implications for UK biomass imports.)

Risks, opportunities and barriers can take on new meaning with biomass

The framing around "risks, opportunities and barriers" relating to imports is a good approach to understanding the levels of biomass available but should recognise that certain risks are difficult to mitigate against and should in fact constitute barriers to import. This is particularly the case for sustainability risks: any reasonable level of doubt that a given import practice may be in breach of strict (social and environmental) sustainability criteria should constitute a barrier to engaging in trade so that we can ensure that our practices do in fact reduce carbon emissions and provide positive co-benefits locally and internationally.

With this in mind, some clear risks to ramping up biomass trade currently include:

- The lack of global agreement on the definition of biomass sustainability, see e.g. Broad et al, 2021[11].
- The insufficient inclusion of non-carbon factors in the UK's biomass sustainability criteria – including but not limited to biodiversity, ecosystem services, land tenure, cultural and social uses of land and biomass, health and air-quality benefits.
- The concern that international partners institutions may not be competent, independent, and robust enough to provide valid certification against the UK's existing – or any future – sustainability criteria.
- Lack of adequate traceability systems to globally ensure sustainability of biomass apart from well-established schemes (e.g. FSC). This implies a significant risk for carbon leakage along supply chains and production practices that are not properly monitored. It also implies the potential for major negative impacts on local communities in low-income countries, should a large international market for biomass rapidly develop. This is particularly acute and has been seen before. Looking at experience with first generation biofuels, we know that negative impacts on food prices are very possible (Malins 2017[41]), as are large-scale land acquisitions (Hufe and Heuermann 2017[42]).
- Energy – but more likely carbon – security increasing the UK reliance on a steady supply of consistent quality biomass from international suppliers and markets that are not yet established.
- Threats to human rights in relation to land in biomass supply countries if land governance structures and the implementation of best practice guidelines are not included in social sustainability criteria. Robust safeguards against e.g. land-grabs, and explicit corrections to imbalances of power that surround competing interests in land are required. Without them, the rights of local communities risk coming second to economic and carbon benefits in the global race to increase biomass imports (Hufe and Heuermann 2017[42], Cronin et al. 2021[43]).

[41] Malins, C. (2017). Thought for food - A review of the interaction between biofuel consumption and food markets. Cerulogy, London. https://www.transportenvironment.org/sites/te/files/publications/Cerulogy_Thought-for-food_September2017.pdf

[42] Hufe, P. and Heuermann, D. F. (2017) 'The local impacts of large-scale land acquisitions: a review of case study evidence from Sub-Saharan Africa', Journal of Contemporary African Studies. Routledge, 35(2), pp. 168–189. doi: 10.1080/02589001.2017.1307505.

[43] Cronin, J. et al. (2021) 'Embedding justice in the 1.5°C transition: A transdisciplinary research agenda', Renewable and Sustainable Energy Transition. Elsevier BV, 1, p. 100001. doi: 10.1016/j.rset.2021.100001.

Use of Biomass - How should we use biomass to reach net zero?

8. Considering other potential non-biomass options for decarbonisation (e.g. energy efficiency improvements, electrification, heat pumps), what do you consider as the main role and potential for the biomass feedstock types identified in Question 2 to contribute towards the UK's decarbonisation targets, and specifically in the following sectors? o Heat o Electricity o Transport o Agriculture o Industry o Chemicals and materials o Other?

The biomass landscape is diverse and complex; individual feedstocks can be used to produce many different energy commodities, provide wood in construction, be converted to chemicals, etc. Several of the technologies required for transforming and using biomass feedstock in the energy sector have not yet been developed and rolled out at scale and therefore costs, efficiencies, life expectancy, and general logistics of biomass use are not yet precisely known. Therefore, any answer to this question that unequivocally suggests that a single best use of a biomass feedstock should be treated with caution. This is particularly true for feedstocks produced from second generation energy crops.

Biomass, of any of the mentioned feedstocks and from domestic or important origin alike, is and will always be in strictly limited sustainable supply. Therefore, biomass – with or without CCS – cannot be relied upon to reduce the need for other strong action on energy and climate change. Rather, the roll out of aggressive programs that reduce the size of the problem at the source are essential to making the contribution from biomass manageable. These include strong energy efficiency programs in all sectors with a particular focus on residential heat; making energy consumption clean at point of use through e.g. electrification or the introduction of clean fuels such as hydrogen or ammonia; and reducing energy consumption by rationalising demand through e.g. principles of circular economy and deeper societal shifts towards more sustainable consumption modes without loss of quality of life.

- This approach is supported by the results presented in a ISR energy modelling research focusing on decarbonisation and the UK emissions reductions goals to 2050. Focusing on the residential sector, Broad et al. (2020[44]) shows that energy demand reduction options that focus on refurbishing and improving households are required to meet emissions targets and make economic sense. When focusing more widely on "The potential role of BECCS in the UK energy system", Broad et al. (2021[13]) shows the level to which a Low Energy Demand future reduces carbon pressure on the whole energy system – changing the way in which Biomass and natural systems can support our 2050 targets. This report also highlights clearly that how unclear it is that an absolute "best use of biomass" exists when considering a whole energy systems perspective. Focusing on forestry and agricultural wastes which currently promise to be the dominant fractions, their use in a system that is strongly carbon constrained in 2050 is driven by their ability to provide net carbon removals from the atmosphere rather than by the most efficient provision of end use energy. The level of net carbon removal is strongly dependent on a) the sustainability of the biomass used and b) the full supply chain emissions attached to each end use.
- The "best use" of biomass in least cost energy system transition pathways is also highly dependent on assumptions that are made for highly uncertain parameters that describe technologies involved in BECCS supply chains, as demonstrated in Broad et al. 2021. For example, if the efficiency of capture of CCS is reduced by 5 per-cent points in 2050 "best use" of BECCS shifts from hydrogen applications over to power - implying complete shifts in infrastructure requirements and system design.
- Taking a whole systems perspective, biomass is used as a vector for carbon removal first, and an energy commodity second. So its best final use should depend strongly on (1) the availability and

[44] Broad, O., Hawker, G. and Dodds, P. E. (2020) 'Decarbonising the UK residential sector: The dependence of national abatement on flexible and local views of the future', Energy Policy. Elsevier Ltd, 140(January), p. 111321. doi: 10.1016/j.enpol.2020.111321.

performance of other CO_2 removal technologies, e.g. DACS or nature-based solutions, (2a) the availability and performance of other energy supply technologies, e.g. renewables, and (2b) the technical characteristics of each step of bioenergy supply chain, and finally (3) the existence of demands which cannot be met by electrification or other low carbon options, e.g. aviation fuels. If biomass with CCS is relied on to remove carbon, the risk of late availability of CCS at scale brings a key risk that we will fail to meet our emissions targets (see Broad et al. 2021). Equally, additional emissions along the supply chain – e.g. high levels of methane emissions from extended storage – may negate the value of biomass with or without CCS altogether and imply the system should instead focus on long term sequestration in natural systems complementing energy demand reduction and the reliance on clean electrofuels.

- Because of these issues, it may be better to ask about the best use of *land* rather than the best use of *biomass*. As shown in the UCL modelling exercise for UKERC (Cronin et al. 2020[45]), using marginal land for afforestation, preferably natural forest regeneration, rather than energy crops can reduce the reliance on BECCS.
- Importantly, the above considers a "carbon only" perspective to the use of biomass in the energy system (see other concerns about carbon being the only factor in Q15). Considering additional co-benefits, trade-offs and ecosystem service perspective to this answer increases complexity and potentially shifts the focus away from the farming of energy crops for CCS applications and back towards reforestation and the restoration of degraded ecosystems.
- Focusing on the role of biomass, land and natural systems in reaching the UK's decarbonisation targets, the immediate focus on rolling out nature-based sequestration options that carry strong socio-economic-environmental co-benefits would be deeply beneficial (see natural capital examples in Q4, and biomass support to farm diversification in Q5). Including reforestation and the restoration of degraded natural ecosystems, these options are known and well understood, will provide multiple benefits alongside the carbon they will start sequestering early on, and could support a basis for clear engagement on questions of national targets and the role of biomass alongside other options including e.g. demand reduction.

9. Out of the above sectors, considering that there is a limited supply of sustainable biomass, what do you see as the priority application of biomass feedstocks to contribute towards the net zero target and how this might change as we reach 2050? Please provide evidence to support your view.

Please see the principles described in Q10 and the uses described in Q8. If the sustainable biomass is lower, the principles should be applied even more strictly.

10.What principles/framework should be applied when determining what the priority uses of biomass should be to contribute to net zero? How does this vary by biomass type and how might this change over time?

As explained in Q8 and Q9, the following principles should be applied:

1. Focus on applications where there are significant co-benefits in terms of biodiversity, socio-economic impacts and ecosystem services as well as carbon removal.
2. Focus on limiting biomass deployment to those sectors and specific applications which are harder to decarbonise using other routes (e.g. electrification).
3. As context of land and biomass use is so important, careful monitoring of whole supply chain is required to evaluate costs, carbon and other environmental and social implications. Policy and regulations (and priorities for biomass) can should be changed as required.

[45] Cronin, J. et al. (2020) Biomass, afforestation and energy demand reduction: trade-offs in the route to decarbonisation. UK Energy Reserach Centre report., UKERC Briefing Note. https://ukerc.ac.uk/publications/afforestation-energy-demand/

11. When thinking of BECCS deployment, what specific arrangements are needed to incentivise deployment, compared to what could be needed to support other GGR and CCUS technologies as well as incentivising wider decarbonisation using biomass in the priority sectors identified?

ISR recently published a report on the potential contribution that BECCS could make to meeting the UK's net zero target, and the implications for sustainability and policy (Broad et al, 2021[11]). Our response to this question draws on the specific policy recommendations from that report. The report makes five specific recommendations:

- First, reduce demand for energy and other resources through efficiency and a more circular economy in order to, in turn, reduce the amount of removals required. This includes action to reduce emissions from those sectors where residual emissions are expected in 2050 (e.g. agriculture and air travel). It should also include incentivising shifts and reductions in demand commensurate with changes in lifestyle (e.g. changing diets by reducing consumption of meat and dairy, or shifting transport modes linked to concepts of "access rather than mobility" and "15-minute cities")
- Second, policy incentives are required and should support a diverse range of removal options. This could involve the reform of carbon pricing so that its scope is extended to removals, alongside strict sustainability criteria. This will help to ensure that cheaper, less risky removal options, such as some forms of afforestation, are prioritised.
- Third, specific policies will be required to scale up engineered removal technologies including BECCS. Generic policies like carbon pricing are insufficient because these technologies are too capital intensive and risky. This could be achieved through contracts for BECCS deployment, which should be implemented incrementally and cautiously. Large facilities on the scale of Drax should not be supported straight away.
- Fourth, policy support for BECCS should be conditional, and subject to rigorous evaluation and performance review. This will allow costs, technical performance, life cycle emissions and sustainability to be assessed before scaling up further. If BECCS is not delivering removals effectively, the government should increase efforts to reduce residual emissions and shift support for greenhouse gas removals to other options. Importantly, any incentives should reward actual and demonstrable removals across the supply chain over single stage capture.
- Fifth, regulations for biomass sustainability need to be reformed and extended to cover the full supply chain: from biomass supply to energy production, and the capture of CO_2 for use or storage. It is misleading to assume carbon neutrality at the point of combustion. This includes the alignment of regulations across borders to ensure a level playing field between UK and imported biomass, and the inclusion of changes to land use in carbon accounting rules.

12. How can Government best incentivise the use of biomass, and target available biomass towards the highest priority applications? What should the balance be between supply incentives and demand incentives and how can we incentivise the right biomass use given one feedstock could have multiple uses or markets?

As discussed in question 8, the best use of biomass should, when considering forestry and energy crops, be reframed as the best use of land and any emissions savings should be considered over the full supply chain from land conversion to final use of the biomass with or without sequestration. With this in mind, and with a view to incentivising early and secure carbon uptake, the best incentives in the short and medium term would include:

- Incentives that recognise land-owners' and farmers' custodial role of land and offer reliable, long lasting, and appropriate funding to support good practices – beyond the simple switch of land use to e.g. energy crops – that enhance soil health, carbon balance, biodiversity, ecosystem services, livelihoods etc. While some services, such as carbon capture in soils and standing forests may benefit from relatively available data and be easily measurable in terms of value, others may require funding beyond any clear or immediate measure of "value for money".

- Incentives should treat carbon sequestered using biomass as equal to carbon sequestered through other means. It should create a level playing field and offer remuneration against net sequestration across the full supply chain – not against capture at any one conversion step.

Note that, importantly, both recommendations should include accounting for what the establishment of biomass might displace when assessing the change in ecosystem services and/or carbon sequestered that merits remuneration.

13.Are there any policy gaps, risks or barriers hindering the wider deployment of biomass in the sectors identified above?

As we note in responses to other questions, the main gaps at present include:

- Comprehensive regulations covering the sustainability of the whole biomass supply chain – including supply chains outside the UK. Some specific supply chains are partially covered by current regulations, but these need to be extended.
- Policy incentives for GHG removal options, some of which involve the use of biomass. As we argued in our response to Q11, it is important to implement policies that support a range of GHG removal options. In addition, these policies need to take into account the specific characteristics and risks of individual options, including BECCS.
- Ensure full supply chain monitoring. This monitoring, verification, and reporting should be systematic, robust, and independent. This will make it possible to remunerate ***actual supply chain*** sequestration rather than focusing on supporting one sub-section of the supply chain (as recommended in Q12). Note that including proper MRV for the full supply chain will also help to highlight areas and processes where the carbon balance may improve as e.g. mechanised and transport related processes are decarbonised and rely on electric or H_2 fuels produced from carbon free supply chains of their own.
- Measures of ecosystem health and resilience should be considered alongside carbon sequestration within the MRV framework. See Q4 for a discussion on how to consider ecosystem services and non-GHG benefits or impacts. It is unlikely that healthy and resilient ecosystems will provide less reliable carbon sequestration over time. Conversely it is possible for natural practices that sequester carbon to lead to strong negative environmental and ecosystem impacts linked to strong sustainability concerns for the biomass produced. Focusing therefore on a full benefits approach that accounts for all the flows and benefits that societies derive from natural capital, beyond just carbon, is essential.

14.How should potential impacts on air quality of some end-uses of biomass shape how and where biomass is used?

We understand this question to be asking how the value of carbon stored should be considered against the negative cost of impacts on health of corresponding increases air quality (AQ) emissions. In other words, asking whether the value of carbon sequestered might compensate for the potential impacts on public health.

We understand the temptation, and perhaps need, to do this kind of cost benefit analysis. However, a more reasonable approach would be to treat the use of biomass feedstock in any application with the same scrutiny as is applied to other polluting activities from an air quality perspective, thus putting them on an equal footing and subjecting these potentially polluting end uses of biomass to strict emission standards in settings where they are most likely to contribute to breaching air quality standards.

Deciding that there are 'acceptable' trade-offs for biomass that differ from those for transport, for example, risks undermining the public legitimacy of the climate and environmental pollution policy.

Supply Chain sustainability – How can we strengthen our sustainability criteria?

15.Are our existing sustainability criteria sufficient in ensuring that biomass can deliver the GHG emission savings needed to meet net zero without wider adverse impacts including on land use and biodiversity? How could they be amended to ensure biomass from all sources supports wider climate, environmental and societal goals?

The sustainability criteria included in the Renewables Obligation and the Renewable Transport Fuel Obligation (from the EU RED) provide a good starting point with regards to the use of high carbon land or high biodiversity land, and GHG savings. The UK Forestry Standard contributes on forestry practices to maintain and enhance forest productivity. However, some updates are required in terms of criteria beyond carbon.

- First, it should be recognised that sustainability is not just about carbon; the definition should be ambitiously expanded to include biodiversity, water, other ecosystem services (e.g. reduced soil erosion), co-benefits to health and wellbeing, and land and labour rights (the latter is particularly in relation to imports).
- Trade-offs and synergies between carbon sequestration provided by bioenergy and BECCS, and other ecosystem services, e.g. biodiversity, water quality, should be monitored and sanctioned or rewarded. Evidence from the fast expansion of first-generation biofuels suggests that the increased production of bioenergy could hamper ecosystem processes and leads to habitat disruption and fragmentation, as well as decreased levels of species richness (see e.g. Joly et al., 2015[46]). While current regulations include some environmental concerns beyond carbon, they need to be expanded to cover each biomass type and all uses of biomass. They also need to reward increased carbon stocks in biosphere, increased water or air quality, or enhanced local biodiversity. Ultimately, these environmental gains would also favour better agricultural yields.
- As the UK embarks in transition to net zero, expansion of biomass production in the UK and abroad (for the imported biomass) should follow net zero rules from its establishment. This would avoid adding further GHG emissions to the atmosphere and the need for additional removal to, e.g. compensate for additional GHG emissions from fertiliser utilisation or fertiliser production, or from increased traffic to transport biomass to the processing plants.
- Social sustainability criteria for biomass supply should be developed and implemented. These should seek to guard against the potential negative social impacts that could result from a large increase in an international biomass market. Experiences with first generation biofuels show that the unintended social consequences can include large-scale land acquisitions, loss of access to land and other resources, impacts on food prices, and impacts on household income (e.g. Creutzig et al. 2013; Tomei, 2015). While most EU biofuel certification schemes currently include some social components, there is enormous diversity in their coverage. While incorporating the social impacts of biomass is challenging, failure to do so runs the risk of worsening the lives of individuals and communities dependent on land - especially in the global South - and ultimately undermining the case for biomass.
- Sustainable international biomass supply chains require alignment of regulations across borders. The UK needs to work across borders to align and establish biomass sustainability criteria. The alignment would ensure that imported biomass meets all the sustainability criteria set for UK biomass, including

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[46] Joly, C. & Verdade, L. & Huntley, B. & Dale, V. & Mace, G. & Muok, B. & Ravindranath, N.H.. (2015). Biofuel impacts on biodiversity and ecosystem services. In book: Bioenergy & Sustainability: Bridging the Gaps. 1st Edition, Publisher: SCOPE, Editors: G.M. Souza, R.L. Victoria, C.A. Joly, Luciano M. Verdade.

potentially more stringent social requirements. This would also help to ensure a level playing field between UK and imported biomass.
- Finally, the sustainability criteria should be continuously monitored and strengthened using a standard process on a regular timeframe basis. That is – as test cases are developed the data from these should be used to inform new iterations of the policy. These new iterations should not affect existing projects – so that we avoid the issue of policy support disappearing and farmers having converted their activity losing their income.

16.How could we improve monitoring and reporting against sustainability requirements?

There is a need to establish an internationally recognised definition of biomass sustainability to increase transparency and correspondence between trading partners. This needs to be created before the international market develops, to avoid potentially negative impacts of fast and unregulated change in land use to supply an increasing demand.

Supporting the establishment of such an international standard relies on

- The existence of national institutions with the mandate, independence, and capability to provide a reliable "sustainable" biomass certification.
- The existence of an independent international body with the mandate to convene and oversee discussions and conflicts that may arise around biomass sustainability.

17.What alternative mechanisms would ensure sustainability independent of current incentive schemes (e.g., x-sector legislation, voluntary schemes)?

Start considering that land-based systems provide more to society than their physical output, e.g. biomass for energy. Farmers are custodians of the land and should be supported and remunerated as such.

Incentives that do not focus on the carbon but instead focus on the co-benefits could encourage a system to develop in which creating sustainable landscapes is the goal rather than an additional condition to operating a productive system. This puts carbon and biomass outputs from these systems in second place.

Examples in the UK include the ELMS scheme[47], which should reward provision of ecosystem services by farmers/ land-owners, e.g. not just the food output. This scheme includes three trial schemes – the Sustainable Farming incentive, remunerating farmers for sustainable management practices – the Local Nature Recovery scheme, paying out against actions that meet local environmental priorities and support nature recovery – the Landscape recovery scheme, including large scale tree planting and salt marsh restoration.

New biomass production could be included in an additional trial, which if proved successful should be pushed forwards

18.What additional evidence could suppliers of biomass-derived energy (for heat, fuels, electricity) provide to regulators to demonstrate they meet the sustainability criteria?

[47] https://www.gov.uk/government/publications/environmental-land-management-schemes-overview/environmental-land-management-scheme-overview

19.How do we improve global Governance to ensure biomass sustainability and what role does the UK play in achieving this? Accounting for Emissions – How can we improve the way we account for biomass emissions? We welcome evidence and views on:

This is an enormous, complex and multifaceted question requiring much more research and evidence.

As discussed in Q15, biomass supply chains have direct and indirect impacts on biodiversity, water provision and quantity, ecosystem services, health and wellbeing, and land and labour rights. The latter is particularly important in relation to imported biomass. Governing these elements requires a global concerted effort, not only to build research and evidence on the most ethical and environmentally-sound course of action, but also to build consensus, as improved governance systems will only be effective if sufficient key actors are in agreement.

This may seem like an impossible task. The UK however has a good track record in terms of showing global leadership in the fight against climate change. The check and balance system implemented with the CCC as an external adviser to government was a first of its kind when established in 2008 and is replicated and/or referred to internationally as an example of successful action. As stated in Q4, the UK also has the most advanced national natural capital accounts framework in the world, accounting for stocks and flows of goods from natural capital, in both biophysical and monetary terms. The UK has also established itself as a market leader in the field of renewables and is currently the European country with the highest levels of installed wind power (Soares-Ramos, E. P. P. et al. 2020[48]). This global and local leadership must continue and, in this context, focus on convening and supporting a global effort to build consensus and common understanding of biomass sustainability.

In the meantime, the UK should use all available channels to support wide implementation of known best practice. This includes support for and implementation of guidance on land governance, including the FAO's Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests, the UN Declaration on the Rights of Indigenous Peoples (including the right to Free, Prior and Informed Consent), and the UN Declaration on the Rights of Peasants and Other People Working in Rural Areas. It also means learning from the implementation of existing certification schemes, including the voluntary schemes accepted by the EU, in order to build on their successes and, crucially, learn from their failures.

With regards to emissions accounting:

- Increase transparency along biomass supply chains, so links between biomass demand and its supply become more apparent, helping to establish clearer responsibilities and accountability across the full supply chain.
- UNFCCC Carbon accounting rules need to be updated to:
    - Recognise links between terrestrial carbon management and bioenergy production. The focus of terrestrial carbon management should be on increasing the rate of land CO_2 sequestration and avoiding carbon debt, which could potentially negate removal by BECCS for decades to come. Solely reducing the use of fossil fuel in the sectors using land (agriculture, forestry) will only contribute marginally to improving overall BECCS supply chain emissions.
    - Drop the assumption of carbon neutrality at the point of combustion and instead rely on better MRV along the supply chain so that biomass carbon content at point of use is explicitly known. This is part of being able to remunerate full supply chains against their net carbon removal.

[48] Soares-Ramos, E. P. P. *et al.* (2020) 'Current status and future trends of offshore wind power in Europe', *Energy*. Elsevier Ltd, 202, p. 117787. doi: 10.1016/j.energy.2020.117787.

- Engage actively in the debate that surrounds territorial vs. consumption-based accounting in the knowledge that offshoring emissions will not support global temperature-based climate targets.

- Clear governance and policy structures need to be put in place to ensure BECCS is delivering CO_2 removal when accounted for over its full supply chain. This could include, but is not limited to accounting, monitoring and verification frameworks applicable globally, provision of guidelines for reporting and verification of safe CO_2 storage, including for traded CO_2.

20.How should the full life cycle emissions of biomass be reflected in carbon pricing, UKETS, and within our reporting standards?

21.How should BECCS be treated for domestic and international GHG emissions accounting and reporting? What are the implications of existing reporting rules on our ability to deliver negative emissions, when for instance, land use change emissions and stored CO2 are being accounted for in different countries?

We understand this question as raising the issue of territorial versus consumption-based emissions accounting.

The knowledge of the writing and editorial team is insufficient to provide a comprehensive view on this topic, and its implications for BECCS and biomass. In a world where supply chains for both goods and services, whether energy related or not, are globalised it cannot be denied that the impact of decisions made within the territory of a nation state will affect change well beyond its geographical border.

Currently, all countries apply territorial accounting principles whereby emissions that occur outside of the nations' territorial borders are accounted for in another country's national inventory. This approach is challenging when long supply chains and complex processes interact with both sources and sinks of carbon that operate on different timescales.

Ultimately, it seems that the full supply chain approach recommended in previous questions suggests a switch to consumption-based accounting. This would avoid risks of double counting both removals and releases of carbon between different institutional borders. This approach does suggest some challenges:

- There is no reason to apply it only to BECCS supply chains: this implies switching to an accounting system that would force the UK to take responsibility for its impact in countries that provide the material commodities that we consume. While this is fair, it also changes the picture of our net zero challenge.

- This approach suggests international consensus on shifting UNFCCC accounting rules and will raise question of national sovereignty linked to e.g. soil carbon increases for example.

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