Supergen Bioenergy Hub

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Harmonising greenhouse gas and sustainability criteria for low-carbon transport fuels, bioenergy and other bio-based sectors

Supergen Bioenergy Hub and Low Carbon Vehicle Partnership Collaboration Project Report

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Reference

Please use the following reference:

Cucuzzella, C., Welfle, A., Röder, M. (2020). Harmonising GHG and sustainability criteria for low carbon transport fuels, bioenergy, and other bio-based sectors. Supergen Bioenergy Hub Report No. 04/2020. Available from: https://www.supergen-bioenergy.net/wp-content/uploads/2020/11/Harmonising-sustainability-standards-report.pdf

Acknowledgment

This report is the output from a joint project between the Supergen Bioenergy Hub and the Low Carbon Vehicle Partnership (LowCVP). The work was funded by a Rapid Response Fund from the Supergen Bioenergy Hub.

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1 Executive summary

Overview

Many countries have developed roadmaps and strategies for the transition to a low-carbon bioeconomy to tackle climate change and build a sustainable future. The concept of bioeconomy, which is based on the utilisation of renewable biological resources, is not new. Societies have always used bio-based resources to generate energy, produce food and materials, or build houses and infrastructure.

Energy and transport are two main sectors utilising biomass to reduce emissions and support climate change mitigation. Increasingly, chemical, construction and manufacturing industries use biomass to create bio-based products and materials to replace fossil- and mineral-based materials.

With the urgent need to mitigate climate change, protect the environment, support economic development and improve the welfare and wellbeing of societies, the concept of bioeconomy becomes increasingly important. However, the transition from a fossil fuel to a bio-based economy and society needs to consider the sustainability implications of biomass use to enable benefits and mitigate negative impacts in the short-, medium-, and long-term across all sectors and for the whole of society. Such a transition and long-term targets are only possible with the support of institutional and regulatory frameworks. These should incentivise sustainable products, practices and services; create a fair market; allow just access to resources, products and services; and prevent, if not prohibit, negative impacts.

Within the current landscape of biomass-utilising industries, the different sectors have regulatory frameworks with different ways of accounting for climate change and sustainability impacts. In light of the growing importance of renewable bio-based resources and materials, it is essential that the same emission standards and sustainability criteria are established across all sectors and are harmonised where appropriate and possible. This will serve to avoid market distortions and unintended negative environmental and social impacts, plus ensuring the establishment of a fair, transparent and competitive market for businesses and end-users.

This report reviews and compares the UK's greenhouse gas (GHG) emission and sustainability standards for sectors utilising bio-based and low-carbon feedstock. This will support a better understanding of the current UK policy and governance frameworks for the different sectors. Based on this, a harmonisation framework for the GHG emissions and sustainable standards for the bio-based sectors is being developed, aiming to support a fair cross-sectoral approach for feedstock use and enable best biomass use and sustainability across all bio-based sectors.

The report will focus on transport and energy (electricity, heating and cooling), as these sectors are currently the most relevant sectors using biomass and play a key role in the transition from a fossil- to a bio-based economy. However, with emerging markets and other developing bio-based sectors and the need to harmonise their GHG emission standards and sustainability criteria, the agriculture, forestry, chemical and manufacturing industries have also been considered.

Key findings

The review of the UK's institutional frameworks and sustainability approaches for bio-based sectors showed the important role of biomass for an increasing range of sectors and markets.

Relevant instruments identified included international agreements, EU and UK policies, and voluntary measures such as certification schemes. The review showed that the main driver behind current

regulations and voluntary frameworks is climate change mitigation. This is not surprising given the overarching framework is based on an international level with the United Nations Framework Convention on Climate Change (UNFCCC) climate change agreements. With the Climate Change Act, the UK has translated these national commitments to climate change mitigation into law. The EU has also adopted the international climate change agreements in its sectoral policies. The most relevant policy for this review is the Renewable Energy Directive (RED II), setting the EU's climate change target in the energy and transport sector. Based on the UK's Climate Change Act and RED II, the UK policies for the transport and energy sectors reflect climate change mitigation and some wider sustainability aspects such as land use and ecosystem services. Many of the policies recognise voluntary certification schemes to address the wider sustainability criteria.

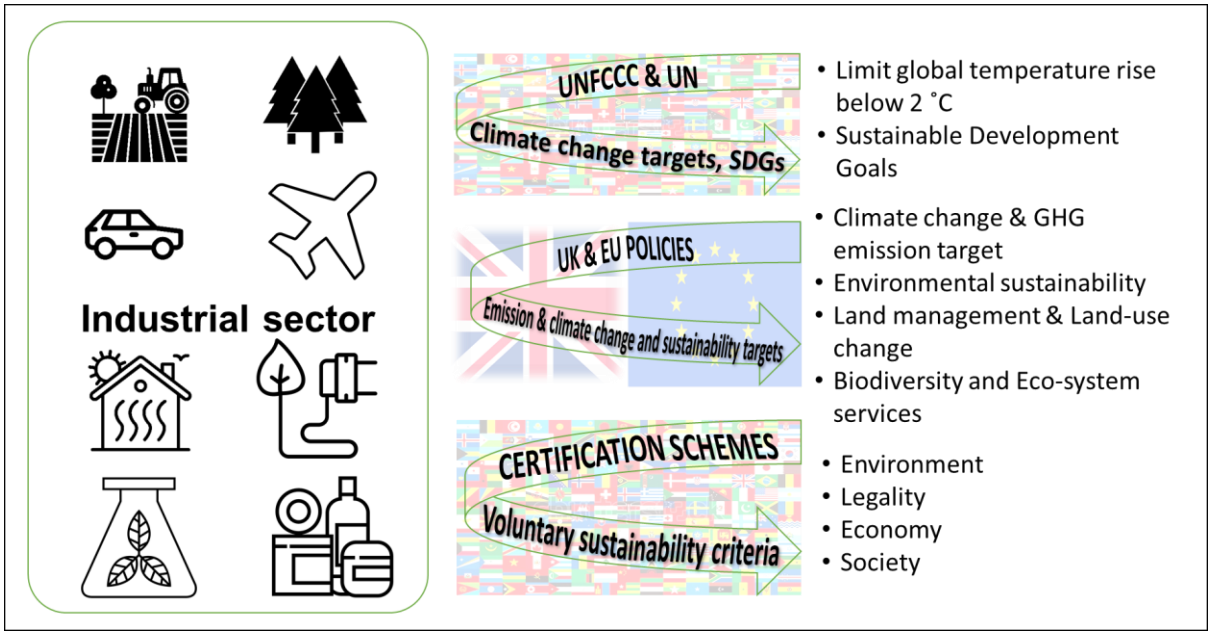

Figure: Bio-based sectors and relevant institutional instruments and measures to support climate change and sustainability

The review of some of the most relevant policies for the UK's bio-based sectors showed that the GHG emission and sustainability standards for biomass and low-carbon feedstocks vary strongly between different sectors. In the energy and transport sector, biomass and low-carbon feedstocks have been used for many years. Policies with details on different sustainability standards address the production and sourcing of biomass with a strong focus on GHG emission reduction, including upstream supply chain emissions and land use criteria. Land use criteria focus on quantifiable carbon stocks in soil and standing biomass. Wider environmental implications such as ecosystem services, land management and biodiversity are included, but do not provide a clear accounting framework.

The policies for other and increasingly emerging bio-based sectors follow UNFCCC guidelines, using Intergovernmental Panel on Climate Change (IPCC) default factors that consider biomass as carbon neutral, hence, biomass has an emission factor of zero. Furthermore, sustainability implications beyond GHG emissions are only considered at a very limited level. Voluntary certification schemes can fill some of these sustainability accounting gaps for the non-energy and non-transport sectors and are a common voluntary requirement for the due diligence of UK industry. However, only a small

number of these certification schemes follows the same detailed accounting requirements as energy and transport policies.

The review also showed the gap in sectoral policies to acknowledge cross-sectoral interfaces, in particular for biomass and resource use, possible co-products and co-benefits. Additionally, the impact and consequences of using or not using biomass feedstocks, apart from indirect land use change in the transport sector policies, is not addressed in any of the policies.

Different sectors using the same feedstock and resources, but reporting their GHG emissions at different detail and with different sustainability standards, limits comparability and fair competition between different sectors.

Based on the findings, a multi-level governance approach has been introduced to overcome the challenges of sector-specific policy frameworks for bio-based industries. This approach consist of the following levels:

- A common policy approach for biomass feedstocks that all sectors utilising biomass have to comply with, supporting fair opportunities and responsibility between the different sectors.
- A decision-making gateway linking feedstock regulations and sector-specific policies enabling the best use of biomass across the different sectors.
- Sector-specific policies setting standards and criteria for sectoral downstream processes, specific to each sector.
- Climate change legislation and sustainability targets building the umbrella framework for the overarching targets across all sectors and related policies.

Certification schemes would provide an additional level of governance and would support good and fair practices along the entire supply chain considering multiple upstream and downstream processes and opportunities. This would also create additional understanding of substitution or replacement effects and possible counterfactuals.

Recommendations

With the urgent need to tackle climate change and build a sustainable low-carbon future, the use of biomass plays an important role in generating energy, providing transport fuels, and producing chemicals and materials. With the existing and increasing demand for biomass across various sectors, common institutional approaches for the best and fair use of biomass are required. The current UK and international governance frameworks can be improved by taking a “best use” approach for biomass that sets the same standards across all sectors for biomass production and biomass sourcing and related resources like land use. The “best use” approach would also require that the cross-sectoral interface and consequences of biomass production and biomass use are considered to enable and maximise climate change mitigation. As biomass production has a strong impact on land, water, ecosystems, biodiversity and communities, particularly rural ones, coherent sustainability targets beyond carbon and climate change need to be included.

2 Introduction

2.1 Background and objectives

Many countries have developed roadmaps and strategies for the transition to a low-carbon bioeconomy to tackle the climate change and build a sustainable future. The concept of bioeconomy, which is based on the utilisation of renewable biological resources, is not new. Societies have always used bio-based resources to generate energy, produce food and materials, or build houses and infrastructures.

Energy and transport are the two main sectors utilising biomass to reduce emissions and support climate change mitigation. Increasingly, chemical, construction and manufacturing industries use biomass to create bio-based products and materials to replace fossil- and mineral-based materials.

With the urgent need to mitigate climate change, protect the environment, support economic development and improve the welfare and wellbeing of societies, the concept of bioeconomy becomes increasingly important. However, the transition from a fossil fuel to a bio-based economy and society needs to consider the sustainability implications of biomass use to enable benefits and mitigate negative impacts in the short-, medium- and long-term across all sectors and for the whole of society. Such a transition and long-term targets are only possible with the support of institutional and regulatory frameworks. These should incentivise sustainable products, practices and services; create a fair market; allow just access to resources, products and services; and prevent, if not prohibit, negative impacts.

Within the current landscape of biomass utilising industries, the different sectors have regulatory frameworks with different ways of accounting for climate change and sustainability impacts. In light of the growing importance of renewable bio-based resources and materials, it is essential that the same emission standards and sustainability criteria are established across all sectors and are harmonised where appropriate and possible. This would serve to avoid market distortions and unintended negative environmental and social impacts, as well as ensuring the establishment of a fair, transparent and competitive market for businesses and end-users.

The Transport Energy Task Force, a collaboration established between the UK Department for Transport (DfT) and the Low Carbon Vehicle Partnership (LowCVP) [1] recommended to the UK government the development of a framework for advanced fuels, based on minimising GHG emissions and ensuring the sustainability of biofuels along the full value chain. This recommendation was developed further by the Asscoiation for Renewable Energy and Clean Technology (REA) Sustainability Working Group [2], which considered the sustainability of all bioenergy vectors to explore the conditions under which advanced biofuels for transport and other sectors may be developed. Aligned with harmonising GHG emission and sustainable criteria across bio-economy sectors, emerging recycled carbon fuels and renewable fuels of non-biological origin must also be considered.

This report reviews and compares the UK's GHG emission and sustainability standards for sectors utilising bio-based and low-carbon feedstock. This will support a better understanding of the current UK policy and governance frameworks for the different sectors. Based on this, a harmonisation framework for GHG emissions and sustainable standards for the bio-based sectors is developed, aiming to support a fair cross-sectoral approach for feedstock use and enable best biomass use and sustainability across all bio-based sectors.

The report will focus on transport and energy (electricity, heating and cooling), as these sectors are currently the most relevant sectors using biomass and play a key role in the transition from a fossil- to a bio-based economy. However, with emerging markets and other developing bio-based sectors and the need to harmonise their GHG emission standards and sustainability criteria, the agriculture, forestry, chemical and manufacturing industries have also been considered.

2.2 Sustainability potential of bioenergy

Biofuels and bioenergy are generated from organic matter such as agricultural and forest residues, manures, energy crops, wood or organic wastes, categorised as biomass. Bioenergy is considered a renewable energy, as the biomass takes up atmospheric CO_2 during the growth of the plants through photosynthesis. When the plant is used as a fuel for energy, this CO_2 is released back into the atmosphere. Depending on the biomass feedstock, the type of fuel and form of energy generated, the removal of carbon at the point of plant growth and a release of this carbon at the point of energy conversion can be within a short (eg, with residues from annual crops) or long (eg, with residues from forests) timeframe [3].

One of the key drivers for bioenergy in the UK is its climate change mitigation potential. While there are variations and related uncertainties for the emission reduction potential, research agrees that bioenergy can make a valuable contribution to the transition to a low-carbon future. However, this is only achieved if bioenergy supply chains follow good practices and low-carbon and sustainability standards throughout.

Bioenergy differs from other renewable and conventional energy pathways as it is directly related to land use, forests and ecosystems from which biomass resources and feedstocks are produced and sourced. This close association within bioenergy systems potentially can lead to environmental and social impacts that can be both positive and negative [4]. With a growing bioeconomy, the demand for biomass feedstocks increases in various sectors in many countries, beyond transport and energy. Consequently, there are likely to be many limitations and notable sustainability implications beyond carbon for the use of biomass to justify the use of bioenergy as renewable.

Land use is one of the most discussed sustainability aspects of bioenergy. Discussion mainly concerns competing uses of land for food and first-generation energy crops with the related potential for increased food prices [5], as well as where energy crop production or fuelwood sourcing could cause a loss of high soil and biomass carbon stocks or biodiversity in forest or grasslands. At the same time, biomass production can also provide benefits to land and land use. Perennial energy crops can be grown on land not suitable for food or livestock production [6, 7]. Increasingly, perennial energy crops are planted for flood prevention and soil protection during floods. In some agricultural rotations, growing biomass feedstocks as an intermediate crop can reduce and avoid fallow periods, which in turn improves soil quality and reduces erosion [8]. Hence, bioenergy does not mean that existing systems are replaced, but instead become an integral part.

Based on the experiences of unsustainable bioenergy systems as well as recognising the wider benefits of bioenergy, many countries, including the UK, have established sustainability guidelines and certification schemes for bioenergy, in particular, biomass sourcing, to reduce negative sustainability impacts. However, there are presently different GHG emissions and sustainability criteria embedded across various government policies for using biomass as low-carbon renewable alternatives to fossil fuels or other non-renewable materials. The sectors of most relevance in recent years have been heat, electricity and road transport. Intrinsically linked to the government goal of a low-carbon economy, the UK Department for Business, Energy and Industrial Strategy (BEIS)

published a Bioeconomy Strategy [9] outlining various bioenergy supply chains and market opportunities for the UK. Additionally, the Committee on Climate Change (CCC) published several reports outlining requirements and potential sectoral and societal transformation for the UK's economy and society to address climate change and support the UK's climate change targets [10].

2.3 Role of bioenergy

Compared to other renewable energies, bioenergy is the most versatile and flexible form of energy. A vast array of biomass feedstocks (eg, energy crops, agricultural and forest residues, manures, organic wastes) can generate electricity, heat or transport fuels, and solid, liquid and gaseous energy carriers as well as bio-based materials by using different bioenergy pre-treatment and conversion technologies as presented in Figure 1.

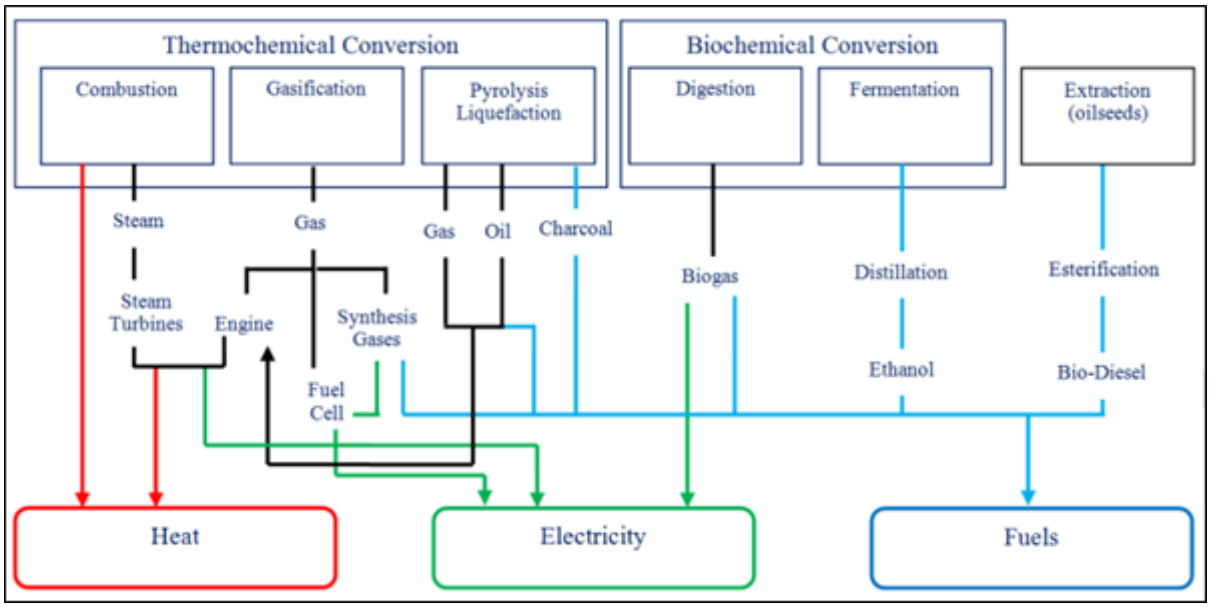

Figure 1 Summary of the core bioenergy conversion pathways and resulting energy vectors [11]

Worldwide, bioenergy makes up about 70% of all renewable energy sources [12]. Traditional bioenergy, for example to provide heat for cooking, is unsustainable and used inefficiently. This has significant negative environmental impacts, such as deforestation and land degradation, and health implications due to indoor pollution and related respiratory illnesses [13, 14]. The use of charcoal or fuelwood within traditional bioenergy systems can also generate GHG emission factors far above some fossil fuel energy technologies [15]. In contrast, modern bioenergy systems describe the generation of fuels and energy using energy-efficient and sometimes highly advanced technologies fuelled by sustainably produced feedstocks. In the UK, about 66% of renewable energy comes from modern bioenergy (Figure 2), providing about 7.3% of the UK's primary energy supply [16]. The majority of this bioenergy is produced using modern technologies with regulations to minimise negative impacts and support the use of sustainable and low-carbon practices and technologies.

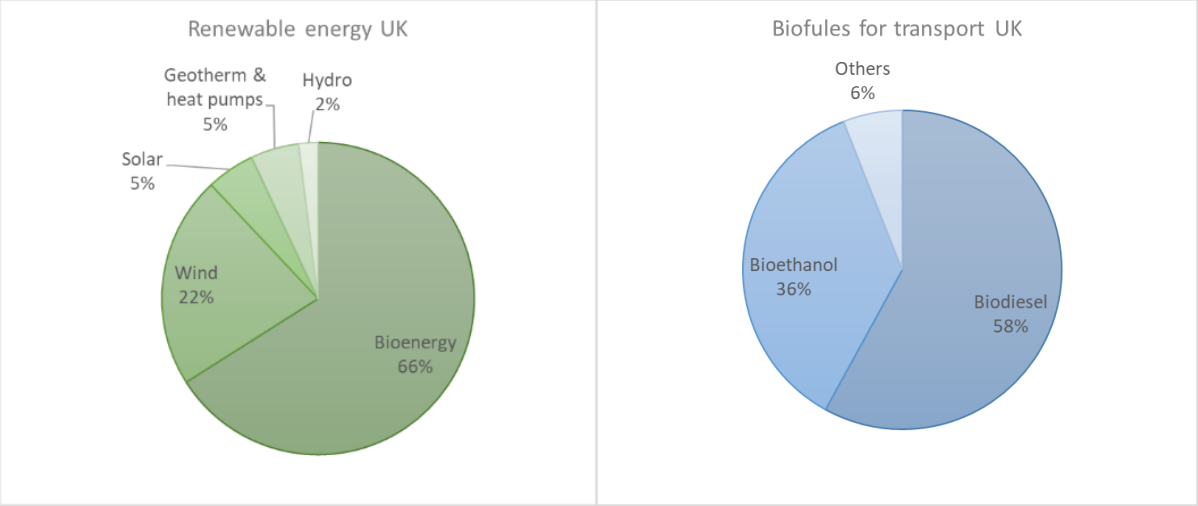

Figure 2 Share of renewable energy and biofuels for transport in the UK (2018) [16, 17]

In 2018, about 1,518 million litres equivalent of sustainable renewable fuel was used in the UK's transport sector, which is about 4% of its total UK road and non-road transportation. 58% of this volume was biodiesel, 36% bioethanol, and 5% other biofuels (Figure 2) [17]. Waste-based feedstocks made up 69% of verified renewable fuel. About 16% of the feedstocks for producing fuel originated in the UK, with used cooking oil providing the largest single UK feedstock. For bioethanol, the largest contributing feedstock was imported corn from Ukraine [17].

The transport sector accounts for 27% of the UK's greenhouse gas emissions [18], and if the UK is to meet its current emission reduction targets, domestic transport will need to reduce its emissions by over 40% by 2030 [19].

Table 1 Changes to the UK Renewable Transport Fuel Obligation for 2017 [20]

	Specified amount, as share of total fuels
Renewable Transport Fuel Obligation Levels	• 9.75% by 2020 • 12.4% by 2032
Development Fuels	• 0.1% by 2019 • 2.8% by 2032
Biofuel Feedstock Crop Cap	• 4% by 2018 • 3% by 2026 • 2% by 2032
Aviation and Advanced Fuels	• Renewable aviation fuels and renewable fuels of non-biological origin brought into the scheme

The UK's Renewable Energy Roadmap [21] showed that energy from biomass will play an increasingly important role for the UK in achieving its climate change, emission reduction and renewable energy targets for heat, power and transport fuels. While the UK has made substantial

progress in the production of renewable electricity for domestic and commercial uses, there remains a significant opportunity to reduce the reliance on fossil fuels in the transport sector.

In 2017, the UK Department for Transport (DfT) announced [22] its intention to raise the targets of the amount of renewable transport fuels (Table 1), paving the way for future growth of the UK biofuels industry. DfT also has a long-term strategy for decarbonising the heavy goods vehicle and aviation sectors where biofuels are expected to contribute. Alongside these targets, the government has imposed sustainability restrictions, limiting the contributions from crop-based biofuels. This can result in a significant rise in demand for non-crop feedstocks, such as wastes and residues. There are consequently many questions about the future availability of biomass feedstocks for the transport sector, what characteristics available feedstocks may have, and how they can be best used to produce biofuels.

3 Institutional frameworks and sustainability approaches

3.1 Framework for climate change targets

To understand the motivation and drivers for UK policy instruments, it is important to understand the hierarchy and targets of policies and legislation. For the UK, this is a combination guided and legislated by international and national frameworks and measures.

The United Nations Framework Convention on Climate Change (UNFCCC) agreements, including the Paris Agreement [23] to keeping a global temperature rise well below 2°C, set the overall climate change targets for the EU and member states like the UK. The UK's Climate Change Act [24] (amended in 2019 [25]) builds the legislation to keep the UK on track for their agreed climate change targets across all sectors, while the policy instruments are guided by these climate change targets.

The UK's climate change target is to reduce GHG emissions by at least 100% by 2050 [26] compared to 1990. The UK adopted a cumulative emission budget approach, setting out 'Carbon Budget' caps on the amount of GHG emissions the UK can emit over five-year periods. These are considered as stepping stones towards the 2050 target (Table 2UK Carbon budgets until 2032 set under the Climate Change Act in 2008) [27].

Table 2 UK Carbon budgets until 2032 set under the Climate Change Act in 2008 [27]

Budget	**Carbon Budget Level**	**Reduction below 1990 level**
1s t Carbon budget (2008-2012)	3,018 $MtCO_2e$	25%
2nd Carbon budget (2013-2017)	2,782 $MtCO_2e$	31%
3rd Carbon budget (2018-2022)	2,544 $MtCO_2e$	37% by 2020
4th Carbon budget (2023-2027)	1,950 $MtCO_2e$	51% by 2025
5th Carbon budget (2028-2032)	1,725 $MtCO_2e$	57% by 2030

The UK is currently in the third carbon budget period (2018 to 2022). The first two targets, from 2008 to 2017, have been met. However, to meet the fifth carbon budget in 2032, the UK government needs to apply measures that are more stringent.

Decarbonising all sectors to mitigate climate change has ramifications for the whole UK economy, and therefore all UK government departments will have to implement measures to reduce emissions. Although the leading UK government departments designated are the Department for Business, Energy and Industrial Strategy (BEIS), which develops policies to reduce GHG emissions (mitigation), the Department for Environment and Rural Affairs (Defra), in charge for domestic adaptation policies, and the Department for Transport (DfT), overseeing the implementation of low-carbon transport.

A wide range of institutional and regulatory instruments has been developed over the last two decades by governments and independent certification companies to set standards addressing biomass sustainability for different industrial sectors. Legally binding regulations have been introduced by both the UK and EU. International organisations have also developed instruments to address sustainability issues by setting voluntary standards for companies to demonstrate and follow due diligence by reducing negative impact, following good practice and enabling sustainability in their activities.

3.2 Energy and transport sector policies

3.2.1 Renewable Energy Directive (RED II) and Fuel Quality Directive (FQD)

The Renewable Energy Directive (RED II) [28] is the key regulatory framework for the promotion of the use of renewable energy from various sources. RED II [28] sets binding climate change and sustainability targets for the renewable energy sector, including transport fuels. The original directive (2009/28/EC) was updated in 2018. The key changes in RED II, were the inclusion of indirect land-use change (ILUC) and the introduction of sustainability requirements for solid biomass. These changes were based on the lessons learned from the unsustainable use of biofuels, which had led to competing land use for other crops for food, feed, non-food production, forests or environmentally vulnerable land. RED II key targets for transport, electricity, and heating and cooling are [28]:

- By 2020:
  - 15% of the total energy comes from renewables (20% in the EU);
  - 10% of energy used in transport must come from renewable sources.
- By 2030:
  - At least 32% of the gross final energy consumption comes from renewable sources;
  - GHG emissions have to fall by 40% compared to 1990 levels;
  - At least 27% of renewable energy has to be consumed in the EU;
  - At least 14% of the total energy employed in transport has to come from renewables.

Table 3 refers to the emissions-saving targets for biofuels for transport and bioenergy (electricity, heat and cooling).

With a focus on transport, the Fuel Quality Directive (FQD, 2009/30/EC) [29] set the GHG emission target for fuel suppliers for land transport. EU Member States have to achieve at least a 6% reduction in GHG emissions for supplied fuel in 2020 compared to the 2010 baseline of average fossil fuel emissions of 94.1 gCO_{2e}/MJ. The reduction target is likely to be achieved primarily using biofuels, electricity, low-carbon fuels and renewable fuels of non-biological origin (RFNBO). The FQD applies to petrol, diesel and biofuels used in road transport, as well as to gasoil used in the non-road mobile

machinery sector [29]. In addition to the GHG emission standards, fuel suppliers have to comply with the sustainability criteria introduced by RED II [30].

Table 3 GHG emission savings from the use of biofuels, bioliquids and biomass fuels [28]

Date on which installation is in operation	Sector	Emission savings*, at least [%]
before 5/10/15	Biofuels, biogases, bioliquids in transport sector	50
From 6/10/15 until 31/12/2020		60
From 1/1/2021		65
From 1/1/2021 until 31/12/2025	Electricity, heating and cooling production from biomass fuels	70
From 1/1/2026		80

*Emission saving = emission reported as saving against the fossil fuel comparator, which is the average carbon intensity of petrol and diesel supplied in the EU [28].

RED II and FQD set GHG emissions and GHG savings for different biomass and low-carbon feedstocks. However, currently they do not specify carbon emissions and carbon savings for RFNBOs and recycled carbon fuels. In the future, these fuels should be taken into account by the transport sector, as well as when they are used as intermediate products for the production of conventional fuels. In the case of RFNBOs, GHG emissions savings should be at least 70% from 1 January 2021 [28]. This way, the promotion of RFNBOs and recycled carbon fuels will contribute towards energy decarbonisation of the transport sector.

3.2.2 Land transport - Renewable Transport Fuel Obligation (RTFO)

The Renewable Transport Fuel Obligation (RTFO) [31] is the UK's primary mechanism for supporting the uptake and increase of sustainable biofuels and other low-carbon fuels in the transport sector. It is the instrument to implement the transport elements of RED II and FQD into UK policy, covering road transport and non-road mobile machinery (NRMM). The Department for Transport (DfT) introduced the RTFO in 2008 to encourage the provision of sustainable renewable fuels. With the introduction of RED II, RTFO [32] was amended to:

- Setting updated GHG savings thresholds for renewable fuels;
- Implementing ILUC values for land-based (crop) biofuels;
- Introducing definitions for wastes, residues and dedicated energy crops;
- Setting a target for advanced biofuels/development fuels with annual increase to reach 1% by 2023 and 1.8% by 2027 of total fuel volume [20, 30], eligible for double RTFCs [20];
- Setting a cap for crop-derived biofuels of 4% from 2018, 3% by 2026 and 2% by 2032 [20, 30, 33] (see Table 1).

Under the RTFO, renewable fuels meet the sustainability criteria if the GHG emission saving thresholds and land criteria for feedstocks are met, or if there are exemptions related to fuels produced from waste or residues.

The sustainability criteria are [30]:

- Renewable fuels achieve at least a 50% GHG emissions saving, if produced in installations starting on or before 5 October 2015;
- Renewable fuels achieve at least a 60% GHG emissions saving if produced in installations starting after 5 October 2015;
- Biofuels may not be made from raw material obtained from land with high biodiversity value in or after January 2008;
- Biofuels may not be made from raw material obtained from land with high-carbon stock, such as forests or land that was undrained peatland, in January 2008.

Table 4 summarises some of the key feedstocks and biofuels and their related GHG emission standards [30].

Table 4 Carbon intensities (default values), carbon savings, DLUC and ILUC emissions associated to each feedstock [30]

Feedstock	**Biofuel**	**Emission intensity (gCO_{2e}/MJ)**	**Emission saving (%)**	**Direct land use change (DLUC) (gCO_{2e}/MJ)**	**Indirect land use change (ILUC) (gCO_{2e}/MJ)**
Wheat	Bioethanol, ETBE, TAEE	70*	16*	($CS_{previous}$ - $CS_{current}$) x 1/P x 1/20 - B	12
Corn		43*	49*		
Sugar cane		24	71		13
Sugar beet		40	52		
Oil crops	Biodiesel	n.a.	n.a.		55
Rape seed		44-52*	38-47*		
Palm oil		29-68*	19*-65		
Sunflower		32-41	51-62		
Soy bean		58*	31*		
Waste wood	Bioethanol, ETBE, TAEE, diesel, DME, methanol	4-22	74-95	Not required to be reported	0
Farmed wood		6-25	70-93		0
Municipal organic waste	Biomethane	23	73	Not required to report land criteria	
Residues (non-agricultural)	Various	No lifecycle emissions before collection	n.a.		
Residues: agricultural, aquacultural, fisheries, forestry					
Carbon-containing feedstock of non-biological origin	RFNBO	n.a.			

n.a. = not applicable; * = exceeds mandatory target

Renewable fuels of non-biological origin (RFNBOs) and other low-carbon and recycled fuels are increasingly recognised as fossil fuel replacement to reduce GHG emissions. Under Article 4 of RED II, recycled carbon fuels are [28]:

- Liquid and gaseous fuels produced from liquid or solid waste streams of non-renewable origin, which are not suitable for material recovery;
- Gas and exhaust gas of non-renewable origin from waste processing, produced as an unavoidable and unintentional consequence of the production process in industrial installations.

3.2.3 Electricity generation - Renewable Obligation (RO) and Feed-In Tariffs (FIT)

The Renewables Obligation (RO) [34] is the UK policy instrument incentivising large-scale renewable electricity generation to help the UK meeting its 15% target of renewable energy provision [28]. It covers the whole range of renewable energy applications beyond bioenergy. For bioenergy, it sets the sustainability criteria for solid biomass, biogas and bioliquid fuels used for large-scale electricity production required under this scheme [35].

RO puts an obligation on licensed electricity suppliers in the UK to acquire an increasing proportion of electricity from renewable sources [35].

Operators of power generating facilities using any form of biomass feedstock (gaseous, liquid or solid) are required to report their sustainability performance, unless they use [35]:

- Sewage gas, landfill gas or municipal waste to generate electricity;
- Solid biomass or biogas with a declared net capacity (DNC) of ≤ 50kW;
- Solid biomass or biogas that do not meet the definition of biomass (eg, biogenic content is <90%).

All bioenergy operators that do not fall under these exemptions have to provide information on the GHG emissions (the lifecycle emissions of the biomass) and land use criteria (the land from which the biomass is sourced) [35].

Table 5 GHG targets and ceiling values for large-scale electricity generation from solid and gas biomass [35]

	Emission target (gCO_{2e}/MJ electricity)	**Emission ceiling (gCO_{2e}/MJ electricity)**
Post-2013 biomass stations before 1/4/2020	66.7	79.2
All biomass and biogas stations from 1/4/2020 until 31/3/2025	55.6	75.0
All biomass and biogas stations from 1/4/2025	50.0	72.2

For solid biomass and biogas, power generators need to meet the GHG emission thresholds based on an annual average rather than an individual consignment basis (Table 5) [35]. The emission target in Table 5 is the annual average GHG emissions of all biomass used in an obligation year. The

emission ceiling is the maximum threshold for any biomass used under Renewable Obligation Certificates (ROCs) [35].

Table 6 shows the GHG thresholds for solid biomass and biogas fuels from a selection of feedstocks under RO [35].

Table 6 GHG thresholds for solid biomass and biogas fuels under RO [35]

Feedstock	**End-use**	**Emission intensity (gCO_{2e}/MJ)**	**DLUC (gCO_{2e}/MJ)**	**ILUC (gCO_{2e}/MJ)**
Forestry residues	Solid biomass and biogas fuels	1-50	$(CS_{previous} - CS_{current}) \times 1/P \times 1/20 - B$	Not required to be reported
Wheat straw		2-21		
Miscanthus		7		
Maize		19-34		
Wet and dry manure		7-8		

Additionally to the GHG emissions, operators have to report on the land use criteria for the sourced biomass. Land use criteria are considered for woody and non-woody biomass. Any biomass classified as waste is exempted from the land use criteria.

The land use criteria for woody biomass require that wood is legally harvested in line with the EU Timber Regulation [36]. Wood must originate from forests managed and maintained in line with Forest Europe Sustainable Forest Management Criteria [37] or international principles and criteria for sustainable or responsible forest management, including [38]:

- Harm to ecosystems is minimised;
- Integrated pest management;
- The productivity of the area is maintained;
- Compliance with the productivity requirements should be monitored;
- The area is managed in a way that ensures the health and vitality of ecosystems is maintained;
- Biodiversity is maintained;
- Those responsible for the management of the area comply with the local and national laws relating to health and safety and the welfare of workers.

The evidence for sustainable land criteria can be provided through eligible certification schemes or through collected evidence that demonstrates compliance.

For non-woody biomass as well as lingocellulosic energy crops, the same land use criteria apply. Biomass cannot be sourced from land that was [35]:

- Primary forest, designated for protecting nature, highly biodiverse grassland, peatland, a continuously forested area, a lightly forested area, or wetland at any time during or after January 2008;
- Where a land use change has occurred that is not permitted under the land criteria;

- If land use change is permitted under the criteria then a carbon stock calculation needs to be performed.

Energy crops are required to include the land criteria for non-woody biomass. If land use change has occurred, not falling under the criteria above, the carbon stock change has to be calculated and added to the supply chain GHG emissions [35].

The UK's Feed-in Tariffs (FIT) scheme [39] was discontinued in 2019. However, it is still deployed for renewable energy installations registered before this date. FIT supports the uptake of a range of small-scale renewable and low-carbon electricity generation technologies, including bioenergy. The sustainability criteria for bioenergy include the supply chain's GHG emissions and land use criteria [40] following the same standards and criteria for biomass feedstocks as the RO.

3.2.4 Heat generation - Renewable Heat Incentive (RHI)

The Renewable Heat Incentives (RHI) for the domestic [41] and non-domestic [42] sector are designed to promote the use of renewable and low-carbon heat in supporting the UK's target of 15% renewable energy [28]. Both schemes are based on the sustainability criteria of the RO but have separate tariffs, joining conditions, rules and application processes, due to different technologies, efficiencies and scales for heat generation compared to electricity generation. As the RO, they cover a range of renewable heating systems beyond bioenergy. However, bioenergy applications are subject to sustainability criteria following the GHG emission standards and land use criteria of the RO. This relates to woody biomass with the requirement to evidence of sustainable wood sourcing through certification schemes in line with the EU Timber regulation [36] or through collected evidence that demonstrate compliance.

Only the non-domestic RHI provides GHG emissions for different feedstocks as it addresses businesses, public sector and non-profit organisations. The RHI's GHG sustainability benchmark requires that lifecycle emissions of biomass heat generated or biomethane injected into the gas grid is 34.8 g CO_2/MJ or below [43], to achieve a 60% GHG emissions saving relative to the EU fossil fuel heat average. The GHG emission thresholds for heat from different feedstocks are presented in Table 7.

Table 7 GHG emission standards for heat production from different biomass feedstocks under the non-domestic RHI [43]

Feedstock	End-use	Emission intensity (gCO_{2e}/MJ)	Emission saving (%)	DLUC (gCO_{2e}/MJ)	ILUC (gCO_{2e}/MJ)
Wood chips	Heat	1-28	n.a.	($CS_{previous}$ - $CS_{current}$) x 1/P x 1/20 - B	Not required to be reported
Wood briquettes/pellets	Heat	2-22			
Wheat straw	Heat	2			
Bagasse briquettes/bales	Heat	17-20			
Palm kernel	Heat	27			
Rice husk	Heat	28			
Miscanthus	Heat	7			
Wheat/straw	Heat	21			
Maize	Heat	19			

3.3 Waste sector regulations

Biomass feedstocks of waste origin are considered a key resource for bioenergy and biofuels. The policy frameworks described below acknowledge waste as a low-carbon feedstock that does not result in land use conflicts and has low GHG emissions.

In the UK, it is necessary to determine the classification of waste resources to identify their suitability for energy waste management pathways. The classification of different wastes will influence how the resource may be collected, transported, managed, disposed and, in the case of bioenergy, the "fuel classification" [44]. This classification determines whether biomass is a product/co-product, waste or a residue.

This is particularly important for the operator who will need to report sustainability criteria. Following the definition of the EC Directive on Waste [45], wastes are considered materials which the holder discards, intends to discard, or is required to discard. Residues from agriculture, aquaculture, forestry and fisheries are materials generated through the harvesting of the desired material, and once the product has been harvested, any further material generated through processing is considered processing residues. In the case of biofuel production from wastes and residues, it is possible to claim an exemption when reporting sustainability criteria if the material from which the fuel was produced is a waste or residue [35].

The current quantities of waste generated in the UK are documented within the UK Waste Statistics managed by Defra [46]. The availability of different types of wastes that are potentially suitable for biofuel production in the future will be driven by a series of dynamics:

- Growth Dynamics – trends in the extent that different waste may be generated through time may be calculated as a function of changing economic development trends for different sectors of the economy;
- Efficiency Dynamics – trends influencing the changing rate that different resources will be generated over the timeframe;
- Policy Dynamics – changes in policy focus, regulations and targets will influence how different wastes streams may be managed compared to the current practice; for example, in the UK there is currently much policy focus on diverting UK wastes from landfill targets driven by recycling and reuse targets;
- Competition Dynamics – the level of available resources for biofuels will be restricted by competition for waste resources; for example, targets for growing the UK's power energy from the waste sector competing for resources.

As current UK policy is closely linked to the waste hierarchy, where the priority is for waste prevention, minimisation, reuse and recycling before energy recovery options are applied. Therefore, if the UK's current waste policy objectives were to be fully achieved, there would be an overall reduction in the level of waste, and thus a reduction in waste feedstocks available for the biofuel sector.

3.4 Agriculture and forestry policies

3.4.1 Agriculture

The key agricultural scheme to support sustainable practices is the Basic Payment Scheme (BPS) [47], which covers sustainable and environmentally friendly uses of agricultural land. Agricultural land is categorised as permanent grassland, arable land and permanent crops. If non-agricultural land is

used by farmers and they want to apply for support, dedicated mechanisms exist such as Countryside Stewardship, the Habitat Scheme, various Woodland Grant Schemes and the Woodland Carbon Fund [47].

The key sustainability standards in agriculture relate to the use of and practices on agricultural land, for example, what is grown, in what way the crop is managed, the rotation and the additional services provided (biodiversity, soil protection, recreation, etc.). One key element of the BPS is the greening rules that farmers need to comply with [47]. The greening rules cover [47]:

- Crop diversification: Farmers with 10 hectares or more of arable land need to grow at least 2 or 3 different crops.
- Ecological Focus Areas (EFAs) on arable land: Farmers with more than 15 hectares of arable land must have EFAs on their land, (eg, buffer strips and field margins, catch crops, cover crops, nitrogen-fixing crops, fallow land, hedges or trees in a line).
- Permanent grassland: If the percentage of permanent grassland in England, relative to the area of agricultural land, falls by more than 5%, farmers who have ploughed permanent grassland may have to re-instate it.

By the end of 2024, the new Environmental Land Management (ELM) [48] scheme will replace the BPS. It aims to encourage farmers to enhance the environment through, for example, tree or hedge planting, river management to mitigate flooding, and creating or restoring habitats for wildlife, following three tiers [48]:

- Tier 1: Adopt environmentally sustainable farming and forestry;
- Tier 2: Practices delivering locally-targeted environmental outcomes;
- Tier 3: Larger-scale, transformational projects such as restoring peatland.

Voluntary schemes like Championing the Farmed Environment are additionally promoting good environmental management through productive farming practices focussing on soil, water, air, wildlife and climate change mitigation. This encourages reducing GHG emissions from agricultural practices, carbon sequestration through plant growth, and renewable energy integration including tools and certification schemes for carbon auditing [49].

3.4.2 Timber regulations

Residues from forests and wood processing are valuable feedstocks for the production of bioenergy. Various institutional frameworks, such as RED II and RO, consider woody biomass as renewable and accredit it within their incentive schemes. As forest and wood processing residues are part of the wider forest sector, the same sustainability standards apply to the residues as to the main timber and wood production and processing. This ensures that sourcing from sustainably managed forests includes the avoidance of deforestation, land use change and losses of carbon and biodiversity through unsustainable management regimes.

The EU's Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan [50] sets a range of measures for the EU Member States to tackle illegal logging happening worldwide in forests. The EU is one of the largest consumers of timber products in the world. Companies and governments that buy timber and timber products from suppliers in Africa, Asia or South America have a significant impact on illegal logging. To help reduce illegal logging, buyers must purchase timber from producers that comply with national laws and act responsibly towards the local population and the environment. The EU FLEGT Action Plan sets measures to prevent the import of illegal timber into the EU, to improve the supply of legal timber and to increase demand for timber from responsibly managed forests.

These measures also support socially beneficial public procurement policies helping to achieve local, regional, national and international sustainability goals.

Similar to FLEGT, the EU Timber Regulation (EUTR) [36, 51] aims to reduce illegal logging by ensuring that no illegal timber or timber products can be sold in the EU. It requires traders who place timber products on the EU market to exercise due diligence procedures and facilitate the traceability of timber products that are traded in the EU, including keeping records of their suppliers and customers. The regulation covers a broad range of timber products, including solid wood products, flooring, plywood, pulp and paper. Recycled products and printed paper are not included. Timber or timber products that carry a valid FLEGT licence are considered compliant with the requirements of the regulation.

3.5 Governance frameworks for other industries – Chemical industry and construction

While other industries such as the chemical industry and construction are increasingly drawing on biomass feedstocks and bio-based materials, there are no dedicated policy measures for biomass use in these sectors. The regulation and due diligence in these sectors is mainly based on voluntary standards and certification schemes. For example, the ISO 14000 family is the International Standard for Environmental Management Systems (EMS) [52]. It has been designed by the International Organisation for Standardisation (ISO) to assist businesses and organisations in reducing their environmental impact. This standard allows any businesses, regardless of size and sector, to set up an EMS to help in reducing waste and pollution, improving resource efficiency and cutting waste management costs. Implementing ISO 14000 standards enables organisations to demonstrate that their business is committed to reducing its environmental impact by improving compliance with existing environmental standards [52].

GHG emissions of chemical, construction and manufacturing industries in the UK are reported through the National Atmospheric Emissions Inventory, with the inventory system based on recommendations and the accounting framework of the UNFCCC.

The EU Emissions Trading System (EU ETS) [53, 54] is one of the key measures to regulate the emissions from industry to reach climate change targets. In the UK, EU ETS will be replaced with a national carbon price or carbon trading instrument after Brexit [55].

The EU ETS covers sectors and installations above certain capacity thresholds, power stations and other combustion plants, oil refineries, coke ovens, iron and steel plants and factories making cement, glass, lime, bricks, ceramics, pulp, paper and board, petrochemicals, ammonia and aluminium. Since 2012, EU ETS also include aviation within the EU [53]. EU ETS is accepting IPCC default emission values with some country-specific values. However, emission factors for biomass are considered as zero [53].

There are no policies for sectors like chemicals, construction and manufacturing in the UK that address sustainability of biomass use in these industries as exist in the energy and transport sector.

3.6 Voluntary certification schemes, standards and industry agreements

In addition to government policies, voluntary certification schemes are one way to address sustainability issues in different sectors, as they set standards through intra-market private and multi-stakeholder mechanisms. As policies, each certification scheme sets out its mechanisms to achieve accreditation. While these vary depending on the scheme and its relevant principles and criteria, the mechanisms are similar across the different schemes, following a set procedure of reporting,

monitoring and auditing. Voluntary certification schemes are regulated by independent organisations; however, as for policies, once accreditation is achieved, the accredited entity has to comply for the duration of accreditation, often through regular reporting and auditing.

In bio-based sectors, certification schemes have a strong focus on biomass production and sourcing. The main purpose of such certification schemes is to ensure that the feedstocks are provided to the UK from sustainable domestic and international sources and markets.

Certification schemes are in most cases sector-specific and a wide range of sectors have schemes including the transport, electricity, heat, agriculture, forestry and timber, waste, chemical and other bio-based sectors. However, some schemes are cross-sectoral as they address for example biomass feedstocks that are used in different sectors and have different processing routes and end-uses. The principles and criteria for certification schemes are usually presented in scheme-specific categories, and may be clustered in four overarching categories: legal, economic, environmental and social.

Some of the voluntary certification schemes are acknowledged under some UK policies, such as RTFO and RO (eg, the Sustainable Biomass Program, the Programme for Endorsement of Forest Certification, the Roundtable on Sustainable Biomaterials and International Sustainability and Carbon Certification), as their sustainability requirements are in line with policy standards. As presented above, the policies have a strong focus on quantitative reporting of GHG emissions (supply chain and land use emissions) and land use criteria. Combining policy frameworks with certification schemes allows wider sustainability criteria to be addressed beyond the frameworks themselves.

There are also some industry agreements under development, like the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [56], to develop agreed sustainability and climate change standards and criteria for the aviation industry.

A selection of the certification schemes and industry schemes for the bio-based sectors are presented in the Annex. There are various other certification schemes approved under UK policies, but one key element of all these schemes is that they are in line with requirements described in the policies.

Although these schemes are voluntary, there is a cost associated for a producer or supplier to gain certification.

4 Comparison of institutional frameworks and sustainability approaches for bio-based sectors

The review of the UK's institutional frameworks and sustainability approaches for bio-based sectors showed the important role of biomass for an increasing range of sectors and markets.

Figure 3 illustrates the different relevant instruments that were identified, including international agreements, EU and UK policies and voluntary measures like certification schemes. The review showed that the main driver of current regulations and voluntary frameworks is climate change mitigation. This is not surprising as the overarching framework is based on an international level with the UNFCCC climate change agreements. With the Climate Change Act, the UK has translated its national climate change mitigation commitments into law. The EU has also adopted international climate change agreements in its sectoral policies. The most relevant policy for this review is the Renewable Energy Directive (RED II), setting the EU's climate change target in the energy and transport sector. Based on the UK's Climate Change Act and RED II, the UK policies for the transport

and energy sectors reflect climate change mitigation and some wider sustainability aspects like land use and ecosystem services. Many of the policies recognise voluntary certification schemes to address the wider sustainability criteria.

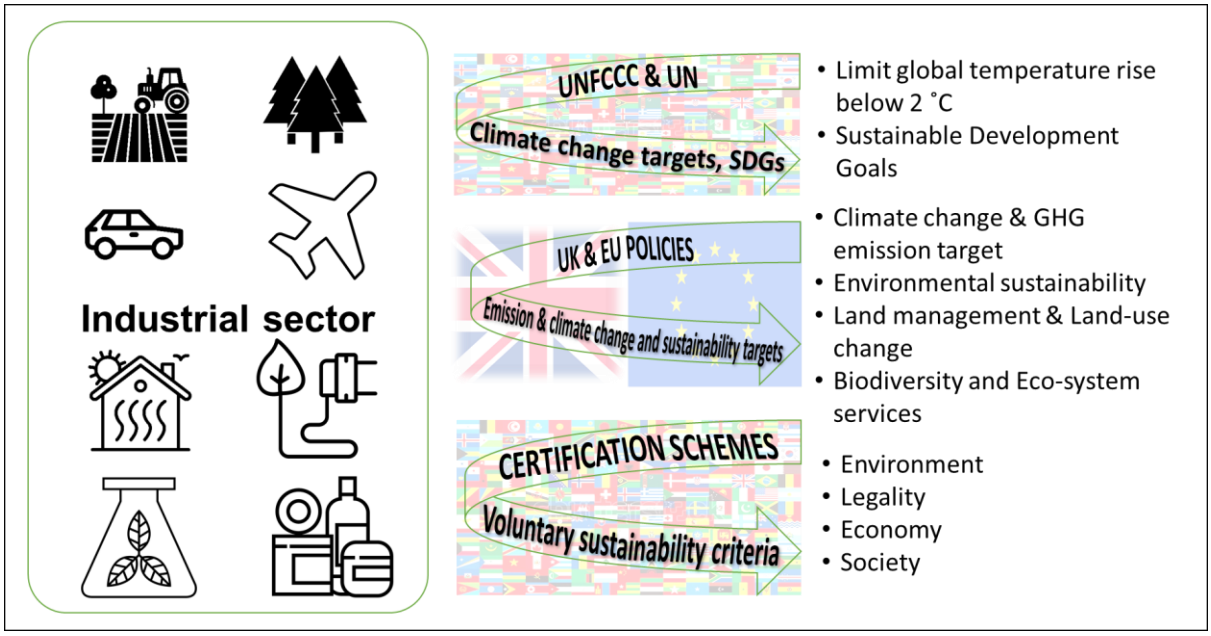

Figure 3 Bio-based sectors and relevant institutional instruments and measure to support climate change and sustainability

The key aspects of the different instruments and measures follow similar categories and principles of sustainability. Still, the criteria and sustainability standards vary between policies and certification/industrial schemes as they serve different purposes.

4.1 Energy and transport sector

Considering the energy and transport sector, the related UK polices (eg, RTFO, RO, RHI, FIT) fall under the same umbrella of RED II and follow its strong focus on the quantification of GHG emissions and land use. GHG standards for land use and carbon stock maintenance are also included and part of the accounting of the overall GHG performance of bioenergy and biofuel supply chains. Additionally, aspects like ecosystem services and biodiversity are part of these sector policies too.

Figure 4 gives an overview of different sustainability criteria of different sectors and sectoral policies and regulations in the UK.

Figure 4 shows that policies for transport and energy include various criteria on GHG emissions such as emission targets/thresholds and emissions savings compared to conventional fossil-based technologies. Apart from GHG emissions, land use criteria are the other central standards of these policies. Land use change is accounted for by considering above- and below-ground carbon stock changes. Additionally, criteria like sustainable land management, ecosystem services, biodiversity, protection of high-carbon stocks and legal sourcing are included. However, these are criteria which are monitored and measured in a qualitative rather than quantitative approach. Evidence for some of these criteria can be provided through acknowledged certification schemes.

While most sustainability criteria in the policies of the energy and transport sectors draw on the same aspects, the most apparent difference is the inclusion of ILUC in transport policy (RTFO) compared to other energy sector policies.

Direct land-use change (DLUC) considers if land use has directly changed in relation to feedstock sourcing and production. It is included in the emission accounting as the change of carbon stocks. It refers to land already used for a specific purpose and the use of the land would directly change to a new use, for example from an annual crop to a perennial crop. As this would cause changes in the carbon stored in the soil (through either an increase or decrease)., this change in sold carbon stock needs to be included in the supply chain emissions.

Compared to this, indirect land-use change (ILUC) considers if the production or sourcing of biomass has indirect impacts on land use somewhere else. This is included with an ILUC factor as part of the GHG emission accounting. Generally, transport and energy sector policies require DLUC emissions to be reported for all purpose-grown feedstocks.

ILUC emissions are only reported for feedstock groups falling under sugar, cereal and oil crops, which are traditionally feedstocks for the production of first-generation biofuel. ILUC factors were introduced with RED II in 2018 and adapted in RFTO. The default ILUC factors need to be included in the emission calculation for transport fuels from these feedstocks. The ILUC factor implies the amount of emissions released to the atmosphere from land use (eg, forest to agricultural land or grassland to agricultural land). While this is also the approach for DLUC, the concept of ILUC applies to biomass feedstock that requires agricultural land, and where DLUC cannot be shown by the operator and hence an indirect impact is likely.

For example, if a grassland is turned into cropland to grow an energy crop, the emissions related to DLUC can be accounted directly. However, if a cropland previously used to grow a food or feed crop is then used to grow an energy crop, the actual land use has not changed. It is now possible that the previously grown crop is grown somewhere else instead (assuming the demand has not decreased). This can potentially lead to indirect land use change somewhere else if the previously grown crop is now grown on non-arable land. However, ILUC factors bear a high level of uncertainty, as they are often hard, if not impossible, to track and trace. Nevertheless, an inclusion of ILUC factors can lead to improved system thinking and building awareness of potential trade-offs and unintended consequences related to supply chain elements and practices. Still, a theoretical framework focussing only on the possible dimensions of systems trade-offs might not necessarily create improved transparency.

There is also the argument from the biofuel producing industry in the UK, as the only sector reporting ILUC, that biofuel production does not only produce biofuels but generates by-products (eg, distillers dried grains with solubles (DDGS) and glycerine). This can substitute feed crops that otherwise would take up agricultural land for their production. Hence, there could be the argument that in some cases biofuel production could potentially reduce the need for arable land to produce animal feed.

4.2 Agriculture and forestry

For other sectors that use land and bio-based resources, like the agriculture and food and forestry and timber industries, the sustainability criteria for biomass production and sourcing differ significantly from the transport and energy sectors (Figure 4). The institutional frameworks for agriculture have a strong focus on land management and soil quality and health. There is also a strong focus on environmental aspects like ecosystem services, biodiversity, and the maintenance or improvement of above- and below-ground carbon stocks. However, while farmers are encouraged to reduce emissions or contribute to renewable energy supply, there are no direct measures that require farmers to report GHG emissions from farming or land use change.

The institutional framework for the forest and timber industry has a strong focus on legal production and sourcing of wood. These are criteria which translate through to bioenergy policies in the case of woody biomass feedstocks. While the maintenance and protection of high-carbon stocks are included in the regulations of the forest and timber sector, this is based on a legal sourcing approach rather than actual reporting of the industry on carbon stock changes.

4.3 Other sectors

Chemical and construction industries are increasingly drawing on bio-based feedstock. However, policies pertaining to these sectors do not include any criteria related to the production and sourcing of biomass. The chemical, construction and manufacturing industries can reduce their GHG emissions, and so reduce their requirement for EU ETS certificates, by using biomass feedstock (Figure 4). The reporting requirements are in this case based on UNFCCC accounting frameworks and IPCC default emission factors.

4.4 Voluntary certification schemes

Compared to polices, certification schemes focus on the wider sustainability of products and services.

Voluntary certification schemes consider requirements across a wide spectrum of sustainability indicators across biomass feedstock and biofuel/bio-material producing sectors. Their main objective is due diligence to provide standards for good practice of supply chains and services. While most certification schemes are sector-specific, some of them, focussing on biomass in particular, can support cross-sectoral product flows and activities. The overarching principles and criteria of certification schemes are similar as they address the different pillars of sustainability: environment, economy and society. With a focus on good governance, certification schemes also include principles in regard to legal frameworks to ensure compliance with laws, regulations, directives and policies.

The reviewed bio-based sectors all deploy certification schemes to support good practice and governance. In some cases, certification schemes also provide evidence of mainly environmental and legal sustainability standards. To be compliant and eligible for sector-specific policies, some of the certification schemes (RSB, SBP, ICAO, ISCC) adapt the GHG emission and land use criteria in line with existing policies and regulations (RFTO, RED II). The certification schemes provide the additional benefits of addressing economic and social criteria. Compared to this, policies miss the opportunity to implement such criteria as the minimum requirement for eligibility. In other words, certification schemes implement policy measures in their criteria, while policies do not require the wider sustainability benefits certification schemes could provide.

With policies having different reporting requirements, operators and supply chain actors might be bound to a very specific certification scheme, which then limits the flexibility to supply products and services to another sector or market.

Sector	Transport & Energy				Agriculture & Forestry		Other sectors	
Policy	**RED II**	**RTFO**	**RO**	**RHI**	**Basic payment scheme**	**EU Timber regulations**	**Chemical industry**	**Construction industry**
GHG emission target	●	●	●	●	♦	♦	♦	♦
Emission thresholds	●	●	●	●	♦	♦	♦	♦
Direct land-use change	●	●	●	●	△	♦	♦	♦
Indirect land-use change	●	●	♦	♦	♦	♦	♦	♦
Sustainable land management	△	△	△	△	●	♦	♦	♦
Eco-system services	△	△	△	△	●	△	♦	♦
Biodiversity	△	△	△	△	●	△	♦	♦
Protection of high carbon stocks	●	●	●	●	●	●	♦	♦
Legal sourcing	△	△	●	●	♦	●	♦	♦
ETS	♦	♦	♦	♦	♦	♦	●	●
Acknowlegdment of certification schemes	●	●	●	●	●	●	●	●

Figure 4 Matrix of GHG emissions and sustainability criteria in different sector policies and institutional frameworks. The coloured shaded areas indicate the focus of sustainability criteria. ● = accounted criteria, ♦ = not applicable, △ = considered but not directly accounted

5 Harmonising GHG and sustainability criteria

5.1 Challenges of evaluating the sustainability of biomass across different sectors

One of the key drivers for bioenergy and other bio-based sectors in the UK and globally is its climate change mitigation potential. While there are variations and related uncertainties for the GHG emission reduction potential, research agrees that bioenergy can make a valuable contribution to the transition to a low-carbon future. However, this is only achieved if bioenergy supply chains follow good practices and low-carbon and sustainability standards throughout. Land use is one of the most discussed aspects of the sustainability of bioenergy. This is mainly about competing uses of land for food and first-generation energy crops with the related potential for increased food prices [5], as well as where energy crop production or fuelwood sourcing could cause a loss of high soil and biomass carbon stocks or biodiversity in forest or grasslands.

The review of policies and certification schemes has shown that the existing institutional and regulatory frameworks for bio-based sectors focus on these two aspects (GHG emissions and land use) to ensure bio-based products and services, including energy, are low-carbon and sustainable.

As discussed in the previous sections and presented in Figure 4, the GHG emissions and land use criteria mainly relate to biomass feedstock production and sourcing. While transport and energy sector policies have a strong focus on these two criteria, other bio-based sectors do not have to comply across all these criteria and in this detail.

To address the different implications of the different types of feedstocks, the transport and energy sector policies consider different GHG emissions and sustainability impacts. For example, carbon stocks and sustainable forest management are highly relevant for forest-based feedstock, while land use change and soil carbon stock changes are most relevant for the production of dedicated annual energy crops. However, this detail is not considered in other sector policies, even if other industries draw on the same inputs, resources and feedstocks.

For example, if a crop is grown for energy, UK policies for bioenergy and transport include upstream supply chain emission for biomass production, sourcing, mobilisation and processing as well as DLUC or ILUC factors. If the same crop is grown for other purposes, the agricultural sector has to comply with crop rotation and diversification, but there is no reference to consider potential ILUC. If the same biomass was used in chemical production replacing a fossil-based feedstock, IPCC default emission factors with zero as emission factor for biomass, would be considered.

In the current policy landscape, various sectors can draw on the same biomass and low-carbon feedstocks, but the existing policy frameworks of each sector have implemented different measures creating an uneven picture in emissions and sustainability standards. This limits a transparent understanding of the real impacts of biomass use in different sectors. Additionally, it limits the understanding of the most sustainable and best use of feedstocks across different sectors.

Bioenergy is often seen as an opportunity to diversify existing supply chains if residues can be used for energy or fuel. However, bioenergy supply chains can also offer valuable by-products, which potentially can lead to environmental and sustainability benefits in other sectors. For example, during the process of producing biofuel from cereal or oil crops, distillers dried grains with solubles (DDGS) and glycerine are by-products that could be used as animal feed. This could reduce the demand for additional land to produce other animal feeds. However, if the same land is used to grow a

lignocellulosic energy crop, less land would be needed for the production of the same amount of fuel or energy and could potentially free up land for other uses.

This shows the importance of understanding the whole system of which bioenergy is a part. Biofuel and bioenergy production often creates or utilises co-products and enables co-benefits. Bioenergy is thus part of a wider product basket, often including main and additional products used different downstream supply chains, and has interfaces with other sectors. Sectoral policies, however, struggle to acknowledge and address parts of the supply chains that fall into and interface with other sectors (eg, forestry, agriculture and waste management). Hence, policies mostly cover sector-specific processes, practices and products and do not recognise cross-sectoral implications.

Additionally, the examples above show the relevance of considering the impact and consequences of using or not using biomass feedstocks for a specific process. Depending on the counterfactual, the GHG emission and sustainability impact of biomass use can change significantly.

This means different sectors might use the same feedstock and resources or have interfacing or consequential interfaces, but the sector-specific policies do not address these in the same way, leading to different accounting and reporting frameworks and different sectoral standards.

5.2 A harmonisation approach

To overcome some of the cross-sectoral challenges, a multi-level governance approach is needed that can address interfaces and cross-sectoral aspects in the same way in all bio-based sectors, while allowing sector-specific instruments and measures where required and providing flexibility in case of innovation, technology development and system changes. Figure 5 presents an approach for such a multi-level governance structure.

Biomass feedstocks are the lowest common denominator across the different bio-based industries. While different types of biomass require different sustainability standards, which are already addressed in the EU and UK's energy sector policies, each feedstock category should have the same sustainability criteria for its production and sourcing. A common approach at the level of biomass production and sourcing would create a level playing field, addressing cross-sectoral aspects like GHG emissions, land use and sustainability of biomass. A common framework for feedstock sustainability would provide biomass producers and biomass users with a coherent approach and support the best use of biomass, and facilitate positive trade-offs across all bio-based sectors.

Once feedstocks are produced and sourced following a common feedstock sustainability framework, a flexible multi-criteria decision-making gateway should support the best and most feasible uses of feedstocks. This gateway would link the levels of feedstock production and feedstock use, and hence connect a common feedstock sustainability framework with sector-specific policy measures.

At the gateway level, biomass users would need to show compliance with the common feedstock sustainability framework and how the feedstock will be used in their specific sector. The gateway approach will support the understanding and acknowledgment of interfaces, benefits and challenges between and for the different sectors. Additionally, this would consider alternative uses and consequences of using a feedstock for a particular application. It would be challenging for industry to provide an evaluation of possible alternative uses, benefits and impacts in other sectors. A multi-criteria assessment model that provides sustainability benchmarks for different biomass, biomass uses and applications could allow industry to evaluate and report the sustainability performance of their own process, and then benchmark it against other applications provided by the model. Such a model could be built around sustainability standards and follow sustainability indicators similar to

certification schemes, or the GBEP sustainability indictors, as well as including harmonised sustainability scores and benchmarks agreed across different government departments. Based on the scores from the model, the user could estimate how their application would perform compared to other sectors or applications, and the results obtained would provide the required evidence to support decision-makers when considering the best use of biomass.

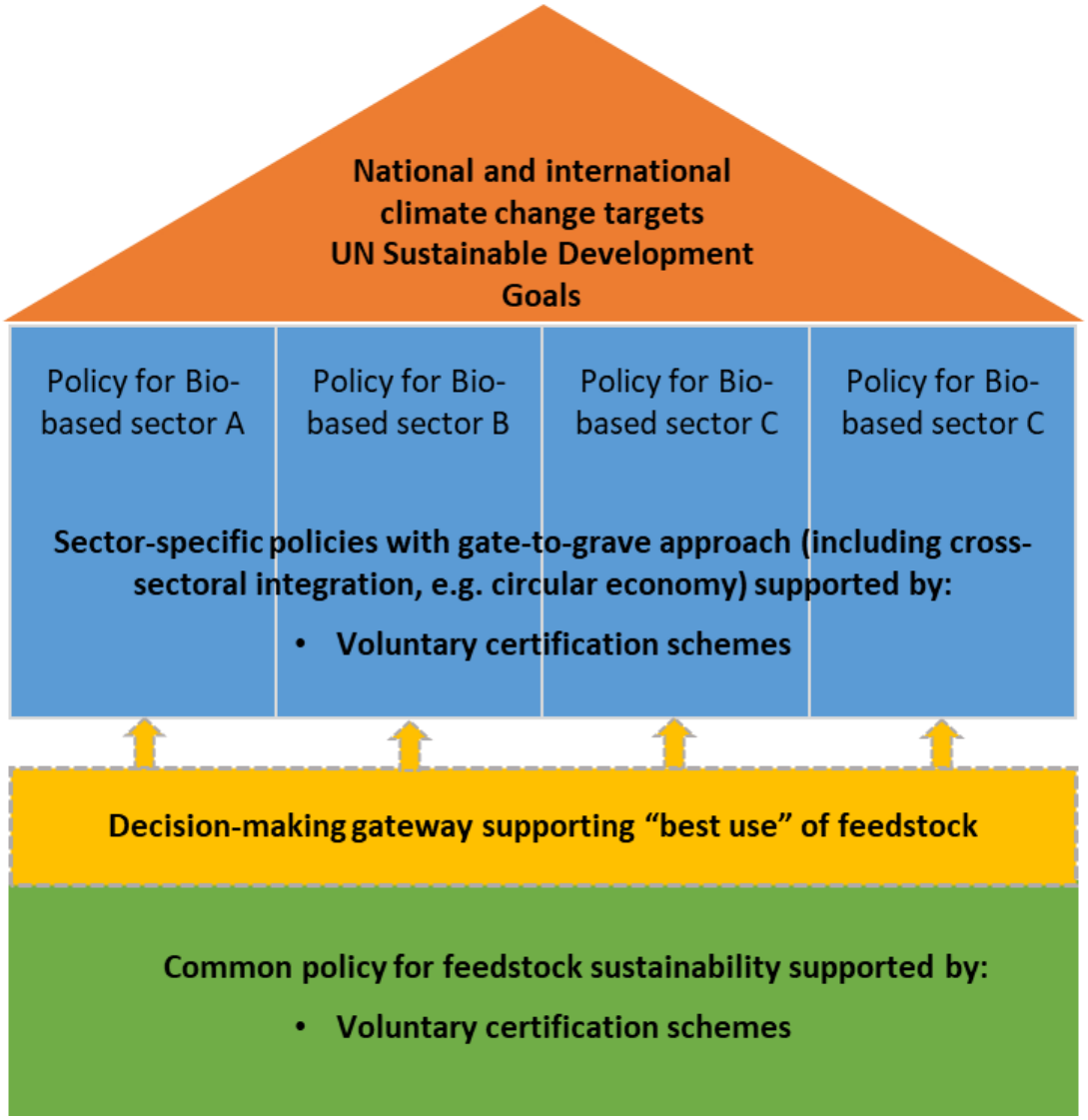

Figure 5 Multi-level governance approach for bio-based sectors.

Such an intermediate stage between common and sectoral governance levels would allow the comparison of the sustainability performance between different sectors and bio-based applications and show how sustainability is addressed within the sectoral frameworks and enabled and maximised across the wider bio-based sectors. This would encourage the best use of biomass across the different sectors.

This decision-making gateway should take a flexible approach that considers different aspects of sustainability, biomass availability and mobilisation, technical application, scale, spatial and temporal aspects, and alternative feedstock use, as well as replacement impact, such as emissions savings, from biomass use. This should be guided by wider sustainability opportunities, risks and trade-offs.

Abundant or at least sufficiently available feedstock will be more likely to enable and maximise sustainability trade-offs and the best use of the feedstock within different sectors. However, if a feedstock is scarce, the use of this feedstock in different applications can have different sustainability impacts, as competing sectors might require an alternative feedstock instead. Potentially this can lead to additional sustainability concerns and risks, which shows the importance of understanding upstream and downstream supply chain impacts and counterfactuals across the different sectors. Decision-making should be based around a suite of different sustainability aspects, not just GHG emissions and land criteria, but additional environmental, economic and social benefits. This would also require an appropriate weighting framework of the different criteria, as the use of the feedstock in one sector could enable different benefits compared to another sector. Hence, co-benefits can support decision-making. Taking a flexible approach would also allow the consideration of technology innovation and development, and market dynamics.

At the sectoral level, policies should address processes, practices and supply chains in the same way that current institutional frameworks do. Even with abundant feedstock resources and the same impacts to the point of biomass sourcing, the downstream impact will vary due to processing, utilisation, scale, location and commercial settings, with different opportunities, challenges and risks in each sector. Therefore, at the sector level, a harmonisation of standards might not be feasible or desirable. Sector-specific policies should address downstream impacts of biomass use and product application, which will vary between sectors. Hence, at this level, policy measures and instruments should address sustainability aspects of sector-specific applications and final use of biomass, bio-based products and services.

Climate change targets would support the GHG emission and sustainability targets across all sectors. These, as they already do, would provide a coherent governance level across all sectors including overall GHG emissions and sustainability thresholds with which all sectors have to comply. This includes the role of biomass not just as a renewable source but also to support net-zero emission targets. A stronger inclusion of sustainability efforts of UN organisations, like the Sustainable Development Goals (SDGs) [57], would support sustainability beyond carbon. While climate change mitigation is part of the SDGs, a wider sustainability umbrella would create high-level sustainability standards across all pillars of sustainability and support a fairer transition to a sustainable bioeconomy.

Certification schemes should provide an additional level of governance and support good and fair practices along the entire supply chain considering multiple upstream and downstream processes and opportunities. This would also create additional understanding of substitution or replacement effects and possible counterfactuals. For example, some certification schemes require a much more detailed and stringent accounting along the full supply chain, including biomass production and sourcing, than current UNFCCC accounting frameworks.

Such a multi-level governance approach could provide transparency of institutional frameworks across sectors and support good governance at the points of common activities and processes and support sector-specific sustainability standards at the same time. Covering wider sustainability criteria through certification schemes and international sustainability efforts like the Sustainable Development Goals would support the different governance levels and provide a harmonised and just approach for sustainable resource use while enabling positive trade-offs across different sectors, supply chain actors and end-users.

6 Conclusion and recommendations

The review of some of the most relevant policies for the UK's bio-based sectors showed that the GHG emission and sustainability standards for biomass and low-carbon feedstocks vary strongly between the different sectors. In the energy and transport sector, biomass and low-carbon feedstocks have been used for many years. Policies with details on different sustainability standards are implemented addressing the production and sourcing of biomass with a strong focus on GHG emission reduction, including upstream supply chain emissions, and land use criteria. Land use criteria focus on quantifiable carbon stocks in soil and standing biomass. Wider environmental implications such as ecosystem services, land management and biodiversity are included, but do not provide a clear accounting framework.

The policies for other and emerging bio-based sectors follow UNFCCC guidelines, using IPCC default factors that consider biomass as carbon neutral, hence, biomass has an emission factor of zero. Moreover, sustainability implications beyond GHG emissions are considered at a very limited level. Voluntary certification schemes can fill some of these sustainability accounting gaps for the non-energy and non-transport sectors, and are a common voluntary requirement for the due diligence of UK industry. However, only a small number of these certification schemes follows the similar detailed accounting requirements as energy and transport policies.

The review also showed the gap in sectoral policies to acknowledge cross-sectoral interfaces, in particular for biomass and resource use, as well as possible co-products and co-benefits. Additionally, the impact and consequences of using or not using biomass feedstocks, apart from indirect land use change in the transport sector policies, is not addressed in any of the policies.

Different sectors using the same feedstock and resources, but reporting their GHG emissions at different detail and with different sustainability standards, limits comparability and fair competition between different sectors.

A multi-level governance approach has been introduced to overcome the challenges of sector-specific policy frameworks for bio-based industries. A common policy approach across all sectors utilising biomass feedstocks would support fair opportunities and responsibility between the different sectors. A decision-making approach linking feedstock regulations and sector-specific policies can enable the best use of biomass across the different sectors. Sector-specific policies would set standards and criteria for sectoral downstream processes, specific to each sector. Climate change legislation and sustainability targets like the Sustainable Development Goals would build the umbrella framework for the overarching targets across all sectors and related policies.

Certification schemes would provide an additional level of governance and support good and fair practices along the entire supply chain considering multiple upstream and downstream processes and opportunities. This would also create additional understanding of substitution or replacement effects and possible counterfactuals.

With the urgent need to tackle climate change and build a sustainable low-carbon future, the use of biomass plays an important role in generating energy, providing transport fuels, and producing chemicals and materials. With the existing and increasing demand for biomass across various sectors, common institutional approaches for the best and fair use of biomass is required. The current UK and international governance frameworks can be improved by taking a "best use" approach for biomass that sets the same standards across all sectors for biomass production and biomass sourcing and related resources like land use. The "best use" approach would also require that the

cross-sectoral interface and consequences of biomass production and biomass use are considered to enable and maximise climate change mitigation. As biomass production has a strong impact on land, water, ecosystems, biodiversity and communities, particularly rural ones, coherent sustainability targets beyond carbon and climate change need to be included.

7 Appendix

7.1 Selection of voluntary certification schemes and industry agreements

7.1.1 Roundtable on Sustainable Biomaterials (RSB)

RSB [58] of high relevance for the UK as it is approved under RTFO. RSB is an independent and global multi-stakeholder coalition, which works to promote the sustainability of biomaterials, including biomass and biofuels. All the materials covered by RSB are derived from a biological source, produced through agricultural processes and forestry, as well as by-products and residues from food, feed, timber, paper and other industries.

The RSB principles and criteria address key sustainability issues and describe how to produce biomass, biofuels, and biomaterials in an environmentally, socially, and economically responsible way. The RSB principles and criteria are based on a management and risk-oriented approach, helping operators to identify and manage sustainability issues in a specific context and therefore reducing risks for operators, brand owners, and investors. The areas covered by RSB principles and criteria include legality, environmental protection, human and labour rights, ecosystem conservation [58].

As RSPO, this certification scheme addresses legal, environmental, economic, and social aspects. RSB principles and criteria consider compliance with regional, national, and international laws and regulations, including workers' rights, which also covers issues of child labour, non-discrimination and equal opportunity policy, minimum wages, including health, safety, and wellbeing of workers and staff, establishment of unions. It also prohibits slave and forced labour and requires the assessment and if necessary implementation of land and land-use rights.

With relevance to RTFO and issues around ILUC, RSB has developed a set of criteria and compliance indicators for economic operators willing to demonstrate that their operations have a low ILUC risk. Three approaches are recognised in this regard, where operators need to demonstrate the following [58]:

- Yield increase: additional biomass was produced through an increase in yield compared to a reference date, without any additional land conversion.
- Unused/degraded land: biomass was produced from a land that was not previously cultivated or was not considered arable land.
- Use of waste/residues: the raw material used is derived from existing supply chains and does not require dedicated production out of arable land.

The RSB's ILUC approach links closely to the environmental principles of the certification scheme. As it is eligible under RTFO [30], the environmental principle and criteria cover some of the GHG accounting and reporting requirements, such as reporting supply chain emissions related to biomass feedstock, supply chain processes and final products and emission thresholds in line with RED II (e.g., 50 or 60% lower than the applicable fossil-fuel baseline, depending on the date on which an installation started operation) [58].

Additionally, RSB requires an emission-control and risk management plan that addresses major pollutants of including carbon monoxide, nitrogen oxides, volatile organic compounds, particulate matter, sulphur compounds, dioxins, and other substances recognised as potentially harmful for the environment or human health [58]. Moreover, the maintenance of ecosystem functions and services,

such as biodiversity. This directly relates to good practices and conversation to avoid any negative environmental impact on soil, water, vegetation, and wildlife [58].

RSB includes an Environmental and Social Management Plan (ESMP) that addresses the direct link between show how environmental and social impacts. For example, this includes the identification of conservation values, the effects of biomass sourcing and supply chain activities on resource use and access for local communities. The social principles of RSB also include cultural aspects as well as socio-economic factors like local employment and food security [58].

7.1.2 Sustainable Biomass Program (SBP)

SBP [59] is a certification system formed in 2013 by European utilities that are using biomass, mostly in the form of wood pellets or wood chips, in large-scale energy generating plants, to ensure that woody biomass is legally and sustainably sourced. This allows companies in the bioenergy sector to demonstrate compliance with regulatory requirements and can be proved through a clear statement of principles, standards, and processes. Ultimately, SBP aims to promote and maintain internationally an economically, environmentally, and socially sustainable biomass supply chains through the development and operation of an independent, third-party certification system [60].

SBP's goal is not competing with or replicating with other existing and well-proven forest certification systems, such as PEFC [61] or FSC [62]. However, there is limited uptake of certification in some key forest source areas and the aforementioned schemes do not yet cover all the key requirements of biomass users. Therefore, SBP is working to develop solutions to address these issues and is in discussion with both FSC and PEFC to determine how these challenges might be overcome. SBP requires good practices and management plans as well as a risk mitigation plan, similar to other certification schemes [63].

Within its legal principles, the SBP is compliant with the European Union Timber Regulation (EUTR) [36], including legally harvested timber only and addressing environmental impacts (e.g. water and soil protection), biodiversity conservation, trade and custom [60]. The legal principle also includes harvest rights, traditional or civil rights of local population and communities, workers' rights (including non-discrimination and equal opportunity criteria, minimum wages, including health, safety, and wellbeing of workers) [60].

The environmental principles, focus on conservation of forest and areas with high conservation values, which also means sourcing from protected areas is prohibited [60]. Is also includes that feedstock cannot be sourced from forests converted to production plantation forest or non-forest lands after January 2008 [60]. Other environmental principals are soil quality and fertility, biodiversity, maintenance of ecosystems, water protection, and air quality. Similar to RSB, feedstocks cannot be sourced from areas that had high carbon stocks in January 2008 and no longer have those high carbon stocks, such as wetlands and peatland [60].

The social and economic principles of SBP require the consideration of feedstock sourcing on the local economy and communities, as well as socio-economic services like employment opportunities and wider commercial and infrastructure development linked to feedstock production and sourcing [60].

7.1.3 Roundtable on Sustainable Palm Oil (RSPO)

RSPO [64] is relevant for the biofuel and bioenergy sector as palm oil and palm oil processing residues can be used as feedstocks to produce biofuels for transport and energy and under biorefinery concepts could also provide value-added products and chemicals.

RSPO is a global, multi-stakeholder initiative on sustainable oil palm products. Members and participants come from different backgrounds, including plantation companies, manufacturers, and retailers of oil palm products, environmental and social non-governmental organisations. The main objective of RSPO is "to promote the growth and use of sustainable palm oil through cooperation within the supply chain and open dialogue between its stakeholders" [64]. This means the certification scheme applies to oil palm plantations as well as processing facilities

To ensure sustainable, responsible and fair production of palm oil, it has been introduced a set of Principles and Criteria (P&C) that embrace legal, economically viable, environmentally appropriate and socially beneficial management and operations. RSPO P&C cover the most significant environmental and social impacts of palm oil production and the immediate inputs connected to it, such as seed, chemicals, and water, together with the social impacts related to on-farm labour and community relations [64].

The RSPO P&C are organised into three impact areas, each related to a different aspect of palm oil production: Prosperity, which concerns a competitive, resilient and sustainable sector; People, on the sustainable livelihoods and poverty reduction, and Planet, for protection conservation and enhancement of ecosystems and environment [64].

Following the overarching categories, RSPO addresses a number of legal aspects, such as providing evidence of legal due diligence of all supply chain actors, including contracted third parties, recruitment agencies, service providers and labour contractors as well as proof of the ownership status, land ownership and right to use. The legal principles also cover human and workers' rights, which also covers issues of child labour, non-discrimination and equal opportunity policy, minimum wages, including health, safety, and wellbeing of workers and staff, establishment of unions [64].

Additionally to the legal environmental principles build a major focus of RSPO. However, compared to policies, RSPO environmental principles focus on good practices and environmental protection, rather than just GHG emission accounting [64]. There is a strong focus on effectively managed plantations and supply chains, including good agricultural practices and plantation management (e.g., pest, disease control, waste management, soil fertility and health, water management, and protection) [64]. Still, pollution and emissions reduction, carbon stock management (above and below ground carbon) are as important. One of the key elements is the protection of high carbon stock landscapes (forest and peatland) to stop any further degradation of natural ecosystems [64]. Within this context, maintaining and supporting biodiversity is also included in the environmental principles.

Economic aspects of RSPO require an implemented management plan for the oil palm plantation and processing facilities ensuring business models that include and support various scales of producers as well as address replanting programmes for long-term sustainability [64].

Social aspects of RSPO address implications for the local communities and their livelihoods, focussing on food and water security, and land-use planning. Participatory approaches are a key element to support and improve the livelihoods of local communities [64].

7.1.4 Program for Endorsement of Forest Certification (PEFC)

PEFC [61] is a worldwide, non-profit, and non-governmental organisation promoting sustainable forest management through forest certification and labelling of forest-based products. Products with a PEFC certificate offer assurances that the raw materials that have been used in their manufacture originate from sustainably managed forests and Trees outside Forests (TOF) areas, recycled and controlled sources [65]. This means that the entire forest supply chain promotes responsible practices in the forest and ensures that wood and non-wood forest products are produced with respect for the highest ecological, social, and ethical standards, contributing to achieve a more sustainable world [65]. With over 300 million hectares of certified forest (as for September 2018), PEFC is the largest forest certification system in the world [66].

PEFC principles and criteria regard different areas, such as: maintenance and enhancement of forest resources and their contribution to the global carbon cycle, conservation of biological diversity in forest ecosystems and maintenance, and enhancement of socio-economic functions and conditions [65].

Within its legal principles, PEFC requires compliance with applicable local, national, and international legislation on forest management including issues like illegal logging, illegal land-use, illegally initiated fires, and corruption. Additionally PEFC legal criteria include practices concerned with nature and environmental protection, protected and endangered species, land-use rights for indigenous peoples, local communities, and other affected stakeholders, human rights, workers' rights, including health and safety issues and non-discrimination and equal opportunity criteria. This does apply to all practice activities related to forest management and wood sourcing [65].

As with other biomass related certification schemes, PEFC includes environmentally focused principles in regards to maintaining and improving the ecosystem, forest carbon stocks, biodiversity and resilience, and reduce and minimise adverse impacts on forest resources and ecosystem degradation. For forest management, good practice principles apply including protection of soil, water, air, biodiversity, wildlife, and minimising emissions form management activities [65].

The social and economic criteria, similar to the other certification schemes, require certified operators to provide adequate public access to forests for the purpose of recreation and respect community ownership rights and safety of the public [65].

7.1.5 International Sustainability and Carbon Certification (ISCC)

ISCC [67] is a global multi-stakeholder certification system. Depending on the market, the scheme offers different types of certificates for the energy, industrial applications, and food and feed sectors. ISCC EU and ISCC Plus provide solutions to address sustainability requirements for feedstocks (e.g., agricultural and forestry biomass, organic wastes and residues, circular materials, and algae) [67]. They also cover biofuels, including biogas, biomethane, bioliquids, solid biomass, as well as RFNBOs. The main objectives of ISCC EU and PLUS certificates are to contribute to the implementation of environmentally, socially, and economically sustainable production, using all kinds of biomass in global supply chains [67].

ISCC EU complies with RED II and FQD of the European Commission, taking part in the regulatory framework for the implementation of renewable energy targets for the transport sector in the European Union. Additionally, ISCC is approved and compliant with RTFO [30] as well as other certification schemes like the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). For example, ISCC can certify compliance with CORSIA’s sustainability criteria and

provide certification for sustainable aviation fuels, in order to guarantee that CORSIA eligible fuel generate lower carbon emissions on a lifecycle basis and are not made from biomass obtained from land with high carbon stock.

With its directive and policy compliance, ISCC EU certification criteria include the monitoring of GHG emissions in line with RED II accounting frameworks and emission reduction/cap requirements [68]. With this ISCC EU includes ILUC approaches for the relevant feedstocks and biofuels. Additionally, ISCC criteria include other environmental sustainability aspects like protection of land with high biodiversity value or high carbon stock, deforestation-free supply chains, environmentally responsible production to protect soil, water, and air [68].

Additionally, legal aspects (e.g., compliance with national and international laws and international treaties, human, labour and land rights, safe working conditions) are included in the ISCC EU and PLUS criteria [67, 68].

ISCC also supports the transition to a circular economy and bioeconomy that approaches plastics waste issues through the “reduce, reuse, recycle” concept, avoiding plastics ending up in the natural environment [68]. Implementing a circular economy is a fundamental step towards achieving climate targets, and improved technologies and applications can stimulate demand for collection and recycling. There is no globally standardised approach to handling plastic waste properly. In combination with the durability, which gives plastic its value in the first place, missing international waste management standards have led to severe environmental pollution. ISCC is providing some solutions through its certification scheme standards [68]. In particular, ISCC PLUS certification provides traceability along the supply chain and verifies that companies meet environmental and social standards [67].

7.1.6 Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

International Civil Aviation Organisation (ICAO) is a UN specialised agency that works with the Convention’s Member States and industry groups to reach consensus on international civil aviation standards and recommended practices and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. ICAO works to ensure that the civil aviation operations and regulations conform to global norms, which in turn permits more than 100,000 daily flights in aviation’s global network to operate safely and reliably in every region of the world.

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [56] is a global scheme to address any annual increase in total CO_2 emissions from international civil aviation. As an industry agreement CORSIA will be implemented in phases, starting with the participation of countries on a voluntary basis, followed by participation of all countries (except those exempted from offsetting requirements) [69]. The pilot (from 2021 to 2023) and the first phase (from 2024 to 2026) would apply to countries that have volunteered to participate in the scheme [69]. CORSIA is ICAO’s instrument to address the increase in total CO_2 emissions from aviation.

ICAO has released CORSIA sustainability criteria for CORSIA eligible fuels [70, 71]. These criteria revolve around the necessity of using eligible fuels that generate lower carbon emissions on a lifecycle basis compared to current fossil fuels and that should not be made from biomass obtained from land with high carbon stock [70, 71]. CORSIA eligible fuels should achieve net GHG emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis [71, 72]. They should not be made from biomass obtained from land converted after 1

January 2008 that was primary forest, wetlands, or peatlands and/or contributes to the degradation of their carbon stock [71]. In the event of land use conversion after 1 January 2008, direct land use change (DLUC) emissions should be calculated [71]. This is in line with SBP certification scheme.

Work on other themes such as water, soil, air, conservation, waste and chemicals, human and labour rights, land use rights and land use, local and social development, food security, is ongoing under the Committee on Aviation Environmental Protection (CAEP) and will be subject to approval by the Council by the end of the pilot phase [70].

While CORSIA is not a certification scheme, it set out a requirement framework on potential certification bodies, to ensure standards in line with other programmes and if applicable regulatory frameworks. Due to the nature of CORSIA independent certification could be provided for carbon offsetting and/or sustainability standards for biofuels.

Categories	Criteria	Roundtable on Sustainable Biomaterials	Sustainable Biomass Program	Roundtable on Sustainable Palm Oil	Program for Endorsement of Forest Certification	International Sustainability and Carbon Certification	Carbon Offsetting and Reduction Scheme for International Aviation
ECONOMY	Production efficiency	●	♦	♦	♦	●	▲
	Reinforcement of economy	●	●	●	●	●	▲
ENVIRONMENT	Preservation of carbon stock	●	●	●	●	●	●
	Protection of ecosystem	●	●	●	●	▲	▲
	Preservation of water and soil health	●	●	●	●	●	▲
	GHG emissions/air pollution	●	●	●	♦	●	●
	Conservation of biodiversity	●	●	●	●	♦	▲
LEGALITY	Compliance with law and regulations	●	●	●	●	▲	▲
	Human rights	●	●	●	●	▲	▲
	Labour rights	●	●	●	●	●	▲
	Child labour	●	●	●	♦	♦	▲
	Health and safety/risk management	●	●	●	●	●	▲
	Land-use rights	●	●	●	●	▲	▲
	Measures against illegal activities	●	●	●	●	♦	▲
	Feedstock legally sourced	♦	●	●	♦	♦	▲
SOCIETY	Socio-economic development	●	♦	●	●	♦	▲
	Food security	●	●	●	♦	▲	▲
	Well-being of communities	●	●	●	●	♦	▲
	Gender equality	●	●	●	●	♦	▲

Figure 6 Matrix of sustainability criteria in selected certification schemes. The coloured shaded areas indicate the focus of sustainability criteria. ● = accounted criteria, ♦ = not applicable, ▲ = considered but not directly accounted

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