Accelerating CCS Technologies

CO2CE

Harnessing the potential of biological CO_2 capture for the Circular Economy

Co-funded by the European Commission within the Horizon 2020 programme

Report: Social and Policy Assessment of CooCE

Project information

Project Acronym	CooCE
Full Title	Harnessing potential of biological CO2 capture for Circular Economy
Project Number	327331
Grand Agreement Number	691712
Programme	ACT3 - Accelerating CCS Technologies
Start date	07/10/2021
Kick Off Meeting	29/11/2021
Website	https://cooce.eu/
ACT Project Officer	Ragnhild Rønneberg
Project Manager	Prof. Tomas Morosinotto
Project Administrator	Prof. Luigi Bubacco

This project is part of the ACT - Accelerating CCS Technologies supported by the Research Council of Norway, Research, and Innovation programme

Document information

Deliverable	D5.2 Report on Socioeconomic and Policy Assessment
Work Package:	WP5
Issue date:	September 2024
Due date:	September 2024
Nature:	R – Report
Dissemination level:	PU - Public
Lead Beneficiary:	Imperial College
Main authors:	Yara Evans, Rocio Diaz-Chavez

Department for Energy Security & Net Zero

UK participants in ACT ERA-NET COFUND Horizon 2020 Project (CooCE) GA. 691712 is supported by The Department for Energy Security and Net Zero (DESNZ) grant number 415000049187 (Imperial College London). Project CooCE is funded by the European Union under Horizon H2020 Grant Agreement No. 691712. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or DESNZ. Neither the European Union nor DESNZ can be held responsible for them.

Table of Contents

Tables

Figures

Acronyms/Symbols

ACRONYM	DEFINITION
bcm	billion cubic metres
(Bio)CNG	(Biological) Compressed Natural gas
(Bio)LNG	(Biological) Liquified Natural Gas
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture Utilisation and Storage
CEAP	Circular Economy Action Plan
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CTS	Capture, Transportation and Storage
CRCF	Carbon Removal Certification Framework
EC	European Commission
EED	Energy Efficiency Directive
EIA	Environmental Impact Assessment
ETD	Energy Taxation Directive
EU	European Union
EU ETS-I/II	European Union Emissions Trading System
EU MSR	European Market Stability Reserve
FiT	Feed in Tariffs
FQD	Fuel Quality Directive
GII	Gender Inequality Index
GGSS	Green Gas Support Scheme
GHG	Green House Gas
H_2	Hydrogen
ILO	International Labour Organisation
ILUC	Indirect Land Use Change
LCA	Life Cycle Assessment
NECP	National Energy and Climate Plan
NIMBY	Not In My Backyard
OSH	Occupational Safety and Health
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
RED	Renewable Energy Directive
RTFO	Renewable Transport Fuel Obligation
SAF	Sustainable Aviation Fuel
SHDB	Social Hotspot Database
SIA	Social Impact Assessment
SLCA	Social Life Cycle Assessment
SWOT	Strengths, Weaknesses, Opportunities, Threats
TEN-E	Trans-European Networks for Energy
TWh	TeraWatt Hour
UK	United Kingdom
WPD	Waste Packaging Directive
WDF	Waste Directive Framework

1. The CooCE concept

The CooCE concept aims to contribute to the shift towards a resource-efficient, low-carbon and climate-resilient economy. It will do so by offering carbon-intensive, highly polluting, and hard-to-abate industries and sectors a way to decarbonise their operations through a portfolio of diverse and flexible CCUS technologies that can also help reduce dependence on fossil resources. CCUS technologies offer an economic incentive for capturing, converting, and transforming CO_2 into valuable commercial products or materials (e.g., construction materials, fuels, chemicals, and plastics) or into feedstocks for further industrial processing. CooCE will help accelerate the market uptake of its technologies by replicating to CO_2 intensive industries and sectors and creating sustainable supply/value chains. This will require working in collaboration with a broad range of stakeholders, including technology providers, research centres, end-users, clusters, CO_2 intensive industries and state agencies.

The CooCE project will develop, demonstrate, and validate a diverse portfolio of novel and flexible technologies at different *Technological Readiness Levels* for the chemical and biological conversion of CO_2 into products for long-term storage of CO_2 emissions. CooCE aims to open a pathway for decarbonisation of businesses in industry, energy, and transportation (air, road, water), thus helping mitigate against climate change. Moreover, by turning CO_2 into valuable bioresources, CooCE will help expand the bioeconomy and the wider circular economy through the sustainable recycling and utilisation of CO_2 helping creating employment opportunities across the economy.

In the CooCE concept, CO_2 will be captured for conversion into (final or intermediate) bioproducts using different technologies (Figure 1). A first product is high purity biomethane, (CH_4>95%) obtained from a novel add-on, cost-effective and highly efficient bioprocess of CO_2 hydrogenation, envisaging the use of excess renewable electricity from wind turbines and/or photovoltaic plants to electrify water electrolysers to generate H_2. This technology enables flexible and seasonal on-site hybrid energy storage, with biomethane being either as a liquid or as compressed gas, the equivalent to LNG that provides a promising alternative for shipping, and CNG that can be used in road haulage and most other vehicles. Also, biomethane can be injected into the natural gas grid, as allowed by legislation in several countries in the EU. Thus, there is a clear market opportunity for CooCE's proposed technology for upgrading biogas to biomethane.

The second CooCE product is BioSA that will be obtained simultaneously with upgrading of CO_2 captured biogas to biomethane and a biochemical route that uses as feedstock carbohydrates from waste streams. CooCE introduces a novel technology that uses waste streams to produce second-generation BioSA, obviating, for instance, the need for biomass feedstocks that require land for cultivation. The CooCE concept is designed to upgrade biogas in bioreactors, treating a range of carbohydrates containing organic wastes to produce biomethane and BioSA in a separate fermentation reactor. BioSA readily replaces the fossil-based chemical succinic acid that is used for making various commodities in chemical, food, agricultural and pharmaceutical industries. There is also rising demand for succinic acid from the industrial, personal care and beverage industries, and increasing adoption of it as a replacement for adipic acid in polyurethane production. As manufacturers seek to increase the renewable content in their products by using more bio-based plastics and polyurethanes so increases the demand for BioSA on a wide range of applications, notably in bioplastics, making it a strong platform chemical. Hence, CooCE's proposed technology for BioSA production has strong market potential.

The final CooCE product comprises biopolymers that will be obtained through bio-catalytic technologies (based on *Cupriavidus necator* and cyanobacteria) that use carbon-rich waste streams for cost-effective conversion into PHAs/PHBs. These biopolymers are accumulated as storage materials within the cells of microorganisms, serving both as carbon and energy reserve. PHAs/PHBs possess similar characteristics to common plastics, are biocompatible and biodegradable, and can replace the commonly used petroleum-derived plastics. They are currently produced at industrial scale, being applied to a broad spectrum of end products, such as bioplastics for packaging, prebiotic and nutritional compounds for medical applications, and bio-creams for cosmetics. Together, BioSA and PHAs comprise high value-add platform, commodity chemicals, proving the building blocks of various biopolymers and bioproducts. In CooCE, they will also be assessed for use as a plasticiser in the packaging production process.

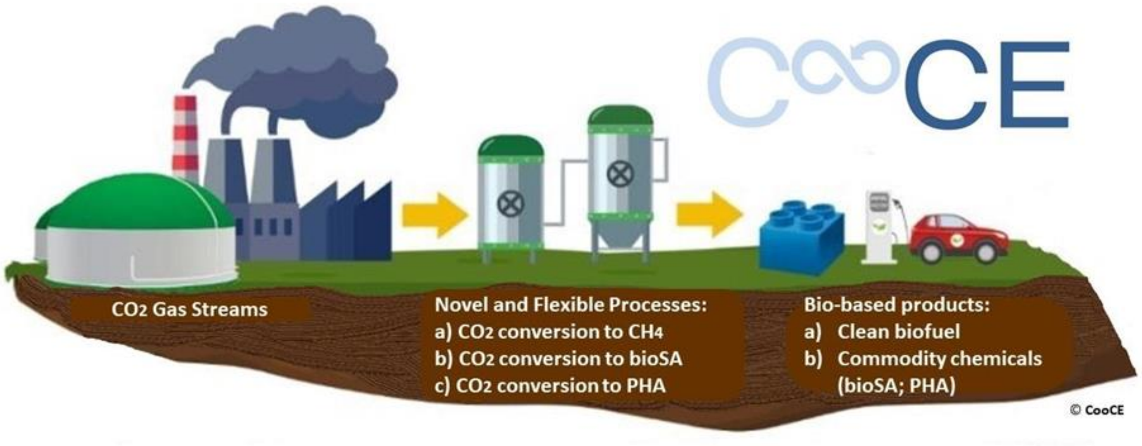


Figure 1: The CooCE Concept

2. The Social sustainability of the CooCE project

2.1 Social Sustainability

The notion of sustainability is implicit in the definition of Sustainable Development put forward by the Brundtland Commission, as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). Since then, reformulations have noted the need to reconcile the environmental, social, and economic dimensions (the 'three pillars' of sustainability). Sustainability assessment that addresses these three dimensions has become established and mandatory for novel technologies involving bioprocesses (Sala et al., 20123; Parajuli et al., 2015; Rafianni et al. ,2018) and need to be assessed across their entire value chain (IEA-BIOENERGY, 2009). Sustainability assessment entails the use of a range of concepts that imply the integration of these three dimensions or 'pillars of sustainability' into a framework of sustainability principles, indicators, along with methods for assessing initiatives, although further pillars (e.g., policy and institutions) should also be incorporated (Dalal-Clayton and Sadler, 2004; Diaz-Chavez, 2006; Spangenberg, 2014). Figure 2 illustrates this integration.

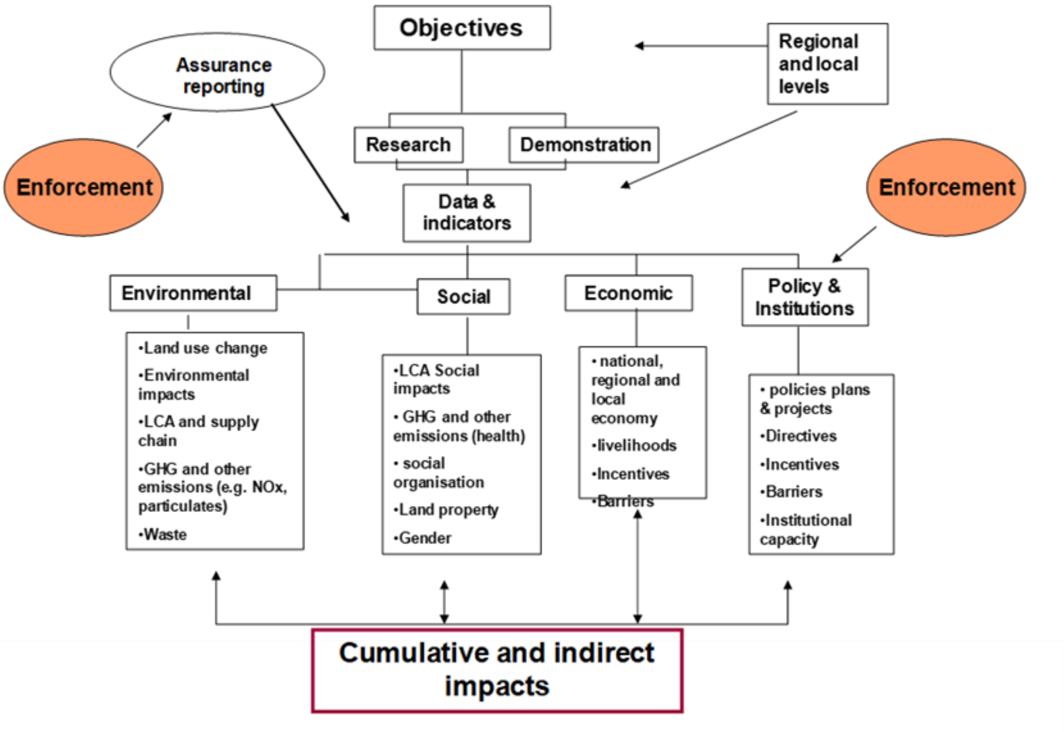


Figure 2: Framework for Sustainability Assessment

2.2 SIA and SLCA for Social Sustainability Assessment

Assessment of the potential social and economic impacts of new techno-processes (e.g. feedstocks, technologies, products) may utilise a range of tools and techniques for greater effectiveness, including SIA and SLCA. Although its initial development dates back to the 1990s (e.g., O'Brien, Doig and Clift, 1996), SLCA has emerged as an important methodology in the last decades, notably following the incorporation of social criteria into LCA by the UNEP/SETAC Life Cycle group and the publication of their own guidelines for SLCA (Grießhammer et al. 2006; Andrews et al. 2009; Benoît et al. 2010; UNEP/SETAC, 2020) which sets the context, outline the framework, and identify research needs and further steps (Andrews et al., 2009).

Within this framework, SLCA complements LCA by focusing on the social dimensions of sustainability, examining the social impacts of a product throughout its life cycle, from production to consumption. It evaluates aspects such as labour rights, community well-being, consumer safety, and societal contributions. SLCA identifies both positive and negative social impacts, aiming to improve conditions for all stakeholders, broadly defined as any group likely to be affected by the product system (Andrews et al., 2009; Benoît et al., 2013).

The SLCA framework is based on four phases of the LCA ISO standard (ISO, 2006). The Goal and Scope and Interpretation stages correspond to those used in LCA, whilst the inventory stage is based on a stakeholder approach that incorporates impact categories, subcategories, and indicators (Figure 3). A stakeholder category comprises a cluster of social actors that have shared interests due to their proximate relationship to the product system being assessed (UNEP/SETAC, 2009; 2020). The impact categories are related to five stakeholder categories: workers, local community, society, consumers, and value chain actors, which are divided into subcategories to be assessed (Andrews et al. 2009; UNEP/SETAC, 2020). SLCA identifies both positive and negative impacts of the product life cycle which should be used to gauge and encourage compliance with policy instruments (e.g., laws, international agreements, certification standards). They can be assigned to different stakeholders and can also be differentiated according to impact categories.

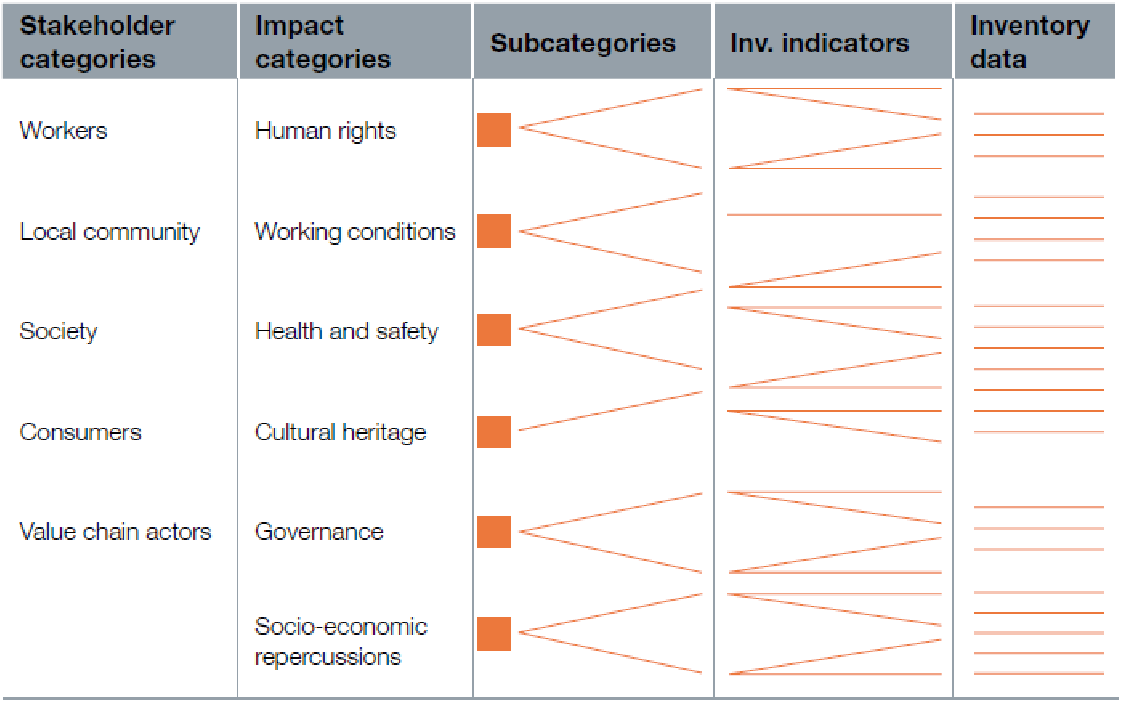


Figure 3: Stakeholders and Impact Categories (UNEP/SETAC, 2020)

The SLCA guidelines (UNEP/SETAC, 2009, 2020; Benoît et al., 2013) propose two types of inventories: Type-1 and Type-2 SLCIA. The Type-1 method first gathers data for the subcategories and then assesses the evidence available using performance reference points. These reference points can represent thresholds to which the data can be related to assess the potential impacts. Type-2 SLCIA instead uses impact pathways to convert inventory indicators into midpoints and then endpoints, as in LCA characterisation models. The social assessment method is employed to assess potential social impacts using both quantitative, semi-quantitative and qualitative data. While all stakeholder groups and subcategories may be identified in any study, only a selection of more relevant categories may need examining. Thus, SLCA combines the modeling capabilities and systematic assessment process of LCA with relevant social science methods. The social aspects examined in SLCA can positively or negatively affect stakeholders across the supply chain or the lifecycle of a product or organisation.

A variety of methodologies and frameworks have been developed for social sustainability assessment based on SCLA, but none is universally accepted (Reitinger et al., 2011; Benoît et al., 2013; de Luca 2015; Fortier et al., 2019; Afshari et al., 2022). SLCA is still evolving and can be used on its own or in combination with other techniques (Ciroth et al. 2011; Klöpffer 2008; Falcone and Imbert, 2018). Given the limitations of current SLCA methodologies, the approach used for the social assessment of CooCE draws from SIA and SLCA, combining elements that enable a more comprehensive and robust analysis, as employed in previous research (Diaz-Chavez and Evans, 2018; 2019; 2021). The approach is illustrated in Figure 4.

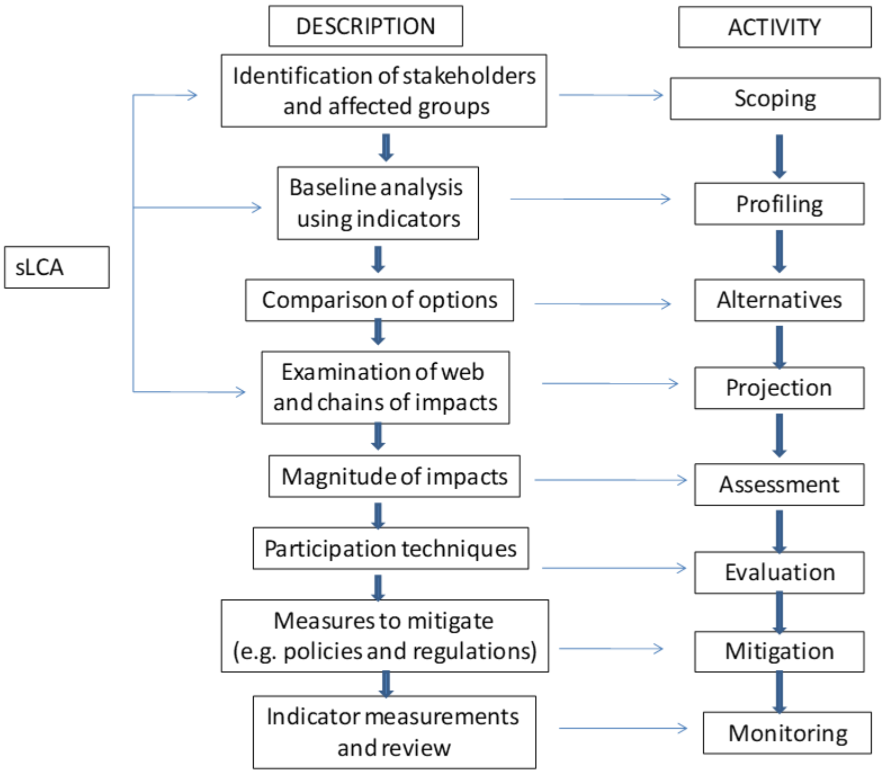


Figure 4: Adapted SCLA and SIA (Diaz-Chavez, 2014)

From the steps common to SLCA, a direct link can be drawn with different techniques, such as, for instance, mapping stakeholders, creating a baseline (i.e., inventory), and identifying and assessing the impacts. Examples of social, economic and policy issues that can be assessed in the context of CooCE are shown in Figure 5.

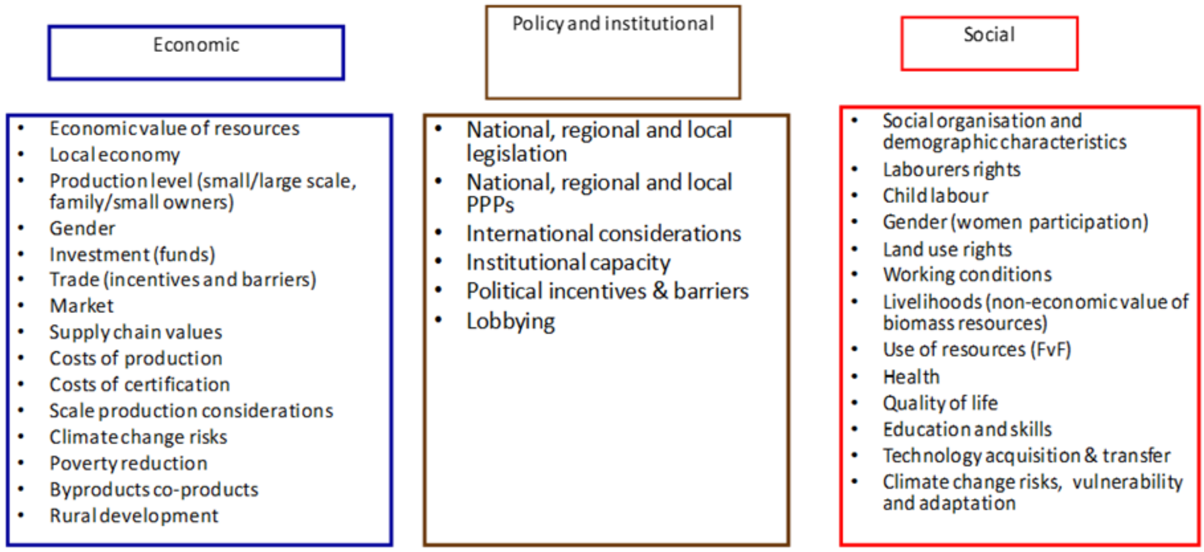


Figure 5: Issues for Impact Assessment (Diaz-Chavez, 2014)

LCA evaluates the potential environmental impacts of a product or process, offering insights into production efficiency and identifying areas for improvement. It covers all phases of a product's life cycle, including raw material extraction, processing, transportation, use, and disposal. Conducting an LCA involves gathering data not only on the primary product but also on the entire life cycle of all materials involved in its production, which is also relevant for green procurement. In contrast, SLCA requires additional data collection related to organisational and social aspects throughout the supply chain, which can be combined with SIA. Figure 6 illustrates the specific techniques.

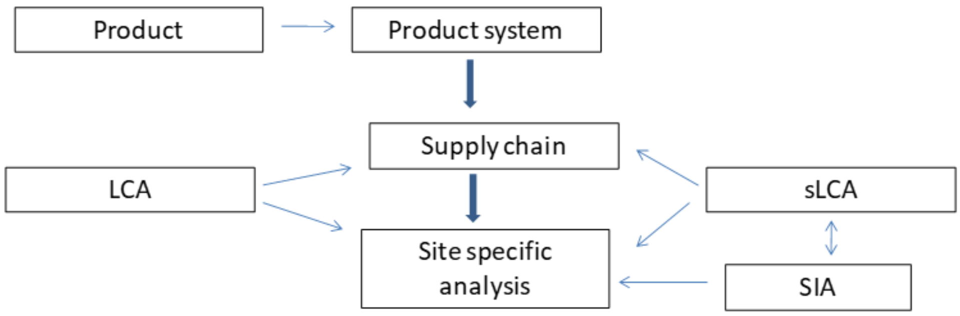


Figure 6: Analysis of a Product System (Diaz-Chavez, 2014)

3. Methodology for Social Assessment of CooCE

The methodological approach for the social assessment of CooCE encompasses the steps discussed next. It is worth highlighting that the scope of the assessment of CooCE is limited to potential impacts and risks since the CooCE concept is still at development stage. For instance, anticipated negative impacts are associated with increased transportation of CO_2 on roads and pipelines (e.g., traffic, air pollution, leakages, etc) that can only be properly assessed once CooCE techno-processes have been implemented at anyone specific location.

3.1 Characterisation of the geographic location of unit process

Contextual information about the geographical location of process units may be provided in SLCA to enhance the assessment, although not mandatory. It is however an integral part of SIA. For CooCE, this is provided at country level, both through indicators analysis, and 'hotspot' analysis. The focus of assessment are four countries where CooCE project partners are developing techno-processes (pilot and demonstration units) and where biogas plants are already operational. The countries are Denmark, Greece, Italy and the UK (shown in Figure 7).

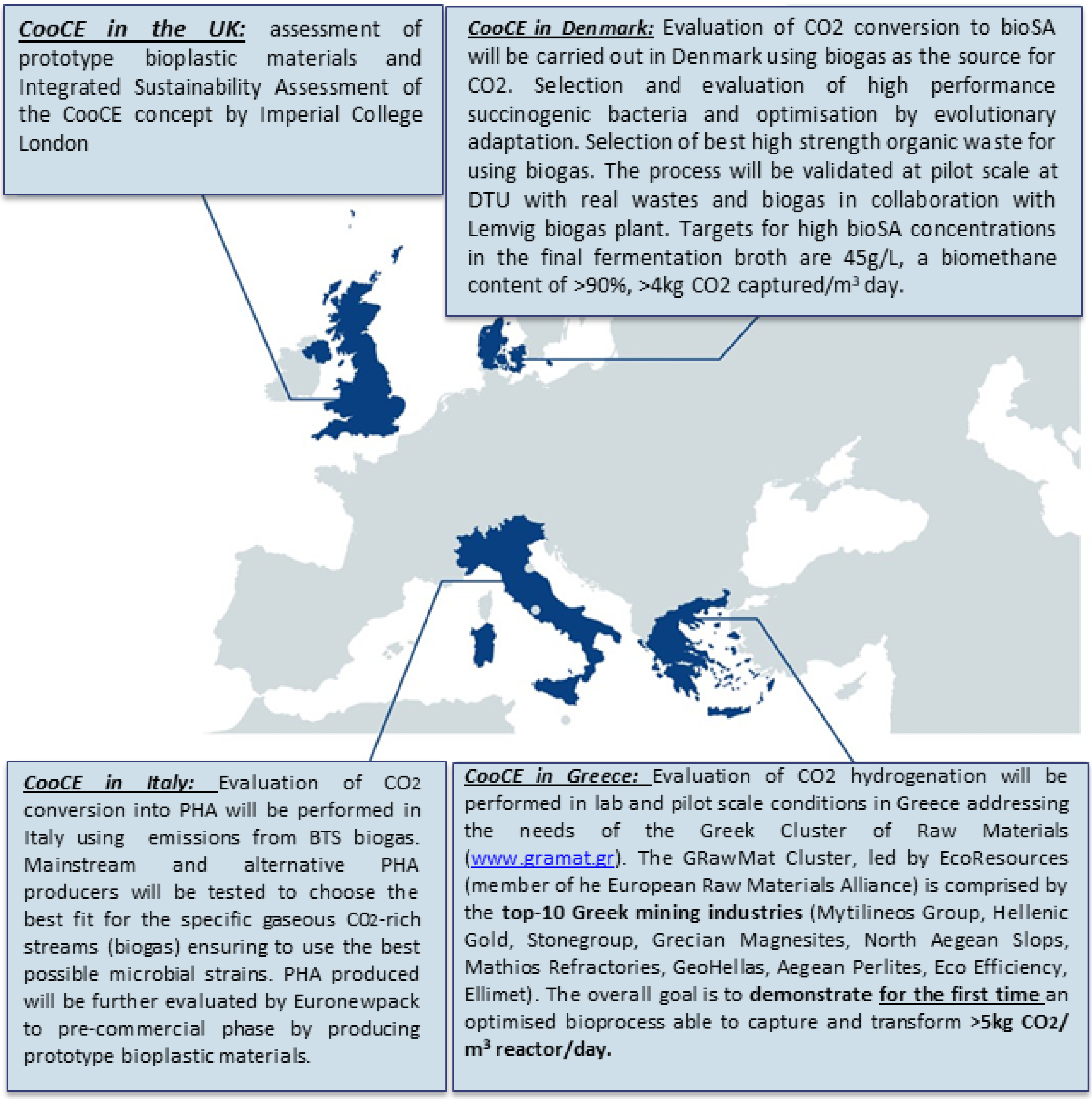


Figure 7 CooCE partner countries

The assessment entails the use of parameters from a composite approach developed by Diaz-Chavez (2014) and employed in previous research (Diaz-Chavez and Evans, 2018; 2019; 2021) which is now adapted for the case of CooCE. It entails the use of primary and secondary data sources. The parameters and related information are shown on Table 1. The applicable supply chain stages are: feedstock (CO_2 point source), processing, transport, storage and utilisation (intermediate and end products).

Table 1 SIA and SLCA Parameters for CooCE Assessment

No	Parameter	Characteristics/ Criteria	Assessment Level	Supply chain stage	Data type and source
1	Trade of feedstock	Incentives and barriers	EU/National	Feedstock	Qualitative Quantitative
2	Identification of stakeholders along the supply chain	Associations Authorities/regulators Businesses CO2 emitters Investors Researchers Etc	National Local	All	Qualitative
3	Policies and regulations	International National Regional Local	National International	All	Qualitative Quantitative
4	CO² point source	Availability of feedstock (CO_2)	Local	Feedstock	Qualitative
5	Land (N/A)	• Availability in EU • Ownership and rights	National		
6	Community participation	Community acceptance of: • feedstocks, processes, products • other involvement	National Local	All	Quantitative Qualitative
7	Quality of life N/A	Improvement of quality of life (longitudinal data needed)	National Local	N/A	Quantitative
8	Rural development and Infrastructure	• Roads • Sanitation • Water	National Local	All	Qualitative
9	Job creation and wages	• Labour conditions • Job creation • Wage regulations	National Local	All	Qualitative Quantitative
10	Gender equity	Inclusion of women	National	All	Qualitative Quantitative
11	Labour conditions	ILO conventions and human rights including: • Child labour • Right to organise • Forced labour	National	All	Qualitative Quantitative
12	Health and safety	Compliance with health and safety regulations	National Local	All	Qualitative Quantitative
13	Competition with other sectors	Competition and negative impacts on other industries and sectors	National Local	All	Qualitative Quantitative

Source: Adapted from Diaz-Chavez (2014) Key: N/A= Not applicable

3.2 Primary data sources: stakeholders' workshop and survey

The primary data used for the social sustainability assessment of CooCE was obtained from both a stakeholders' workshop and a stakeholders' survey.

A stakeholders' workshop was held in June 2023 as a side event at a major biomass conference. The workshop was attended by 22 people, mostly based in Europe, representing diverse sectors (academic, research, business, and industry). Participants engaged in a SWOT analysis of the CooCE concept, and of specific aspects of CooCE/CCUS (e.g., deployment, market demand, regulatory frameworks), with results reported fully in project deliverable D5.4 (Evans and Diaz-Chavez, 2023).

A stakeholders' online survey was run between June and October 2023, to gather their views on the CooCE concept and of CCUS more widely through a series of questions on CCUS and climate change, development and scaling up, challenges and opportunities, etc. In total, 70 valid questionnaires were obtained. The data was analysed through use of simple statistical measures (i.e., frequencies and percentages) and incorporated into later sections of this report.

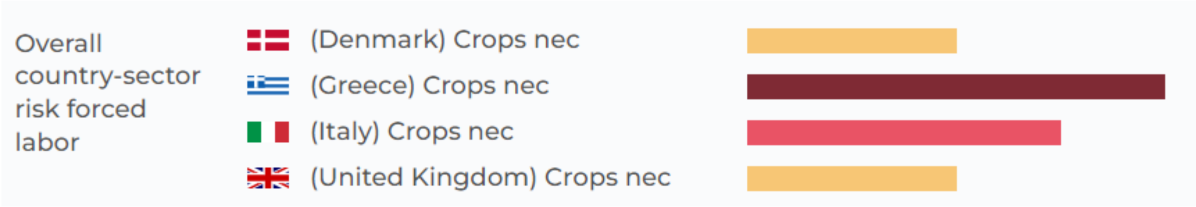
3.3 Secondary data sources: published databases for indicators

The secondary data comprised data for indicators drawn from published secondary databases and where appropriate, from academic sources and the grey literature. Specifically, the SIA was based on indicators drawn from a range of databases (e.g., EUROSTAT, The Global Economy, ILOSTAT, OECD, STATISTA, UNDP, and others (see Annex I for definitions).

The SLCA in turn was based on indicators from the SHDB[1], used for the social assessment of the CooCE product system through a 'hotspot analysis' (parameters 8-12 on Table 1) and to obtain a 'combined social hotspot index' for these countries (explained below). According to the UNEP-SETAC (in Norris and Norris, 2015) 'hotspots are the elementary processes in a region or situation that may seem problematic, where social issues are at risk or, conversely, opportunities exist'. Conceived for use in SLCA, the SHDB is a tool that enables the identification of hotspots or potential risks in supply chains in specific economic sectors at country level, based on potential social impacts. It is an extended input/output Life Cycle Inventory database providing a solution to enable the modelling of product systems and the assessment of potential social impacts (Norris and Norris, 2015). The potential social impacts of activities in specified economic sectors at country level can be identified through a range of indicators that are used to measure the risk levels associated with social issues, highlight an opportunity to address them (SHDB, 2024).

The SHDB covers social risks in 57 economic sectors in 244 countries. The database is structured around five social categories, with each category subdivided into themes, comprising 23 themes, and over 160 risk indicators. Risks are expressed by country and sector, commodity or production activity (Norris and Norris, 2015, SHDB 2024). These social categories were defined based on standards, policy frameworks and expert advice. Each indicator is assigned a risk rating (0 = low risk; 1= medium risk; 2= high risk; 3= very high risk) for each country sector according to characterisation rules specific to that indicator (SHDB, 2024) and each risk level is assigned a colour to aid visualisation (green = low risk; orange = medium risk; dark orange = high risk; dark red= very high risk). An example is shown in Figure 8 for the overall country-sector risk of there being forced labour in crop production in CooCE countries.

[1]Most LCA tools lack the ability to specify the geographical location of production activities within a country—information that is essential for social impact assessments. The SHDB can play a role equal to that of LCA databases in assessing product hotspots, but with the added benefit of geographical accuracy and identification of potential social impacts. The SHDB system's current Global Input-Output model is based on the GTPA7. Quantitative statistics and qualitative information by country and sector are used to develop characterisation models. Country-specific sector risk results help provide understanding of the context in which firms operate. The activity variable used in the SHDB is worker-hours. Thus, the SHDB can be used to identify how many worker-hours are involved for each unit process in the supply chain, for a given final product or service output from the system. worker hours are relevant because they represent evidence of the intensity of work required by each country-specific sector directly related to production. Work intensity is one of the criteria proposed to prioritise decision and action (Norris and Norris, 2015).



Source: SHDB (2024)

Figure 8 Overall risk of forced labour in the crops sector in CooCE countries

The SHDB includes a life cycle impact assessment method that allows for obtaining a 'combined social hotspot index' for a particular social category in any specific sector and country. This is obtained through the averaging of all indicators and assigning extra weight to particularly important indicators, yielding a risk rating between 1-4 for each social category. The risk ratings for all social categories are then summed up, divided by the highest sum possible for that sector, and multiplied by 100 to generate a value between 0 and 100 for the index (SHDB, 2024). The index is useful for comparing sectors across countries and visualise 'hotspot' issues, that is, the varying levels of risk for each sector and country. Figure 9 illustrates the social hotspot index for CooCE countries in the crops sector for all the five categories in the SHDB. However, it is to be noted that the SHDB does not allow for assessing positive impacts and given that the data provided is aggregated by industry sectors, it is not possible to differentiate between specific products or technologies.

Source: SHDB (2024)

Figure 9: Social Hotspot Index for Crops in CooCE countries

3.4 The CooCE product system

The CooCE concept is to be implemented along three pathways to obtain distinct products based on the extraction of CO_2 from biogas (biofuels, BioSA and PHAs). For the purposes of the assessment, inputs to and products from the different CooCE techno-processes (raw, intermediate, final) were grouped according to sector classification used in the SHDB. To these were added the sectors corresponding to the processes and products that CooCE aims to replace (i.e., the reference system). Therefore, the main inputs and products assessed in the SIA/SLCA configure the CooCE product system, that is, all sectors that constitute the value chain (see Annex II for definitions):

- Chemicals (process/product)
- Electricity (process/product)
- Gas (process/product)

- Transport (logistics)
- Water (process)

The SHDB was used to assess a range of issues and identify hotspots in the economic sectors encompassed by CooCE, as discussed later in the report.

3.5 Mapping the Stakeholders

Various methodologies exist for stakeholder mapping (e.g., UNEP/SETAC, 2009; 2020). Stakeholder selection should be comprehensive and include those at the production level, industry, consumers, society at large and any other value chain actors. Stakeholder participation is emphasised in both SIA and SLCA, where inventory data and impact assessment categories are specified for the stakeholders defined. An example of an approach for mapping stakeholders appropriate to CooCE is shown in Figure 10.

Mapping the stakeholders in CooCE

The mapping of stakeholders uses a quadrat for categorising the stakeholders.

Stakeholders at the production level comprise biomass suppliers to biogas plants, biogas plants, and interest-group representatives (e.g., NGOs, associations, Research and Innovation).

Next to them are stakeholders at the industry level, including consumers of CooCE's intermediate and final products (biofuels, biochemicals and biopolymers, bioplastics, biopackaging) and interest-group organisations (e.g., NGOs, associations, Research and Innovation).

The last two groups of stakeholders comprise government representatives at the local/regional level, and at the national level, along with agencies enforcing regulatory frameworks.

The links between these different stakeholders are traced through lines (full or broken). The closer the gaps in the lines are, the closer the relationship is or should be.

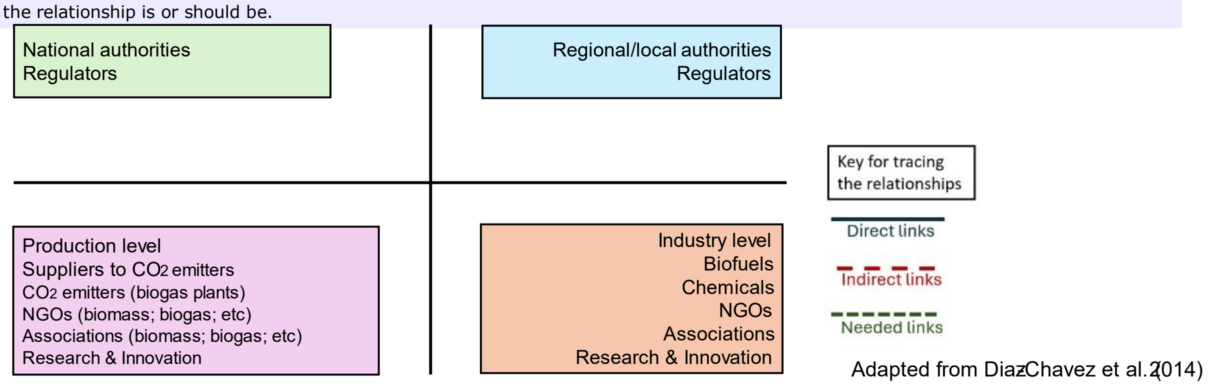


Figure 10 Mapping the Stakeholders

3.6 Assessment, uncertainty, and subjectivity

As with other life cycle assessment methodologies, SLCA seeks to minimise uncertainty and provide clearer and robust analysis to support the decision-making process. While these methods share an orientation towards uncertainty, they differ markedly in how they analyse subjective information, and in understanding the role such analysis play in reducing uncertainty about the results (UNEP/SETAC, 2009' 2020). Often, in SLCA subjective data (which tends to be qualitative) is the highly appropriate to use (e.g., stakeholders perceptions about technologies, the role of markets and regulatory frameworks, social and environmental impacts, etc). Nevertheless, uncertainty in the assessment can be reduced through a critical approach to and scrutiny of data and sources, acknowledging limitations where they occur.

3.7 System Boundaries

System boundaries specify which unit processes are part of the product system and need to be included in the assessment. The sustainability assessment of CooCE encompasses the entire value chain, from CO_2 capture, transformation into intermediate products (i.e., chemicals and polymers) and use of final products (i.e., biofuels, bioplastics, biopackaging). The SLCA focuses on CooCE's impacts along its chain assessed at the national level and in the sectors specified (Figure 11).

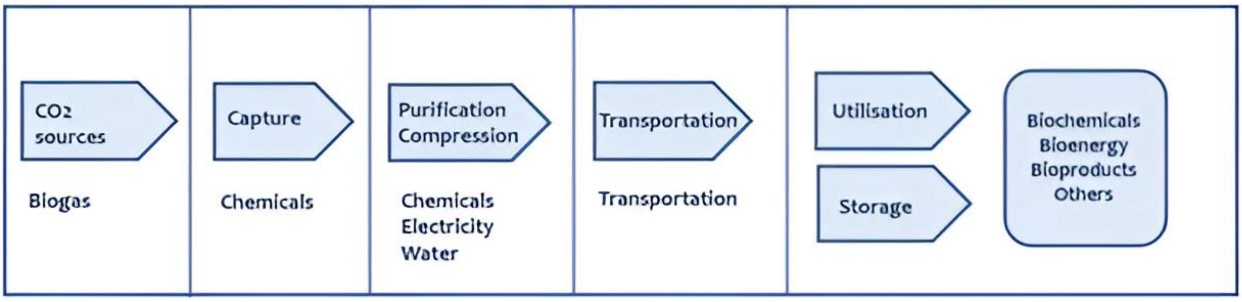


Figure 11: CooCE Product System: Boundaries and Sectors

3.8 Methodological harmonisation for the assessment of CooCE

As discussed earlier, the social sustainability assessment carried out here draws on tools and techniques from diverse methodologies. Table 2 illustrates the harmonisation of methodologies for the social assessment of CooCE. The overall social sustainability assessment of CooCE is thus based on the results obtained from utilisation of this harmonised methodology.

Table 2 Harmonisation of Methodologies: Social Sustainability and Policy Assessment of CooCE

Countries	Denmark, Italy, Greece, UK
• SIA (parameters/indicators)	√
• SLCA (parameters /indicators)	√
• Mapping of stakeholders	√
• Stakeholders' workshop	√
• Stakeholder's online survey	√
• SHDB (risks and 'hotspots')	√
• Policy review	√

4. Social Assessment of CooCE

This section starts by introducing some key indicators for CooCE countries (Table 3) along with a synopsis of biogas and biomethane production in each country. It then moves on to introduce and discuss the data results obtained for the four CooCE study countries for the social assessment. The relevant SIA/SLCA parameters are introduced in turn along with description and analysis of data from the primary and secondary data noted.

Table 3 CooCE Countries Indicators

Country indicators (2021)	Denmark		Greece		Italy		UK	
Total Population (N) (2022)	5 910 577		10 361 270		58 940 424		67 299 048	
Urban Population (%)	88.2		80		71.3		84.2	
Human Development Index	0.948		0.887		0.895		0.929	
Gender Development Index	0.957	0.937	0.900	0.872	0.906	0.879	0.934	0.922
Life Expectancy at Birth (years)	M	W	M	W	M	W	M	W
	79.5	83.3	77.5	82.9	80.5	85.1	78.7	82.8

Expected Years of Schooling	18.1	19.3	20	20.1	15.9	16.6	16.8	17.8
Mean Years of Schooling	12.8	13.2	11.7	11.1	10.9	106.	13.4	13.4
Labour Force Participation Rate (age 15+/%)	67.7	57.7	58.1	43.3	57.6	39.9	67.1	58.0
Gross National Income per capita (PPPS)								
Men	70,961		35,368		55,187		53,265	
Women	49,876		22,890		31,100		37,374	

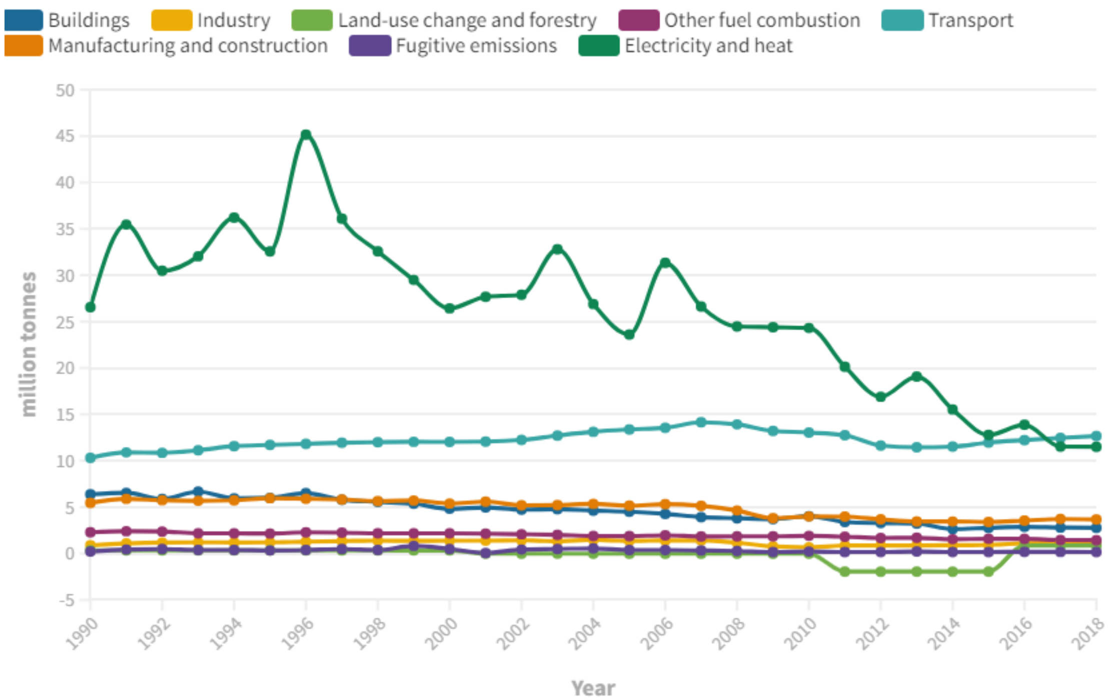
Sources: FAOSTAT (2024); UNDP (2024); OECD (2024)

4.1 CO_2 emissions and biogas production in CooCE countries

This section provides a brief overview of CO_2 emissions and biogas production in Denmark, Greece, Italy, and the United Kingdom, the four CooCE countries where biogenic CO_2 from biogas may be potentially captured for utilising in CooCE biotechnology applications to produce biomethane and biochemicals and biopolymers (i.e., biosuccinic acid and PHAs/PHBs).

4.1.1. Denmark

CO_2 emissions by Denmark are shown in Figure 12 for different sectors, covering three decades. As the graph shows, most have remained unchanged at low levels, except for three sectors. Emissions from *Land Use Change* and *Forestry* dipped below zero (i.e., negative emissions) between 2011 and 2015 (remaining stable in this period at -1.9 m tons), whilst in *Transport* they increased from 10.3 million tons in 1990 to 12.7 million tons in 2018. Emissions from *Electricity and Heat* oscillated between growth and decline, although the overall trend was towards decline, from a high of 45 million tons in the mid-1990s, to a low of 11.5 million tons at the end of the period.



Source: CooCE (2024); https://cooce.eu/co2-streams-and-emissions/

Figure 12: Denmark's Carbon Dioxide Emissions by Sector (1990- 2018)

Biogas production in Denmark dates back to the mid-1970s, following the first oil crisis, with the first farm-scale biogas plant established in 1975 and the first centralised plant set up about a decade later. In the 1990s, the introduction of biogas subsidies and CHP production spurred the construction of more plants. However, between 2011 and 2022, the number of plants decreased from 196 to 123 due to several factors: the closure of smaller wastewater treatment plants, leading to sludge being redirected to larger facilities; the shutdown of small agriculture-based biogas plants; the conversion of many power-generation biogas plants to biomethane upgrading; and all new anaerobic digestion plants producing biogas for biomethane. This decline in the number of plants also resulted in a drop in total biogas production, with the remaining 123 plants producing 1,501 GWh of biogas in 2022 (EBA, 2023).

The decline in biogas production has been more than compensated by a sharp rise in biomethane production. The first biomethane plant was established in 2012, and the number of plants grew rapidly, reaching 59 by 2022. Biomethane production gained momentum in 2015, surpassed biogas output in 2018, and increased by 1,097 GWh from 2021, reaching 6,780 GWh by August 2023. This growth has made Denmark one of Europe’s fastest growing biomethane producers, ranking as the fourth largest. Biomethane now accounts for 39% of the Danish gas grid. The trend is expected to continue, with a 2022 survey by the Danish Biogas Association indicating that around 40 new biomethane plants were under construction and 30 existing plants were considering expansion (EBA, 2023).

Since 2018, the Danish parliament has introduced new energy policies to align with the Paris Agreement and achieve the country's targets of zero emissions by 2050 and 55% renewable energy by 2030. One of the key goals is to increase biomethane production to meet 100% of Denmark's gas demand by 2030. Additionally, new regulations prevent any new biogas or biomethane capacity from entering the 2012 subsidy scheme. However, existing biogas plants are guaranteed subsidies for biomethane or electricity production from biogas for at least 20 years, until 2032. In 2020, the Danish Parliament also established a new tender-based scheme for biomethane injected into the gas grid, which will be operational between 2024 and 2030 (EBA, 2023).

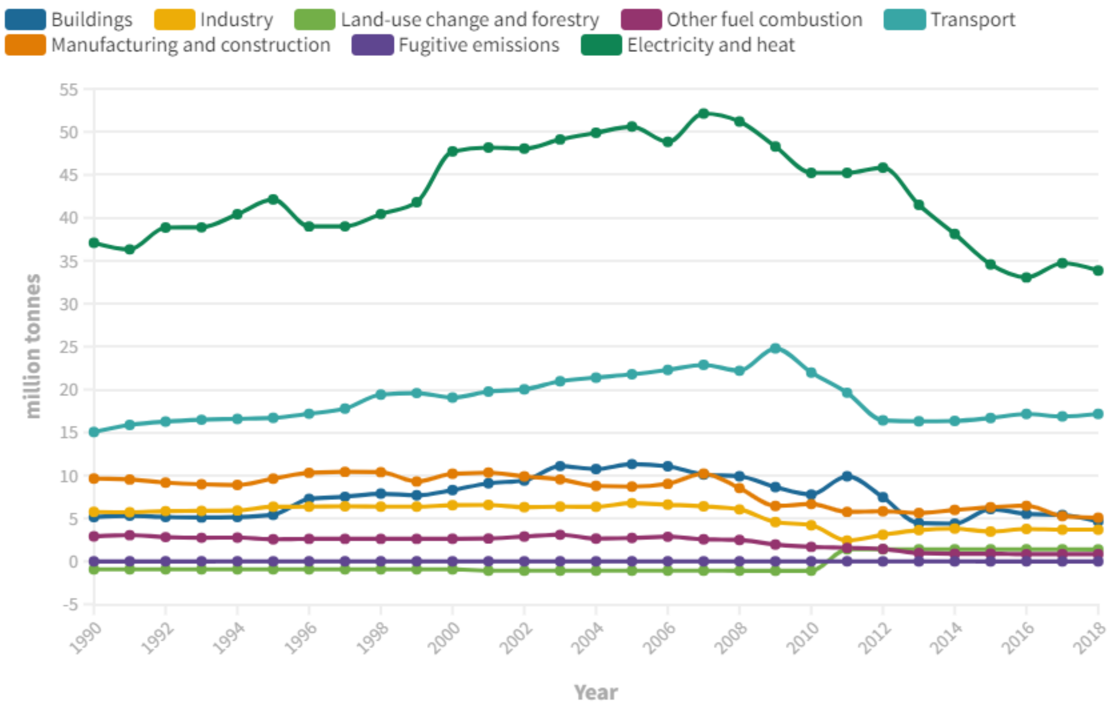
Agriculture-based plants, located either on farms or at centralised facilities, are the primary sources of feedstock for biogas and biomethane production in Denmark. Manure treatment also plays a crucial role, especially in rural areas with high livestock densities. Approximately 76% of Denmark's biogas is produced by 42 agriculture-based plants, while 95% of biomethane comes from 56 biomethane plants utilising agricultural residues. Most biomethane plants are connected to the distribution grid, with one plant linked to the transport grid. A national biomethane registry has been in place since 2011. Energinet, Denmark's transmission system operator for electricity and natural gas, issues certificates to biomethane plants verifying that renewable gas has been injected into the gas grid as a substitute for natural gas, meeting the criteria for guarantees of origin under the EU’s Renewable Energy Directive (EBA, 2023; see discussion in section 4.4.3).

The expansion of the biomethane sector could potentially limit the opportunities for implementing the CooCE concept in terms of upgrading CO_2 into biomethane, due to potential competition with biomethane plants for available biogas. However, this constraint may be mitigated if biogas production continues to grow (see section 4.12 for further discussion).

4.1.2 Greece

CO_2 emissions by Greece from different sectors for over three decades are shown in Figure 13. The graph shows that the volume of emissions has fluctuated most markedly in the *Electricity and Heat* sector, from 37.1 million tons in 1990 through a peak of 52.1 million tons in 2007 to the lowest level in the period at 33.9 million tons. Emissions from the *Transport* sector increased gradually through the period, from 15.1 million tons in 1990 through to a peak of 24.8 million tons followed by a decline to 17.2 million tons at the end of the period. Emissions from *Buildings* also increased from 5.2 million tons in 1990 to a peak of

9.9 million tons in 2011, declining thereafter to 4.7 million tons in 2018. Emissions levels from other sectors varied much less over the period (EBA, 2023).



Source: CooCE (2024); https://cooce.eu/co2-streams-and-emissions/

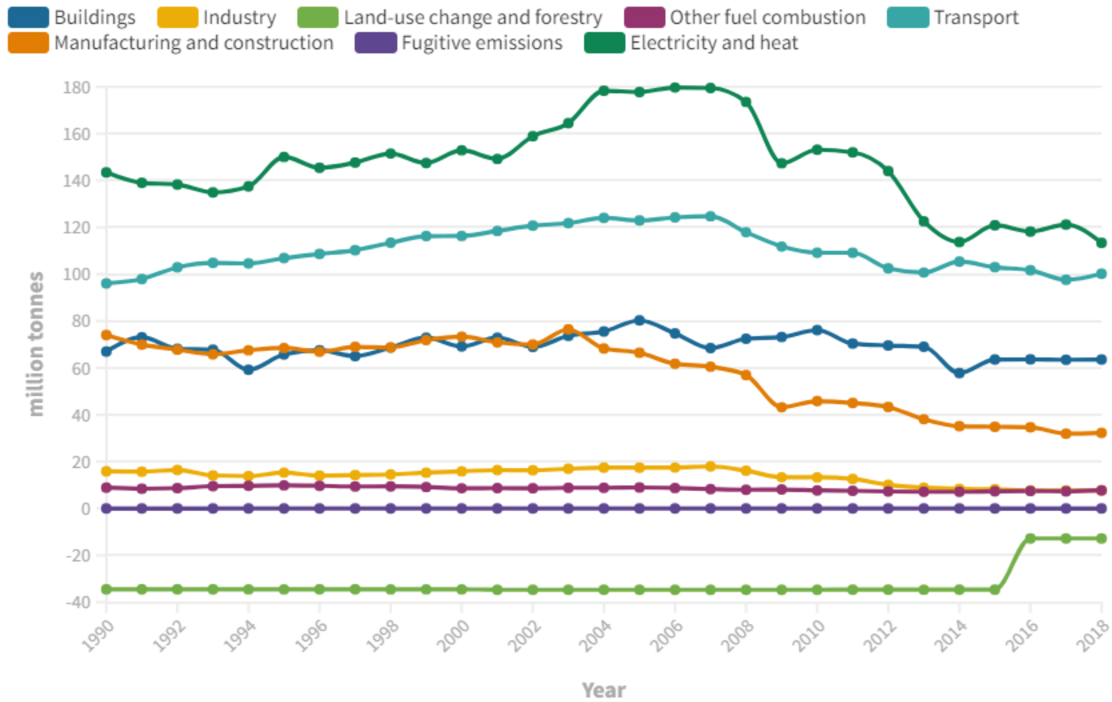
Figure 13: Greece's Carbon Dioxide Emissions (1990-2018)

From the start of biogas production in Greece in the early 2000s, sewage and landfill plants dominated the biogas sector, up until 2010. That year, the national government introduced two distinct FiTs for renewable energy, one tariff for landfill biogas plants (up to €120/MWh), and another for agricultural residue biogas plants (up to €220/MWh). This helped boost biogas production from agricultural residues since 2011. New FiTs were introduced in 2016 for landfill biogas plants (up to €129 /MWh) and agricultural biogas plants (up to €225 /MWh), sparking an increase in the number of biogas plants to 75 in 2022, and particularly from agricultural residues plants which amounted to 75 plants producing a total of 753 GWh, out of a total of 1.28 TWh from all biogas plants. Manure makes up about 88% of the agricultural feedstocks used in biogas plants (EBA, 2023).

There is currently no biomethane market in Greece. However, a new support scheme effective from the end of 2023 aims to encourage the production of biomethane at existing biogas plants as well as incentivising the building of new biomethane plants. Greece's National Energy and Climate Plan includes targets for biomethane production, which are expected to rise from 2.1 TWh/year by 2030 to 9.7 TWh/year by 2050 (EBA, 2023).

4.1.3 Italy

CO_2 emissions by Italy are shown in Figure 14, being distributed by sectors over a period of thirty years. As the graph shows, emissions from *Electricity and Heat* are the highest, peaking at 179.5 million tons in 2007, although declining sharply to 113.4 million tons in 2018. *Transport* was the second highest emitter over the period, from a peak of 124.7 million tons in 2007 to 100.2 million tons in 2018. Emissions from *Buildings* also rose over the period, peaking at 80.3 million tons in 2005, although declining to 63.6 in 2018. Emissions from *Manufacturing* also increased slightly over the period, peaking at 76.5 million tons in 2003, but falling markedly to 32.3 in 2018. A further notable change was in the levels of negative emissions from *Land Use Change* and *Forestry*, which changed little from -34.5 million tons in 1990 through 2016, when it declined markedly to -12.8 million tons in 2016, remaining at that level in 2018.



Source: CooCE (2024); https://cooce.eu/co2-streams-and-emissions/

Figure 14: Italy's Carbon Dioxide Emissions (1990- 2018)

Biogas has been produced in Italy since the early 1990s and the subsidy, a green certification system, was set up in 1999. But it was the introduction in 2008 of the FiT for small renewable energy plants that mostly drove the construction of most biogas plants, leading to a sharp increase in their numbers up to 2012. The support scheme was changed in 2013, entailing a reduction in the level of subsidies but an extension in their terms, from 15 to 20 years, but it was still attractive enough to lead to steady expansion of biogas plants up until 2021. The current system supports the production of electricity from biogas through CHP and a FiT scheme for newly built biogas plants. New legislation in the aftermath of the war in Ukraine has incentivised existing biogas agricultural plants to expand their production of electricity. A total of 1800 biogas plants are operational producing at total of 24 TWh, of which some 9 TWh were used for generating electricity. Most of biogas production in Italy is based on agricultural residues (EBA, 2023).

In Italy, biomethane was first produced from biogas upgrading in 2012, and over the years several demonstration plants (<50 m3/h of biomethane) were built, although they lacked grid connection. Following the introduction of legislation to incentivise the production of biomethane in 2018, several biomethane plants were built, totalling 51 operational plants in 2022, turning Italy into one of the fastest growing biomethane markets in Europe. At the end of 2022, four plants were connected to the distribution grid and 19 were connected to the transport grid, although nine are yet unconnected (EBA, 2023).

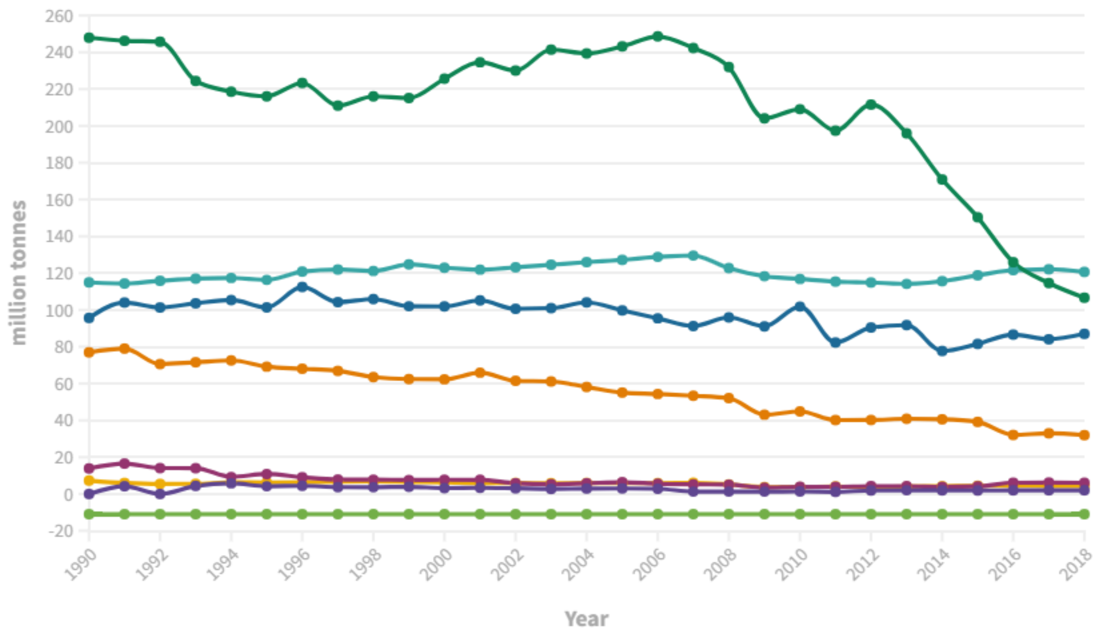
The 2018 legislation was extended until end of 2023, whilst another one came into effect in 2022, so that two schemes have run concurrently, and plants that started operation in 2023 could claim incentives from either. The 2018 law supports the production of biomethane for the transportation sector whilst the 2022 law includes production for other sectors too. Funding totalling €4.53 bn are available over a 15-year period as long as plants are completed by mid-2026 to contribute to the annual production of some 4bcm.

Most biomethane produced in Italy originates from organic municipal solid waste (30 plants), which accounted for 70% of the 4,371 GWh produced in 2022, the rest being produced from agricultural residues (18 plants), industrial wate (2 plants), and sewage sludge (one plant) (EBA, 2023).

Following the 2018 *National Biofuels Obligation* policy that encourages biomethane production for use in the transportation, nearly all biomethane production in Italy is used in transport as advanced fuel. The country hosts 1,542 CNG filling stations and 126 LNG filling stations. At the end of 2022, six Bio-LNG plants were operational, and a further 31 plants in the pipeline are expected to come on stream by 2025, which are all expected to raise Bio-LNG production capacity to 3,058 GWh per year by 2025, contributing a considerable share of the European Bio-LNG market (EBA, 2023).

4.1.4 UK

CO_2 emissions from all sectors in the UK are illustrated in Figure 15 for the period between 1990-2018. As can be seen, the highest emitter was *Electricity and Heat* for most of the period, except towards the end (when it was overtaken by *Transport*), peaking at 248.6 million tons in 2006, although declining gradually from 2012, to its lowest level in 2018, at 106.6 million tons. Emissions from *Transport* were the second highest over the period, reaching at peak of 129.6 million tons in 2007, and although declining to 120.7 million tons in 2018, it surpassed those from *Electricity and Heat*. Emissions from *Buildings* were the third highest, although experiencing peaks and troughs, from a high of 120.9 million tons in 1996 to its lowest level in 2014 of 77.7 million tons, rising 87 million tons in 2018. CO_2 emissions from *Manufacturing* and *Construction* declined for the most part during the period, from a high of 79 million tons in 1991 through to a low of 32 million tons in 2018.



Source: CooCE (2024); https://cooce.eu/co2-streams-and-emissions/

Figure 15: United Kingdom's Carbon Dioxide Emissions (1990-2018)

Biogas has been produced in the UK since the early 1990s, following the introduction in 1989 of indirect subsidies through the Non-fossil Fuel Obligation mechanism which required electricity from supply companies to be generated from non-fossil sources. Various support frameworks have since replaced it (e.g., 2002 Electricity Act; 2008 Energy Act; 2011 Renewable Heat Incentive). The number of biogas plants in the UK has increased steadily over the past decade, with an estimated 1,111 biogas plants being operational by the end of 2022, making the UK the third highest country hosting biogas plants in Europe.

Over the last five years biogas production has stagnated, with some 20 TWh of biogas produced annually. Feedstocks comprise mostly farm residues (agricultural wastes, manure, crops) and waste (food and industrial). Nearly half of total biogas production is derived from landfill, whilst 16% is obtained from sludge. About 7.6 TWh of electricity was generated from 20 TWh of biogas produced in the UK in 2002. However, biogas production is expected to stagnate in the future due to governmental incentives being directed towards biomethane production (EBA, 2023).

The number of biomethane plants rose markedly over the last decade, from 5 units in 2011 to 138 in 2022, making the UK the third country with the highest number of biomethane plants in Europe. Biomethane production has increased markedly too, from 102 GWh in 2014 to 6.9 TWh in 2022 (EBA, 2023).

A FiT scheme has been in place since 2011 to support biomethane production from anaerobic digestion and its injection into the natural gas network. Biomethane plants are paid per unit of energy injected, with rates varying according to plant size and year of commissioning. But while there was a steep growth in the number of biomethane plants up to 2016, a steady decrease in the RHI tariffs since mid-2015 has slowed down the rate of growth, although it is expected to pick up again following the introduction of a new support mechanism in late 2021 (Green Gas Support Scheme) to incentivise biomethane injection further which was revised in 2023. Some 300 biomethane plants are in the pipeline, while existing biogas plants are also likely to switch to biomethane production for renewable fuel. By the end of 2025, some 45 new plants are expected to be built under the new scheme, with an average biomethane capacity of >750 m3/h, adding some 16 MWe of electrical capacity and 5,700 Nm^3/hr of biomethane to the market (EBA, 2023).

Regarding biomethane for transportation, 27 bio-CNG and 12 bio-LNG filling stations were already operational by mid-2021. Another four filling stations are being built to supply bio-CNG and a further 29 are being planned, 20 of which are expected to supply Bio-CNG and another one to supply both Bio-CNG and Bio-LNG (EBA, 2023).

The most used feedstock in the UK for biomethane production is agricultural waste, accounting for 49% of biomethane produced in 2022, comprising 79 plants. A total of 33 biomethane plants used organic municipal wastes and food wastes, whilst ten plants used sewage sludge, and nine further plants used industrial wastes. Around 81 plants are connected to the distribution grid, and 24 to the transport grid (EBA, 2023).

4.2 Trade of Feedstock

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Carbon trading	Incentives Barriers	EU National	Feedstock	*Qualitative* Literature Workshop *Quantitative* Survey

The CooCE concept envisages the integration of CO_2 capture and processing technologies into existing industrial sites and power plants to capture their carbon emissions. However, CooCE technologies are currently being developed for capturing carbon from biogas plants as a key innovation that will help drive the expansion of the circular bioeconomy. Therefore, CO_2 from biogas plants is the key feedstock whose availability is a central requirement (as discussed more fully in section 5.4).

The stakeholders workshop revealed a perception that CCUS faces slow market expansion in the EU due to a combination of historical challenges, including, regulatory and policy frameworks for CCUS lagging behind those for renewable energy sectors, weak incentives and financial mechanisms (e.g. carbon pricing, subsidies) relative to other regions, and investor uncertainty about the financial viability of CCUS projects and the regulatory landscape. But other potential barriers identified are high costs associated with different circular economy pathways for CCUS and the complexity of new markets for biogas producers, and currently high product prices. Indeed, CCUS is not yet seen as a viable investment for businesses operating in most industrial sectors particularly, for instance, cement and steel, as carbon capture costs are much greater than can be incentivised at current EU ETS allowance values (BEIS, 2019). Besides, costs will vary considerably between different industrial sectors, as will their ability to afford carbon capture which depends on the specific technologies used, along with locally contingent factors, such as labour and energy costs (BEIS, 2019; Warren, 2019; Naims, 2020; UNECE, 2021).

4.3 Identification of Stakeholders

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Identification of stakeholders along the supply chain	Associations Authorities/regulators Businesses CO2 emitters Investors Researchers etc	National Local	All	*Qualitative* Desk search Research Partners *Quantitative* Survey

The mapping of stakeholders followed the method discussed previously (section 4.5). The aim was to identify major stakeholders and trace the linkages between them. These stakeholders were identified through desk research and linked with help from project partners. The stakeholders and linkages are shown in Figure 16 for each of the CooCE countries. As can be seen in Figure 16, the linkages are traced between different stakeholders as direct, indirect and those perceived as needed, if not yet necessarily extant. This mapping is not exhaustive. Rather, it aims to identify key social actors that would or should collaborate in the implementation of the CooCE concept. It envisages a 'multi-actor approach,' as employed in other EU projects (EU, 2023). In the case of CooCE, this entails bringing together biogas plants and other CO_2 emitters, scientists, investors, regulators, policymakers, business owners, associations, and other stakeholders, to collaborate throughout the concept's implementation to develop novel practical solutions to emergent problems through knowledge exchange and innovation dissemination.

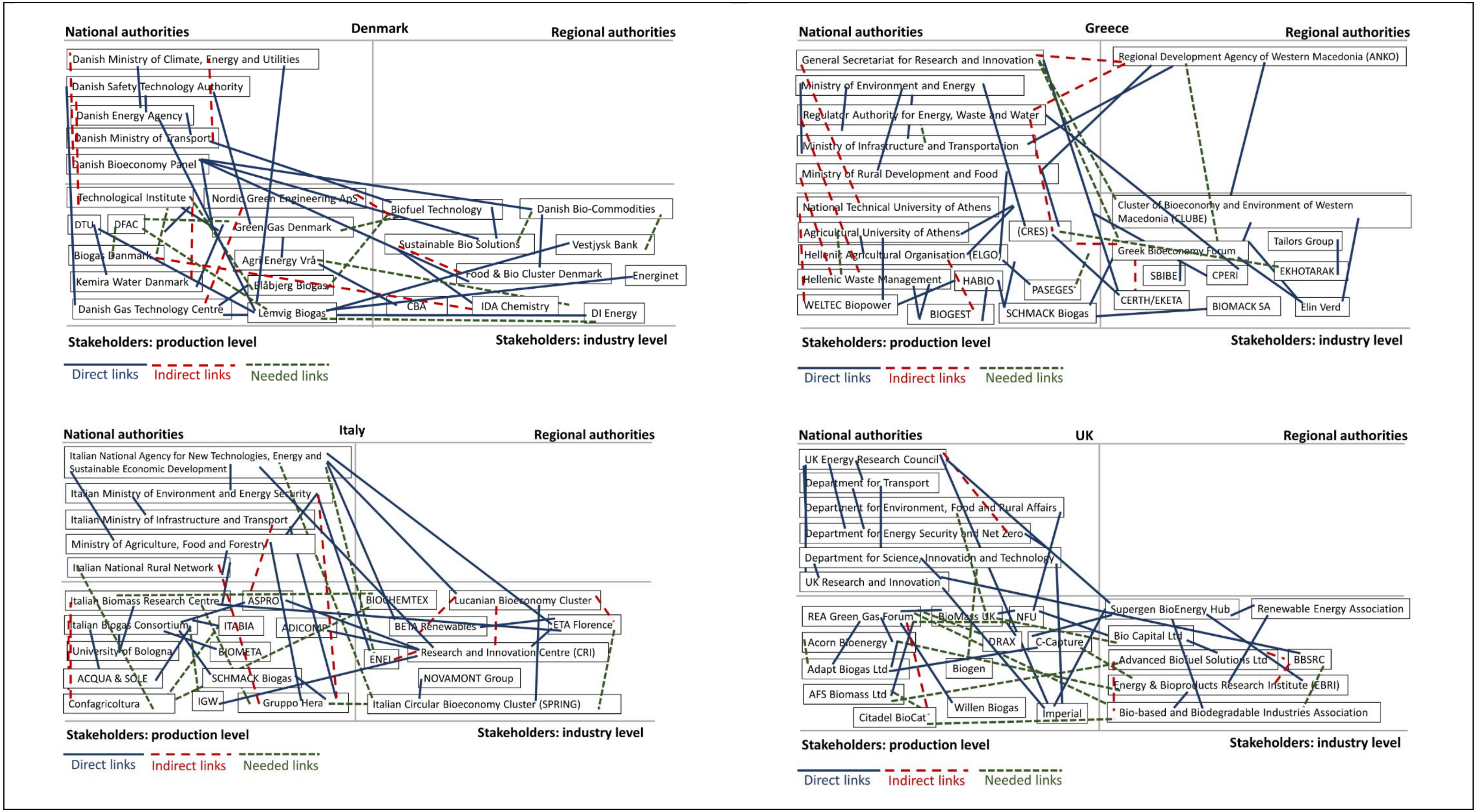
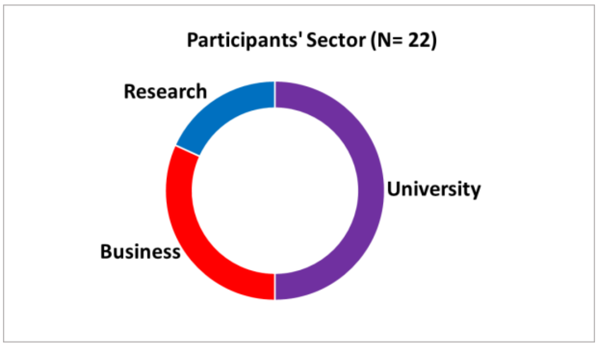


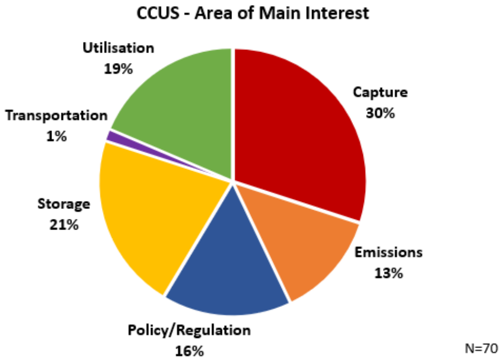
Figure 16 Mapping of CooCE Stakeholders

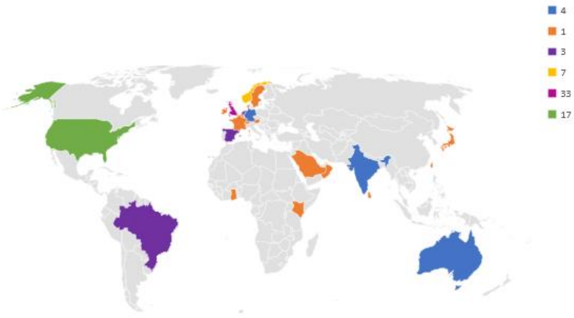
To these stakeholders complement those who took part in both the stakeholders' workshop and in the online survey. Information about their characteristics, location, and sector, activity, or interest are shown in Figure 17.



Workshop (2023)

Workshop (2023)





Survey (2023)

Survey (2023)

Figure 17 CooCE stakeholders - Workshop and Survey

The mapping of stakeholders aims to highlight the need for stakeholder engagement, which has been increasingly emphasised as a fundamental factor to the success of projects and initiatives of all kinds, including the development and implementation of bio-technological innovation such CooCE's. The advantages of engagement include: harnessing a diversity of views that can enhance innovation; sharing insights and local knowledge; building trust; facilitating regulatory approval; mitigating risks related to public perception, regulatory hurdles, and project feasibility; enhancing collaboration to access and utilise resources, funding and expertise; helping ensure transparency and accountability (van Heek et al., 2017; Leibensperger et al., 2021, Jäger et al., 2023; Mota-Nieto and García-Meneses, 2024).

Stakeholder engagement requires the active and meaningful participation of stakeholders, from design through to post-implementation and throughout the stages of any value chain created. As the diagrams in Figure 16 indicate, a wide variety of stakeholders may be involved in CooCE, who will need to work together effectively under existing regulatory frameworks to ensure the integration and commercial success of the chain (e.g. suppliers of biomass to biogas plants, CO_2 capture, compression, storage, transportation through pipelines or roads, supply of intermediate and final products). Yet, effective stakeholder engagement can be notoriously difficult (Leibensperger et al., 2021; Jäger et al., 2023; Mota-Nieto and García-Meneses, 2024). Challenges include knowledge gaps that may lead to differentiated views on risks, benefits and technological feasibility; perceived lack of transparency and voice in decision-making; regulatory uncertainty leading to hesitancy and opposition; perception that risks of CCUS technologies outweigh the benefits (e.g. environmental risks, health impacts); concerns over equity and fairness where projects are sited in vulnerable or marginalised communities; and conflicting interests (van

Heek et al., 2017; Leibensperger et al., 2021; Jäger et al., 2023; Mota-Nieto and García-Meneses, 2024). Indeed, according to one stakeholder at the workshop, one weakness of the CooCE concept was exactly the ‘*multitude of stakeholders involved in such circular economy approaches.’* Developing strategies and actions to address these challenges and ensure a comprehensive approach for collaboration among stakeholders will be paramount to CooCE’s successful implementation.

4.4 Policies and Regulations

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Policies and regulations	International National Regional Local	National International	All	*Qualitative* Literature Workshop *Quantitative* Survey

The CooCE concept encompasses a variety of strategies and policy instruments enforceable at different geographical scales (e.g. local, national, supra-national). The focus here is on the EU region since it is the key geographical remit of the project. The UK has enacted its own regulatory frameworks since its exit from the EU in early 2020 but a brief assessment of key relevant instrument is provided later (section 4.4.6). Figure 18 shows the main current instruments that cover different aspects of the CooCE concept across five thematic areas.

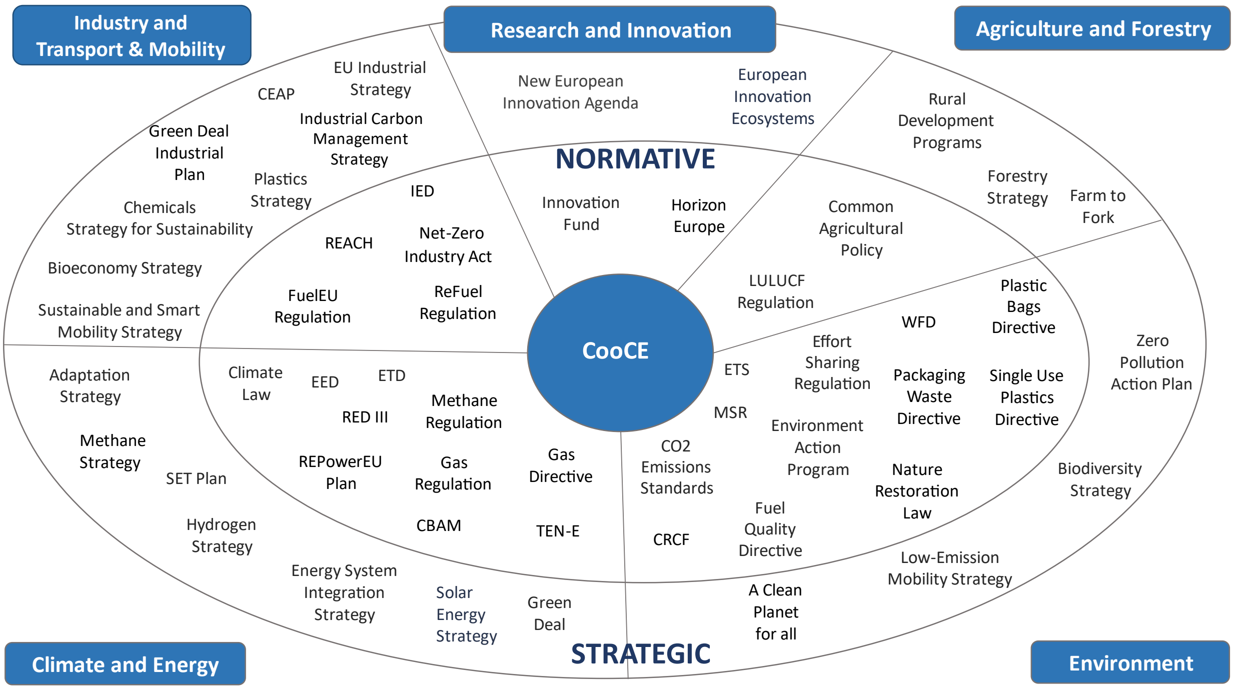


Figure 18: Strategies and Policies Relevant to CooCE

The EU policy landscape has gone through a momentous and ambitious reorientation since the EC adopted the Green Deal in 2019, an overarching strategy aimed making Europe the first climate-neutral continent by 2050 so as to fulfill its commitments to 2015 the Paris Agreement. To help enable its delivery, the EC put forward the ‘Fitfor55’ package of legislation to overhaul the EU’s climate, energy, land use, transport and taxation policies. The aim is to achieve a new intermediate target of at least 55% reduction in net GHG emissions by 2030, compared to 1990 levels. The 'Fitfor55' enables the implementation of the Climate Law that came into force in 2021. It encompasses both a raft of revised and new laws on climate and energy, setting out legally binding climate targets for all key economic sectors in the EU. The assessment focuses on normative policy instruments (i.e. enforceable law) most relevant to CooCE (strategies are introduced in Annex III). They are described next, along with implications for CooCE as to whether they enable or hinder the implementation and scaling up of the CooCE concept to sustainable commercial ventures. The overall policy assessment is introduced later (section 7).

4.4.1 Climate and Energy

Energy Taxation Directive (CNS 2021/0213)

This directive provides the framework for taxing electricity, motor vehicles, aviation fuels, and most heating fuels in EU member states. Its primary goal is to enhance the functionality of the EU's internal energy market and prevent competitive distortions arising from varying tax systems. In 2021, the EC proposed a revision to align the directive more closely with other EU policies, supporting the energy and climate goals outlined in the Green Deal. The revision aims to better reflect the climate impact of different energy sources and encourage behaviour change. It outlines three key objectives: aligning energy product and electricity taxation with EU energy and climate policies to help meet 2030 targets and achieve climate neutrality by 2050, maintaining the integrity of the EU internal market by updating tax structures and reducing the use of tax exemptions, and ensuring member states can continue to raise revenue. These objectives are to be achieved by introducing tax rates based on the energy content and environmental impact of fuels and electricity, and by expanding the taxable base through the inclusion of more products and the removal of certain exemptions and reductions. However, a lack of consensus on the proposed changes has stalled negotiations, and the revision remains unresolved (EC, 2024a; EUROPAPARL, 2024a).

Assessment: This directive is highly relevant to CooCE's proposed biomethane, as it offers lower tax rates for renewable energy sources compared to fossil fuels. The directive introduces a taxation structure based on energy content and environmental performance, providing favourable rates for cleaner fuels such as biomethane to encourage their production and use. It also aims to gradually eliminate tax exemptions and subsidies for fossil fuels, particularly in transport and heating, fostering a more competitive market for renewable gases. Additionally, the directive ensures stable tax revenues for EU member states from renewable energy production, which could further incentivise investments in renewable gas infrastructure. CooCE's biomethane, whether in LNG or CNG form, currently benefits from energy tax exemptions as a biofuel when used in the aviation and maritime sectors, potentially increasing its uptake in these industries. Yet, concerns persist that the introduction of taxes based on energy content and environmental performance could complicate the taxation system, making uniform implementation across the EU challenging due to differences in energy and economic conditions. There is also criticism that the directive may not go far enough in promoting renewable technologies, as lower taxes on certain fossil fuels, although reduced, could still slow down the transition to cleaner energy sources.

Climate Law (EU Regulation 2021/1119)

This is the foresmost piece of legislation aimed at enabling the EU to achieve the Green Deal's goal of net zero greenhouse GHG emissions by 2050, setting a legally binding target with an intermediate goal of reducing emissions by at least 55% by 2030 compared to 1990 levels, andit includes a process for establishing a 2040 climate target. The legislation also mandates regular progress monitoring, with reviews every five years (EUR-lex, 2024b). The 2023 progress report revealed that despite progress, the EU is not currently on track to meet its 2030 target of removing 310 million tonnes of CO_2 per year (EC, 2024b). Member states are required to take all necessary measures to meet these targets, including detailing their strategies in their integrated National Energy and Climate Plans (NECP), as outlined in the Regulation on the Governance of the Energy Union (EU Regulation 2018/1999, EUR-lex, 2024c). These ten-year plans cover the period 2021-2030 and address five key energy dimensions: decarbonisation, energy efficiency, energy security, the internal energy market, and research, innovation, and competitiveness. Member states were obligated to submit their updated NECPs, reflecting the EC's assessments and recommendations, by the end of June 2024. Denmark, Greece, and Italy have already submitted their final NECPs, while the UK's departure from the EU in January 2020 eliminated the need for a submission.

Assessment: this regulation acknowledges CCUS as one of the tools that will help achieve its targets, especially for hard-to-abate sectors such as heavy industry and long-haul transport. Through its capture of CO_2 for subsequent storage into finished bioproducts (e.g., biomethane, biosuccinic acid and biopolymers), the CooCE concept stands to make an important contribution to overall efforts by the EU at meeting the reduction and removal targets set in the Climate Law.

REPowerEU (COM 2022/230)

This plan was adopted by the EC in 2022 to reduce the EU's reliance on fossil fuels from Russia, following the energy market disruption caused by the war in Ukraine. It generally aims to accelerate the transition to renewable energy sources (EUR-Lex, 2024d; EC, 2024c). The plan focuses on saving energy by reducing gas consumption, diversifying energy supplies with more wind and solar power, and increasing the production of clean energy through expanded renewable installations. It also introduced amendments to legislation already under revision as part of the 'Fit-for-55' package, such as RED III.

Assessment: this instrument has no significant impact on CooCE since the concept entails capturing CO_2 from existing emitters in various sectors (e.g., biogas and industrial sources) across the EU for subsequent storage into finished bioproducts. It will therefore contribute to efforts to meet targets for reducing and removing GHGs from the atmosphere as set in key EU instruments (e.g., *Climate Law, Methane Regulation, Industrial Emissions Regulation, Renewable Energy Directive*).

TEN-E regulation (EU Regulation 2022/869)

This long-standing policy focuses on planning cross-border and trans-European energy infrastructure, aiming to connect energy networks across the EU and promote greater cohesion and collaboration. Its main objectives are to eliminate bottlenecks in the EU energy infrastructure, ensure energy security, facilitate the integration of increasing shares of renewable energy, promote stronger market integration among EU countries, and boost competitiveness. The directive was recently updated to establish a legal framework supporting the expansion of electricity grids within and beyond Europe, coming into effect in June 2022 (EUR-lex, 2024e). Key measures in the revised regulation include: new and updated categories of energy infrastructure and redefined priority corridor areas; dedicated offshore grid planning to enable the expansion of offshore projects; support for hydrogen, electrolysers, and local low-carbon and renewable gases; a requirement for all projects to meet mandatory sustainability standards; improved regulatory and permitting processes to speed up the implementation of projects of common and mutual interest; and enhanced cross-sectoral energy infrastructure planning, including cooperation between EU and non-EU countries.

Assessment: the revised regulation is significant for CooCE as it includes provisions for biogas and biomethane projects, which can benefit from EU funding for infrastructure development, such as pipelines and storage facilities, enabling access to broader energy networks. Projects that connect production in one EU country to consumption in another may qualify for "Project of Common Interest" (PCI) status, which facilitates easier permitting and funding access. By supporting the integration of biogas and biomethane into the EU's existing gas networks, the regulation provides producers with opportunities to reach wider markets and expand their operations by linking to transnational grids. Nevertheless, the regulation could better prioritise renewable gases to ensure a more level playing field with natural gas and to increase support for renewable gas infrastructure. Although the permitting process has been streamlined, smaller biogas producers might find it difficult to benefit if the process remains slow or if they cannot meet the criteria for EU funding. The emphasis on transnational networks might also limit the involvement of smaller producers focused on local markets in key infrastructure developments. There is also concern that investment in gas infrastructure could favor fossil-based gases over renewable ones, potentially leading to stranded assets. Finally, the regulation's focus on large energy corridors and urban connections may overlook the infrastructure needs of rural areas, restricting rural producers' ability to connect to broader energy grids or participate in cross-border markets.

The Renewable Energy Directive – RED III (EU Directive 2023/2413)

This revised instrument provides the legal framework for promoting clean energy across all sectors of the EU economy. The original directive (RED I, 2009/28) was the first EU legal instrument aimed at promoting renewable energy use, establishing binding national targets for member states regarding the share of renewable energy in total energy consumption across sectors, including a sub-target for renewable energy in transport. Its primary objective is to mandate and encourage the transition from fossil fuels to renewable energy. The directive limits the use of crop-based biofuels and prioritises biofuels derived from materials listed in Part A of Annex IX, making them eligible to count towards national targets. Member states use these materials to determine support levels for various biofuels within their national frameworks. The list of materials is reviewed every two years, but items already listed cannot be removed before 2030. The directive was amended in 2018 (RED II) and again in 2023 (RED III). The most recent version, which came into force in November 2023, sets a new binding target for renewable energy of at least 42.5% by 2030 (up from 32% in 2018), with member states encouraged to aim for a collective target of 45% (EUR-lex2024f). Member states must transpose the directive into national law by May 2025. The revised directive also aims to help the EU achieve an annual biomethane production target of 35 bn cubic meters by 2030.

In the transport sector, the directive has shifted support away from crop-based biofuels towards advanced fuels and non-biogenic renewable sources. The new target under RED III for renewable energy use in transport (including renewable fuels and electricity) is at least 29% by 2030, or a greenhouse gas intensity reduction of at least 14.5% by 2030 (EUR-lex2024f). Additionally, the combined share of advanced biofuels, biogas from Annex IX Part A feedstocks, and renewable fuels of non-biological origin must be at least 1% by 2025 and 5.5% by 2030 (EUR-lex2024f). These targets are binding only at the EU level, allowing member states to determine their national contributions in their National Energy and Climate Plans (NCEPs), which were approved by the European Commission in 2023. For transportation energy targets, member states had the option to reduce their reliance on crop-based biofuels by lowering the cap below the 7% limit. However, the final energy consumption cannot be lower than the baseline national targets set for 2023, which become enforceable upon the directive's transposition.

Assessment: CooCE's technological innovation involves upgrading CO_2 to produce biomethane, a biofuel that can be used as a liquid fuel (similar to LNG), offering a promising alternative for shipping, or as compressed gas (equivalent to CNG) for use in road haulage and other vehicles. Additionally, CooCE's biomethane can, in principle, be injected into existing natural gas grids without modification. As a result, CooCE's biomethane may contribute to EU national renewable energy and GHG intensity reduction targets, provided it complies with the biomass types or sources specified in Part A of Annex IX (e.g., agricultural residues, animal manure, landfill waste). The revised EU targets for increasing annual biomethane production by 2030 should drive demand and attract investment in production. The directive also reinforces sustainability criteria for biomethane production, encouraging producers to adopt advanced technologies and processes to meet these standards, such as using waste and residues to avoid land use change and environmental degradation. However, smaller biomethane producers may face challenges in meeting these sustainability criteria due to the administrative and financial burden, as upgrading to more efficient technologies might be unaffordable without financial assistance. By calling for the streamlining of permitting procedures and the creation of 'renewables acceleration areas' that prioritise biomethane production, RED III aims to address administrative delays and facilitate faster deployment of biomethane infrastructure. Nevertheless, insufficient investment in infrastructure for biomethane injection may limit small producers, particularly in rural areas, from distributing their biomethane efficiently and cost-effectively.

Energy Efficiency Directive (EU Directive 2023/1791)

This directive, originally enacted in 2012, aims to improve energy efficiency across the EU by setting a cap on total EU energy consumption and outlining measures to help member states collectively meet this target. The directive was last revised in 2023 and came into effect later that year (EUR-lex, 2024g), expanding the EU's energy efficiency goals. Member states are required to transpose the revised provisions into national law within two years. The updated directive introduces new measures to accelerate energy efficiency by applying the "energy efficiency first" principle, which ensures that only the necessary amount of energy is produced, prevents investment in stranded assets, and promotes cost-effective energy demand management. The revision strengthens the legal framework for applying this principle, requiring member states to consider energy efficiency in all relevant policy and major investment decisions across both energy and non-energy sectors. To achieve these goals, the directive sets a legally binding target to reduce the EU's final energy consumption by 11.7% by 2030, compared to 2020 levels. Each member state is required to determine its own indicative national contribution, taking into account its national context. Additionally, the directive mandates an increase in annual energy savings, from 1.3% in 2024-2025 to 1.9% starting in 2028, with an overall average of 1.49% annual savings during this period (EUR-lex, 2024g).

Assessment: CooCE's technologies fall within the scope of this directive as they have the potential to contribute to the revised binding targets for reducing overall energy consumption across various sectors. This includes transportation, through the use of biomethane produced from biogenic gas, and electricity, by injecting biomethane into the grid via existing infrastructure.

Carbon Border Adjustment Mechanism (CBAM) – EU Regulation 2023/956

This instrument is designed to prevent 'carbon leakage,' which occurs when EU-based companies shift carbon-intensive production to countries with less stringent climate policies or when carbon-intensive imports replace EU products. The mechanism ensures that the carbon cost of imports matches that of domestic production by applying fair carbon pricing to emissions generated during the production of carbon-intensive goods entering the EU. It also encourages cleaner industrial practices in non-EU countries. The instrument came into effect in May 2023, with a transitional phase starting in October 2023 (running until 2025), targeting imports of carbon-intensive goods such as cement, iron and steel, aluminum, fertilisers, electricity, and hydrogen, all of which have a high risk of carbon leakage due to their production processes. During the transitional phase, companies can choose from three reporting methods until the end of 2024: full reporting according to the new EU methodology, reporting using an equivalent method, or reporting based on default reference values. From January 2025, only the EU methodology will be accepted, and the mechanism will be fully operational under its definitive regime starting in 2026 (EUR-lex, 2024h).

Assessment: This instrument is relevant to CooCE as it may enhance market incentives and funding opportunities for scaling up its renewable energy technologies, such as the upgrading of biogas into biomethane, to replace imported fossil fuels. It also supports CooCE's chemical platform for producing biosuccinic acid and PHAs/PHBs as alternatives to their fossil-based counterparts. Additionally, the mechanism could promote cross-border projects and collaborations with non-EU countries, fostering greater alignment on climate policies and expanding export opportunities for CooCE's technologies and products, thereby increasing their impact on reducing emissions. However, CooCE's involvement in sectors regulated by the mechanism, such as energy-intensive industries or goods subject to carbon pricing, may lead to additional administrative and compliance costs, including those related to monitoring and reporting emissions for imported goods or services. Despite these challenges, the instrument is favorable to CooCE as it rewards low-carbon innovation, aligning well with the concept's advanced technologies.

Gas Directive (EU Directive 2024/1788)

This instrument was first introduced in 2009 as part of a legislative framework for the EU's internal energy market. Its revision began in 2021, aiming to transform the energy market into one focused on hydrogen and decarbonised gases, with the updated framework coming into effect in 2024 (EUR-lex, 2024i). The revised gas directive introduced significant changes across ten chapters and 90 articles, including: expanding the scope and definitions to incorporate renewable gases and hydrogen as integral components of the future gas market; establishing rules to ensure competitive, consumer-oriented, flexible, and non-discriminatory gas markets, including sustainability and certification standards for renewable and low-carbon gases, which are expected to take a larger share of the internal market; extending EU gas market principles, such as third-party access, unbundling of transmission and distribution system operators, and independent regulatory authorities, to include hydrogen and renewable gases; and capping long-term contracts for unabated fossil fuel gas by 2049 to ensure the EU meets its 2050 climate neutrality goals. The directive also enhances coordination between network development plans for hydrogen, electricity, and natural gas.

Assessment: This instrument is highly relevant to CooCE's renewable gas (biomethane) produced from upgrading CO_2 from biogenic sources, as it is likely to expand and strengthen the gas market where CooCE's biomethane is traded and consumed. The non-discriminatory access to gas infrastructure for renewable gas producers creates new opportunities for biogas producers to integrate their products into the EU gas grid, supporting the transition away from fossil fuels. Clearer rules on grid connections will simplify the process for biogas producers, making market participation easier. The introduction of a certification system for renewable gases will require biogas production to comply with the directive's sustainability and emissions standards aimed at reducing greenhouse gases. Additionally, the EU's investment in repurposing natural gas infrastructure to accommodate renewable gases should lower costs for biogas producers and facilitate wider distribution. The phase-out of long-term contracts for unabated fossil gas by 2049 is likely to boost demand for renewable alternatives, creating a growing market for biogas. Overall, the directive may help establish a more favorable regulatory framework, supporting market expansion, enhancing energy security, and promoting sustainability.

Gas Regulation (EU Regulation 2024/1789)

This instrument, initially introduced in 2009 as part of the legislative framework for the EU's internal energy market, has been revised since 2021 as part of the hydrogen and decarbonised gas markets package (EUR-lex, 2024j). The revised regulation consists of five chapters and 69 articles, sharing similarities with the updated Gas Directive. These include expanding the scope and definitions to incorporate renewable gases and hydrogen as essential components of the future gas market and integrating hydrogen and renewable gases into EU gas market principles, such as third-party access, the unbundling of transmission and distribution system operators, and independent regulatory authorities. New measures include a 75% tariff discount for the injection of hydrogen and renewable gases into the gas grid, new rules on capacity for hydrogen and renewable gases, hydrogen blending with other gases, and cross-border coordination on gas quality. The regulation also introduces the development of a comprehensive legal framework for EU cross-border hydrogen networks, the establishment of the European Network of Network Operators for Hydrogen, and a push for increased biomethane production. The revised regulation came into force in June 2024.

Assessment: similar to the Gas Regulation, this instrument facilitates biomethane producers' access to gas infrastructure for injecting their biomethane into the gas grids. However, it does not fully address concerns regarding the prohibitive cost of network access for biomethane producers. Implementing cost-sharing measures with gas operators could help alleviate the financial burden on producers, thereby supporting the expansion of the biomethane market.

Methane Regulation (EU Regulation 2024/1787)

This instrument is part of the 'Fit-for-55' package and is designed to reduce methane emissions from the energy sector. In 2021, the European Commission proposed regulations targeting methane emissions in sectors such as oil, fossil gas, coal, and biomethane after it has been injected into the gas network. The regulation establishes standards for measuring, reporting, and verifying methane emissions in the energy sector. It aims to reduce emissions rapidly through mandatory leak detection and repair, along with a ban on venting and flaring. Key measures for member states include: mandatory measurement, reporting, and verification of methane emissions from energy activities and infrastructure; mandatory detection and repair of leaks across all fossil gas infrastructure, as well as other infrastructure involved in the production, transport, or use of fossil gas, including as a feedstock; legislation to eliminate routine venting and flaring across the entire energy supply chain, from production onwards; and expanding the Oil and Gas Methane Partnership framework to include companies involved in gas and oil upstream, midstream, and downstream activities, as well as the coal sector and abandoned sites. The regulation took effect in June 2024 (EUR-lex, 2024k).

Assessment: this instrument is highly relevant to CooCE, as it imposes stricter requirements for monitoring, reporting, and verifying emissions related to the upgrading of biogas into biomethane. It also mandates more frequent leak detection and repair for facilities that deal with methane, including those involved in the production, transportation, and storage of biogas or biomethane. These requirements may result in additional operational costs for CooCE implementers, particularly for detecting and repairing infrastructure such as pipelines and storage facilities. However, these compliance costs could be offset by potential EU funding or technical assistance aimed at supporting low-emission technologies and infrastructure, for which CooCE implementers may be eligible. Additionally, the regulation is expected to drive demand for biogas and biomethane, thereby improving CooCE's prospects in the renewable gas sector.

4.4.2 Policy Area: Industry and Transport and Mobility

Industrial Emissions Directive (EU Directive 2024/1785)

This EU instrument, which regulates industrial pollutant emissions, was first introduced in 2010 and revised in 2021 to align with the goals of the EU Green Deal. The revision raises the threshold for including livestock farms to 350 livestock units for cattle and pigs, 280 for poultry, and 350 for mixed farms, while excluding cattle farming from its scope. It strengthens permit issuance requirements and tightens regulations on breaches, setting a minimum fine of 4% of the operator's annual turnover in the EU. Additionally, the directive allows affected parties to seek compensation. Companies are also required to include transformative plans in their environmental management systems, outlining their contributions to a circular and climate-neutral economy by 2050. The rules for livestock farming will be applied progressively, starting with large farms in 2030, and member states must establish e-permitting systems by 2035. The revised directive came into force in April 2024 (EUR-lex, 2024l).

Assessment: This instrument introduces stricter limits on pollutant emissions and harmful substances, and it is relevant to CooCE as it applies to industrial processes and energy production activities, such as biogas or biomethane plants, which are integral to its technological processes (e.g., upgrading biogas to biomethane and its storage). The directive mandates the use of the most efficient technologies and processes for emissions control, potentially leading to additional costs for installing new pollution control systems, modifying existing operations, or adopting cleaner production methods. The CooCE concept aligns with the directive's focus on resource efficiency and circular economy principles, enhancing waste-to-energy processes and supporting sustainable practices.

Net-Zero Industry Act (COD 2023/0081)

This instrument was proposed by the European Commission in 2023 as part of the Green Deal industrial plan to accelerate the deployment of net-zero energy technologies necessary for achieving the EU's 2030 and 2050 climate goals and to strengthen the resilience of its energy system. It seeks to increase the EU's manufacturing capacity for net-zero technologies to meet at least 40% of the EU's annual deployment needs, while also setting a target for annual CO2 injection capacity of 50 million tonnes by 2030. The act came into force in June 2024 (EUR-lex, 2024m).

Assessment: As CooCE involves renewable energy production, implementers stand to benefit from the provisions outlined in this policy, such as streamlined permitting processes, financial incentives, and priority status, which could help accelerate scaling efforts. This policy also grants CooCE implementers access to grants, loans, or subsidies aimed at advancing technologies that support the EU's net-zero goals, as well as opportunities for investment through Net-Zero Industry Academies that provide upskilling, and project support aligned with these objectives. However, the policy places a strong focus on scaling up established technologies such as wind and solar, potentially increasing competition for financial resources, leaving smaller producers such as CooCE at a disadvantage. Moreover, the policy prioritises projects that can scale rapidly and make significant contributions to the EU's net-zero goals. For CooCE implementers working on a smaller, localised model, this may create pressure to expand beyond the project's original scope to meet support eligibility criteria, potentially straining resources and affecting productivity and efficiency.

REACH (EU Regulation 2022/586)

The REACH was introduced in 2007 to protect human health and the environment from the risks posed by chemicals, promote alternative testing methods, and ensure the free movement of substances within the internal market, while fostering competitiveness and innovation. REACH places the responsibility on industry to assess and manage chemical risks and provide relevant safety information to users. Additionally, the EU can implement further measures for highly hazardous substances to supplement actions at the EU level. In 2016, the European Commission launched a REFIT (Regulatory Fitness and Performance Programme) initiative to review REACH, with a report in 2018 identifying areas for improvement, including: increasing knowledge and management of chemicals across the supply chain by urging manufacturers to provide updated information and improve the quality of safety data sheets; enhancing risk management, simplifying authorisation requests, improving the restriction process, and applying the precautionary principle; aligning with worker protection and waste legislation; strengthening enforcement; and supporting SMEs in complying with REACH. The latest revision of REACH, covering several substances, took effect in April 2022 (EUR-lex, 2024n), with further revisions expected in the near future (EC, 2024d).

Assessment The revised regulation on the restriction and authorisation of chemicals classified as substances of extremely high concern does not apply to CooCE's production of biosuccinic acid, as this bio-based building block is used in various sustainable chemicals and materials, ensuring compliance with the regulation. Bio-PHAs, in turn, are produced through microbial fermentation, employing biotechnological processes that avoid hazardous chemicals, and downstream processing, such as purification, also excludes the use of restricted substances. As a subset of bio-PHAs, bio-PHBs are biodegradable polymers with applications in industries such as plastics, packaging, textiles, and coatings, and typically avoid the use of harmful chemicals that pose risks to human health and the environment. The bio-based nature of these substances makes them safer and less toxic alternatives to fossil-derived chemicals, aligning with the regulation's objectives to reduce the risks associated with chemical substances, which may provide a competitive edge in the EU chemicals market.

ReFuelEU Aviation (EU Regulation 2023/2405)

This instrument establishes EU-wide harmonised rules for sustainable aviation fuels (SAF) applicable to fuel suppliers and airline operators (EC, 2024e; EUR-lex, 2024o). It sets targets for SAF and synthetic aviation fuels from 2025 to 2050, requiring fuel suppliers to progressively blend higher levels of SAF, including synthetic low-carbon fuels, into the jet fuel supplied at EU airports. The regulation mandates fuel suppliers to provide an increasing share of sustainable aviation fuels at EU airports and aims to address fuel tankering practices, where more fuel than necessary is loaded at airports with cheaper prices, which increases aircraft weight and emissions. The regulation promotes fair competition among air transport operators and helps reduce emissions. Fuels must be certified for sustainability in accordance with the RED III and feed and food crop-based aviation biofuels are excluded from the targets. The regulation directly binds obligated parties, and member states must enforce strict penalties for non-compliance. The instrument came into force in early 2024, but some provisions will take effect in early 2025, when fuel suppliers must ensure that all fuel provided to aircraft operators at EU airports contains a progressively increasing minimum SAF share. The targets include at least 2% SAF by 2025, 6% by 2030, 20% by 2035, 34% by 2040, 42% by 2045, and 70% by 2050. Additionally, synthetic fuels must make up 35% of the fuel mix by 2050 (EUR-lex, 2024o).

Assessment: although biomethane is not classified as a direct SAF under this regulation, it could play a crucial role in supporting the aviation sector's broader decarbonisation goals. CooCE's biomethane could be utilised as a feedstock in the production of synthetic fuels through power-to-liquid or gas-to-liquid processes, where it can be converted into syngas and subsequently synthesised into sustainable aviation fuels. The regulation is expected to increase demand for renewable energy sources and feedstocks for SAF production, and biomethane, with its low-carbon profile, is a highly attractive option for integration into various renewable energy systems. It can be supplied as a renewable gas or converted into liquid form for use in SAF production. Additionally, biomethane can be reformed into green hydrogen, another potential feedstock for SAF. Biomethane producers may also benefit from access to funding, subsidies, and incentives aimed at expanding the supply of renewable feedstocks for aviation fuel production.

FuelEU Maritime (EU Regulation 2023/1805)

This regulation establishes a common EU framework to increase the use of renewable and synthetic low-carbon fuels in international maritime transport, aiming to reduce GHG emissions from the shipping sector (EUR-lex, 2024p). Key provisions include: a gradual reduction in the GHG intensity of fuels used by the shipping sector, with targets set at 20% by 2035, 38% by 2040, 64% by 2045, and up to 80% by 2050; a special incentive regime to promote the adoption of renewable fuels of non-biological origin, which have a high decarbonisation potential; the exclusion of fossil fuels from the certification process; and a voluntary pooling mechanism, allowing ships to combine their compliance balances with others, provided the pool meets the average GHG intensity limits. Revenues generated from the regulation's implementation will be directed toward decarbonisation projects in the maritime sector, with an enhanced transparency mechanism. The regulation is binding on ship operators and applies to all energy used by ships at EU ports of call and for voyages between EU ports. It came into force in September 2023.

Assessment: under this regulation, CooCE's renewable and low-carbon biomethane could support the maritime sector in meeting its targets for reducing the carbon intensity of marine fuels, providing a market incentive for ship operators to incorporate biomethane into their fuel mix. Biomethane can be used directly or converted into liquefied biomethane, offering a cleaner alternative to LNG, with the advantage of integrating into existing LNG bunkering infrastructure without significant retrofitting. Additionally, biomethane can be blended with other renewable gases, such as hydrogen or ammonia, to help meet the regulation's carbon intensity reduction goals. However, for biomethane to be used as a maritime fuel, it must comply with the sustainability criteria outlined in the regulation, including verification that it is produced from renewable sources and achieves substantial GHG emissions reductions. Compliance will require the establishment of certification schemes. Scaling biomethane production remains a challenge, and its widespread use as a maritime fuel will necessitate significant expansion of production capacity and distribution infrastructure. Furthermore, the regulation does not provide clear guidance on prioritising biomethane over other fuels such as hydrogen and ammonia. Without robust financial support or effective carbon pricing mechanisms, the higher production cost of biomethane compared to fossil-based LNG may discourage its adoption in the maritime sector.

4.4.3 Policy Area: Agriculture

Common Agricultural Policy (EU Regulation 2024/1468)

The CAP, established in 1962, has been a cornerstone of the EU's agricultural strategy (EC, 2024f). It is a comprehensive policy designed for all EU member states, with the goals of supporting farmers, increasing agricultural productivity, ensuring a decent income for farmers, addressing climate change, sustainably managing natural resources, preserving rural landscapes, and promoting rural employment in farming, the agri-food industry, and related sectors. CAP includes key measures such as income support for farmers, regulation of agricultural product marketing, and rural development initiatives. In its 2021 revision, CAP was aligned more closely with the EU's Green Deal objectives, introducing national CAP Strategic Plans, which allow each member state to tailor the implementation of CAP instruments, including direct payments, rural development, and sectoral interventions. CAP aims to foster a smart, resilient, and diversified agricultural sector to secure food supplies, improve environmental care and climate action, and strengthen the socio-economic fabric of rural areas. The policy's goals are further divided into nine specific objectives focused on economic, environmental, and social sustainability: ensuring a fair income for farmers, boosting competitiveness, balancing power in the food supply chain, taking climate action, promoting environmental care, preserving landscapes and biodiversity, supporting generational renewal, maintaining vibrant rural areas, and ensuring food and health quality. Recent revisions to CAP also included updates to the nine good agricultural and environmental condition standards. The updated policy came into effect in May 2024 (EUR-lex, 2024q).

Assessment: CooCE aligns with this policy as its proposed biofuel, biomethane, will be produced by upgrading biogas generated from various agricultural feedstocks such as animal manure, crop residues, and organic waste. Biogas production from agricultural waste supports the policy objectives of reducing GHG emissions, promoting renewable energy, and advancing circular farming practices, making producers eligible for financial incentives, grants, or payments from eco-schemes. Yet, a noted limitation of the CAP is that it does not prioritise biogas production from agricultural waste over dedicated energy crops, raising concerns about land use and sustainability. These include issues such as monoculture leading to soil degradation, competition between food and energy crops, and subsidies that may disproportionately benefit large-scale industrial farming over smaller farms.

Land Use, Land Use-change and Forestry Regulation- LULUCF (EU Regulation 2023/839)

This instrument, introduced in 2018, aims to include GHG emissions and removals from land use, land-use change, and forestry (LULUCF) within the 2030 climate and energy framework for the period 2021-2030. It establishes a binding commitment for EU member states to ensure that any accounted GHG emissions from land use, land-use change, or forestry are fully offset by an equivalent removal of CO2 from the atmosphere during the same period, following the "no debit rule" (where GHG emissions cannot exceed GHG removals in the sector). Though recently revised, the core measures from the original legislation, including the "no debit rule," remain unchanged. The revision applies to two periods: 2021-2025 and 2026-2030. In the latter period, the regulation broadens its scope to include all managed land and introduces an EU-wide net removals target for 2030, aiming to boost the EU's net removals by approximately 15% and reverse declining trends. It also simplifies compliance by shifting from accounting benchmarks to using reported emissions and removals, supported by advanced monitoring technologies such as geographical data and remote sensing. The revised regulation came into effect in April 2023 (EUR-lex 2024r).

Assessment: CooCE aligns with the regulation as its biomethane is produced by upgrading biogas sourced from agricultural waste, thus avoiding the challenges linked to biogas from dedicated energy crops, such as land use change, competition for feedstocks, and reduced biodiversity. The regulation's relevance to CooCE lies in its overarching goals of reducing carbon emissions and promoting sustainable land use practices. However, a key concern is that the regulation may unintentionally discourage waste-based biogas production due to unclear guidelines on feedstock eligibility and land use, potentially leading to the misclassification of agricultural residues or waste streams. This creates uncertainty for biogas producers focused on circular, waste-based production.

4.4.4 Policy Area: Environment

Nature Restoration Law (EU Regulation 2024/1991)

This landmark piece of legislation is the first comprehensive, continent-wide EU law for addressing biodiversity loss and restoring degraded ecosystems across the EU, being a key element of the *Biodiversity Strategy*. Key aims are: restoration of degraded ecosystem terrestrial, freshwater, and marine habitats through binding targets (20% of the EU's land and sea areas by 2030 and all ecosystems in need of restoration by 2050); enhance biodiversity, by restoring natural habitats and promoting species recovery across the EU through improving the condition of natural areas, supporting wildlife and enduring long-term ecosystem health; mitigate climate change: restoration of ecosystems (e.g. wetlands; forests; peatlands) to enhance natural carbon sinks that are crucial for absorbing CO_2 thus mitigating the impacts of climate change and contributing to climate adaptation by improving ecosystem resillience against extreme weather events; promote sustainable land use by encouraging the sustainable use of land and resources, promoting practices that support biodiversity while also reducing GHG emissions from land use; support green jobs and economy in conservation, ecosystem management, and nature-based tourism, as well as promoting the adoption of sustainable practices (e.g. agriculture; forestry). This law sets legally binding restoration targets for restoration of various ecosystems (e.g. forests, agricultural lands, wetlands, rivers, marine areas) that member states must meet by understanding specific actions detailed in their National Restoration Plans. It came into force in June 2024 (EUR-lex, 2024s1; EC, 2024k).

Assessment: this regulation is relevant to CooCE at it impacts on its value chain upstream, that is, at the level of feedstocks used for producing the biogas that CooCE capture and processing technologies will upgrade to biomethane, which will also have implications downstream for further bioproducts (e.g., biosuccinic acid and bioplastics). Specifically, biomethane production that depends on agricultural residues or biowaste could be affected by land use restrictions and requirements to restore ecosystems, so producers will need to ensure that feedstock sourcing does not interfere with biodiversity restoration goals. There is concern that restrictions on the use of land for agricultural purposes could make it harder to source sufficient residues, leading to increased competition for available feedstocks, driving up costs for producers ultimately reducing the potential for biomethane to contribute to the EU's renewable energy and climate targets, whereas, instead, the law should provide more incentives or recognition for renewable energy production that helps reduce waste and supports climate action, rather than imposing limitations on feedstock availability. Moreover, the law creates a conflict between environmental restoration goals and the EU's circular economy objectives, which could be resolved by recognition of use of agricultural residues for energy as a sustainable practice that aligns as a sustainable practice with both the circular economy and climate mitigation efforts.

The Emissions Trading Scheme: ETS- I (EU Directive 2023/959)

A cornerstone of the EU's climate policy, the ETS is a key tool for reducing GHG emissions (e.g. carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride) in a cost-effective manner. The ETS remains the world's first major carbon market and is the largest multi-country, multi-sector GHG emissions trading system globally. It operates on a "cap and trade" principle, which sets a limit on total emissions allowed by all participants, converted into tradable emission allowances. Each allowance permits the emission of one tonne of CO_2 equivalent. Companies can trade these allowances as needed. Participants must monitor and report their annual emissions and surrender sufficient allowances to cover their output. Revenues from the ETS primarily flow into national budgets, where member states use them to support investments in renewable energy, energy efficiency, and low-carbon technologies that further reduce emissions. The sale of allowances also funds low-carbon innovation and the energy transition within the EU. Established in 2005, the ETS covers around 45% of EU greenhouse gas emissions and operates in phases, currently in its fourth phase (2021-2030). Over the years, the directive has been revised to align with the EU's broader climate goals. The latest revision began in 2021 to adjust the ETS in phase 4 to meet the European Climate Law's 2030 target of reducing net emissions by 55%. This revision lowered the emissions cap, extended coverage to new sectors, and improved the ETS's overall functionality. Key updates include a tighter emissions cap, a more ambitious linear reduction factor, revised rules on free allocation of allowances and market stability, the inclusion of maritime transport, and the creation of a new ETS for buildings and road transport. The revised directive, effective from 2023 (EUR-lex, 2024s), aims to cut emissions in covered sectors by 62% from 2005 levels by 2030. The linear reduction factor was set to 4.3% annually from 2024 to 2027, increasing to 4.4% from 2028. Additionally, the overall emissions ceiling will decrease by 90 million allowances in 2024 and by 27 million in 2026. From 2024, the ETS will cover maritime transport emissions, requiring shipping companies to surrender allowances for 40% of verified CO2 emissions, rising to 70% in 2025 and 100% in 2026. Member states with over 15 shipping companies per million inhabitants will receive 3.5% of the additional allowances due to the cap increase for maritime transport (EUR-lex, 2024s2).

Assessment: this directive is particularly relevant to CooCE's proposed biomethane, which can be utilised as a liquid fuel or compressed gas for transportation (in both shipping and road transport) and it can also be injected into the natural gas grid. Since biomethane is derived from biogas, the directive's stricter carbon pricing may drive increased production and consumption of biogas and its upgrading to biomethane, as these serve as cost-effective alternatives to fossil fuels. Additionally, the directive prioritises biogas produced from waste or residues, creating opportunities for businesses in the agricultural and forestry sectors to reduce methane emissions and generate additional revenue through the sale of biogas or carbon credits. Nevertheless, concerns exist that the lack of specific support measures for biogas (e.g., subsidies or guaranteed purchase prices) under the directive may limit the potential for biogas production. Furthermore, the directive alone may not provide sufficient market stability for biogas producers, underscoring the need for more predictable and stable financial incentives to encourage long-term investments in the sector.

The Emissions Trading Scheme: ETS-II (EU Regulation 2023/957)

This new 'cap-and-trade' mechanism is designed to reduce GHG emissions in road transport, buildings, and additional sectors, particularly smaller industries not covered by ETS-I (EUR-lex, 2024t). It requires fuel suppliers to monitor and report their emissions, as well as to surrender sufficient allowances to cover those emissions and disclose ETS costs passed on to consumers. The ETS2 cap aims to reduce emissions by 42% by 2030 compared to 2005 levels, with a linear reduction factor set at 5.1% from 2024 and 5.38% from 2028. Emissions monitoring and reporting will begin in 2025, and the scheme will become fully operational in 2027, when a 30% increase in allowance volumes will be auctioned to ensure market liquidity.

Assessment: this new regulation extends the ETS-I to additional sectors, including transportation, making it highly relevant to CooCE, as its proposed biomethane can serve as a low-carbon transportation fuel to replace diesel and natural gas, meeting the increasing demand from transport fleets, trucks, and public transport systems. A key advantage of CooCE's biomethane is that it is upgraded from biogas produced from agricultural and organic waste, meeting the sustainability criteria outlined in the regulation. But, as with the ETS-I, the regulation needs to establish more stable pricing mechanisms to allow renewable energy producers to plan for long-term business growth. Additionally, smaller producers may face challenges in securing the necessary financing to upgrade infrastructure and meet rising market demand.

Effort Sharing (EU Regulation 2023/857)

This regulation sets annual binding GHG emission reduction targets for each member state in sectors not covered by ETS I, including domestic transport (excluding aviation), buildings, agriculture, small industry, and waste. These sectors account for nearly two-thirds of the EU's total emissions. The regulation was last revised in 2023, establishing new targets for member states to collectively achieve a 40% reduction in emissions compared to 2005 levels. The targets for CooCE countries (excluding the UK) starting in 2023 are as follows: Greece, -50%; Italy, -22.7%; and -43.7% (EUR-lex, 2024u).

Assessment: CooCE is well-aligned with this regulation, as its proposed biomethane will be obtained from upgrading biogas produced from agricultural and organic waste, helping to reduce emissions in line with the regulation's objectives. Additionally, since CooCE's biomethane can serve as a low-carbon transportation fuel, it can further contribute to emissions reductions in that sector. This regulation may therefore stimulate demand for biogas and biomethane and drive growth in the sector, with waste-based biogas playing a key role in compliance. However, a concern is that the criteria for setting national targets (e.g., GDP and cost-efficiency) create inconsistencies in ambition levels across EU countries, leading to a fragmented biogas and biomethane market and disparities in the provision of incentives, with some member states offering stronger support to producers than others. The lack of harmonised support mechanisms across the EU may make it difficult for producers to scale operations across borders. Another issue is the potential competition for organic feedstocks (such as agricultural residues and waste) between biogas and other renewable energy technologies or industries, which could increase costs for biogas production. Finally, the regulation's lack of clear long-term investment prospects may discourage investors and producers from scaling up operations.

Emission Performance Standards (EU Regulation 2023/851)

This regulation establishes CO2 emission performance standards for new passenger cars and light commercial vehicles. Originally introduced in 2019, it was revised in 2021 to further reduce CO2 emissions from cars and vans, supporting the EU's 2030 and 2050 climate objectives. The revision aims to promote the deployment of zero-emission vehicles, improve air quality, increase energy savings, reduce vehicle ownership costs, boost innovation in zero-emission technologies, strengthen the EU's technological leadership in the automotive sector, and create jobs. The revised targets are more ambitious for the EU fleet-wide average CO2 emissions from new cars and vans. By 2035, emissions from new vehicles registered in the EU must be reduced by 55% for passenger cars and 50% for vans, with a goal of achieving 100% reduction by 2035 (meaning zero emissions from all new vehicles). Incentives for zero- and low-emission vehicles will end in 2030, except for manufacturers registering fewer than 1,000 new vehicles, who can apply for derogations. Derogations for manufacturers with larger fleets (between 1,000-10,000 cars or 1,000-22,000 vans) will expire in 2029. Starting in 2024, manufacturers can voluntarily report vehicles' lifecycle CO2 emissions, with mandatory reporting beginning in 2028. The revised regulation came into force in April 2023 (EUR-lex, 2024v).

Assessment: although vehicle manufacturers are the primary focus of this regulation, it is relevant to CooCE as it promotes the adoption of low-carbon renewable fuels such as CooCE's proposed biomethane, which can be used as a liquid fuel or compressed gas, particularly for heavy-duty transport. The regulation may also encourage more decentralised renewable fuel production, such as the expansion of biogas facilities in rural and agricultural areas, to supply biomethane for local transport fleets. Biogas producers may find a niche market in the heavy-duty vehicle sector, including trucks and buses, where electrification is more challenging, positioning biomethane as an immediate, scalable solution. However, the regulation is perceived to place too much emphasis on electrification at the expense of alternative fuels such as biomethane, potentially limiting the growth of biogas and biomethane in the transportation sector. Additionally, it lacks adequate provisions to support the development of refueling infrastructure for CNG/LNG/biomethane. Another concern is the absence of strong incentives for the development of biogas-powered heavy-duty vehicles, which are better suited for running on biomethane than electricity due to their energy density and range requirements.

Fuel Quality Directive (EU Directive 2023/2413)

This key instrument aims to reduce GHG emissions and air pollutants by setting carbon intensity reduction targets for fuel suppliers. It applies to petrol, diesel, biofuels used in road transport, and gasoil used in non-road mobile machinery. Since its introduction in 1993, it has been revised multiple times and has facilitated the creation of a unified fuel market, allowing vehicles to operate throughout the EU using compatible fuels. In 2012, it was updated to establish minimum quality standards for gases, solid particles, and chemicals to reduce the health and environmental impacts of petrol and diesel fuels in road transport. It ensures fuel compatibility with engines and exhaust after-treatment systems (e.g., catalytic filters) by limiting biofuel blending that may not be suitable for all engines (e.g., a 7% limit on biodiesel or FAME, and 10% on ethanol). Fuel suppliers are also required to include estimated indirect land-use change emissions in their reports on EU market fuels. The directive was further amended by RED III in 2023, which removed the GHG intensity reduction target and introduced a more ambitious 2030 target for transport fuels and energy carriers (EUR-lex, 2024w).

Assessment: this directive is relevant to CooCE as it imposes strict limits on the carbon intensity of fuels, encouraging the adoption of renewable and low-carbon alternatives such as CooCE's biomethane to help reduce GHG emissions in the transportation sector. CooCE's biomethane, produced from agricultural residues and organic waste, allows suppliers to lower the carbon intensity of their fuels by capturing methane and recycling waste, helping them meet the directive's targets and market their biomethane as a certified low-carbon fuel. The directive offers specific incentives for advanced biofuels, such as biogas from waste materials, which are prioritised for regulatory and financial support. Additionally, compliance with fuel quality standards may facilitate fuel exports outside the EU. However, the directive promotes a wide range of low-carbon fuels, which could increase competition with other advanced biofuels such as hydrogen and synthetic fuels, potentially limiting the market share for biogas. Nonetheless, the directive creates opportunities for biogas and biomethane in sectors that are difficult to electrify, such as heavy-duty transport, maritime, and aviation.

Waste Framework Directive- WDF (COD 2023/0234)

The Waste Framework Directive establishes fundamental concepts and definitions related to waste management, including the definitions of waste, recycling, and recovery. It was revised in 2015 to support the EU's Circular Economy Package. The directive outlines basic waste management principles, requiring that waste be handled without endangering human health or harming the environment, with no risks to water, air, soil, plants, or animals, and without creating nuisances such as noise or odors or negatively impacting areas of special interest. It also specifies when waste ceases to be considered waste and becomes a secondary raw material, distinguishing between waste and by-products through a five-step 'waste hierarchy.' This hierarchy prioritises waste prevention, followed by preparation for re-use, recycling, recovery, and disposal. The EC sets the criteria for different types of waste, particularly 'end-of-waste' criteria, which define when waste transitions into a product or secondary raw material. These criteria aim to promote recycling by providing legal clarity and reducing administrative burdens. A review of the directive, initiated in 2023, is ongoing and seeks to set higher targets for re-use and recycling of municipal waste, reduce food and textile waste, and minimise the environmental impact of waste management (EUR-lex, 2024x). For food waste, the revision also aims to clarify concepts and terminology for consistent legal interpretation.

Assessment: the CooCE concept aligns fully with the WDF, supporting its goals of waste reduction and reuse. CooCE will achieve this by capturing CO2 and upgrading it into biomethane, using it as a feedstock to produce biosuccinic acid for packaging and disposable plastic products, as well as PHAs/PHBs for biodegradable plastics. These bio-based materials can effectively replace fossil-based alternatives, helping to reduce emissions and promote the circular economy—key objectives of both the directive and CooCE. While the directive allows member states flexibility in its implementation, this could result in inconsistent regulations and enforcement across the EU. The focus on waste prevention and reducing organic waste processed through anaerobic digestion might also decrease the availability of feedstocks for biogas/biomethane producers who depend on food waste and agricultural residues. Additionally, the directive does not provide enough financial incentives to make waste-based feedstocks economically viable for biosuccinic acid production, as converting waste into usable feedstock is costly, making it hard for producers to compete with fossil-based alternatives without substantial subsidies or market incentives. Furthermore, the directive lacks strong measures (such as quotas, subsidies, or public procurement requirements) to prioritise biodegradable plastics over fossil-based ones. Its biodegradability standards are unclear, leaving PHAs/PHBs manufacturers uncertain about what qualifies as truly biodegradable. There is also insufficient clarity on the end-of-life management of biodegradable plastics, such as the conditions under which PHAs and PHBs are compostable.

Packaging Waste Directive – PWD (COD 2022/0396)

This directive was originally established in the early 1990s to harmonise national measures on packaging and packaging waste management, ensure a high level of environmental protection, and maintain the proper functioning of the EU internal market by removing barriers created by differing packaging design rules among EU countries (EUR-lex, 2024y). In 2020, the European Commission proposed a revision to address over-packaging and reduce packaging waste, applying to all packaging and packaging waste, alongside amendments to EU Directive 2019/904 on single-use plastics. The proposals include measures such as ensuring all packaging is recyclable by early 2030, with scalable recycling beginning from that time, and introducing minimum recycled content in plastic packaging starting in 2030, which will increase by 2040 (e.g., 30% for single-use plastic beverage bottles). Other requirements focus on designing packaging to minimise material use and volume, as well as making it compostable and reusable. The proposal also set mandatory targets for member states to reduce per capita waste generation, with reductions of 10% by 2030, 15% by 2035, and 20% by 2040 from the 2018 baseline. Micro-companies are exempt from certain obligations, such as packaging minimisation and minimum recycled content requirements. The revised proposal was adopted in April 2024.

Assessment: this directive is highly relevant to CooCE, as the concept involves capturing CO2 to produce biosuccinic acid for biodegradable plastics and PHAs/PHBs for packaging materials, serving as replacements for fossil-based alternatives. CooCE's bioplastics and biopackaging stand to benefit as the packaging supply chain transitions to sustainable materials, as envisioned by the directive. Growing demand for bio-based chemicals, such as biosuccinic acid and biodegradable polymers such as PHAs/PHBs could drive production increases. However, a key challenge for PHAs and PHBs manufacturers is the inconsistency in composting and recycling infrastructure across the EU, where the ability to compost or recycle these materials varies, leading to biodegradable plastics often ending up in landfills due to inadequate local waste management systems. Additionally, consumer understanding of biodegradable materials is uneven, increasing the risk that consumers may not distinguish between compostable plastics and other plastics labeled as “biodegradable,” which may not fully degrade in natural environments.

Plastic carrier bags (EU Directive 2015/720)

This directive, which came into force in May 2015, aims to reduce the consumption and use of lightweight plastic carrier bags in the EU. It amends an earlier directive on packaging and packaging waste, designed to prevent or minimise the environmental impact of packaging and waste (EUR-lex, 2024z1). The current regulation requires member states to implement various measures, such as setting national reduction targets, applying economic tools (e.g., taxes or fees), and imposing marketing restrictions, provided they are proportionate and non-discriminatory. Mandatory measures include ensuring that annual consumption of lightweight plastic carrier bags does not exceed 40 bags per person by December 2025, or an equivalent target by weight, and requiring that lightweight plastic carrier bags are charged at the point of sale (implemented by the end of 2018).

Assessment: CooCE falls under the scope of this directive, as it aims to develop biodegradable plastic materials from biosuccinic acid, and biopolymers (PHAs/PHBs) derived from CO_2 capture. These materials could be used to manufacture plastic bags that comply with the directive, helping to expand the market for biodegradable or compostable bags as they replace conventional fossil-based plastics. However, the higher production costs of bio-based and biodegradable plastics compared to conventional plastics could hinder the widespread adoption of biodegradable carrier bags, particularly in price-sensitive markets where consumers and retailers may prioritise cost over sustainability. Furthermore, the limited availability of composting infrastructure in various EU countries could result in bio-based plastic bags ending up in regular waste streams, such as landfills or incinerators, reducing their potential to decrease waste. Additionally, consumers may lack awareness or understanding of how to properly dispose of biodegradable bags, such as ensuring they are processed in appropriate composting facilities.

Single Use Plastics (EU Directive 2019/904)

This directive targets the reduction of environmental impacts from single-use plastic products, particularly those contributing to marine litter. It encourages circular solutions that prioritise sustainable, non-toxic, reusable products and systems over single-use items, with the primary goal of minimising waste generation, as outlined in the earlier-described waste hierarchy. The directive addresses ten specific products (including plastic bags) and mandates that, where sustainable alternatives are readily available and affordable, certain single-use plastic products cannot be sold in EU member states. For other products, the directive seeks to limit their use by implementing measures such as reducing consumption through awareness campaigns, introducing design requirements (e.g., attaching caps to bottles), and imposing labelling requirements to inform consumers about plastic content, proper disposal methods, and the environmental harm caused by littering. Additionally, it sets waste management and clean-up responsibilities for producers through Extended Producer Responsibility schemes. The directive was proposed in 2018, came into effect in June 2019, and required member states to incorporate it into national law by 2021 (EUR-lex, 2024z2).

Assessment: This directive is highly relevant to CooCE, as the concept involves capturing CO_2 to produce biosuccinic acid for manufacturing biodegradable plastics and PHAs/PHBs for packaging materials, offering sustainable alternatives to fossil-based plastics, and reducing plastic pollution. The directive mandates the reduction or outright ban of certain single-use plastic products, such as polystyrene containers, which CooCE's biomaterials can effectively replace. It is expected to accelerate the shift towards bioplastics in the EU, increasing demand and driving market growth. However, a significant challenge for biosuccinic acid and PHAs/PHBs manufacturers is the inconsistent availability of composting and waste management infrastructure across the EU. In areas lacking proper composting facilities, bioplastics may not be correctly processed, potentially ending up in landfills or incinerators. Additionally, educating consumers on the proper disposal of biodegradable plastics will be essential. Another issue is the higher production costs associated with transitioning from fossil-based single-use plastics to biodegradable alternatives, as bio-based materials are more expensive. State subsidies may be necessary to support market expansion and reduce costs for manufacturers.

Carbon Removal Certification Framework – CRCF (COD 2022/0394)

This regulation, proposed in 2022, aims to facilitate the deployment of high-quality carbon removals by establishing a robust certification system. It introduces certification based on four main criteria: quantification, additionality and baselines, long-term storage, and sustainability (referred to as QU.A.L.ITY). Specific methodologies for different carbon removal activities will be developed through delegated acts. While certification is voluntary, schemes must be approved by the European Commission, ensuring compliance with the framework's criteria, independent verification of carbon removals, and full disclosure of certified carbon removal information. Certification schemes must also maintain public registries using automated and interoperable systems, with member states responsible for overseeing the operation of nationally registered certification bodies. An EU-wide registry will be established within four years, with a review in 2026 to evaluate further carbon farming activities. The regulation was agreed upon by the European Parliament in April 2024, setting certification rules for carbon removals in farming, industrial carbon removal (e.g., bioenergy with carbon capture and storage), and binding carbon in long-lasting products and materials (up to 35 years). The regulation is expected to come into force by the end of 2024 (EUR-lex, 2024z3).

Assessment: The proposed regulation has limited relevance to CooCE because, while its biotechnologies and bioproducts involve capturing CO_2 from biogas production and other industrial sources—thereby contributing to carbon removal—they would not qualify for certification under this framework. This is due to the fact that CooCE's products do not meet the long-term carbon storage requirement. For example, biofuels release CO_2 back into the atmosphere upon use, and the carbon stored in bioplastics and biopackaging is short-lived. The regulation's strict definition of permanence, which requires captured CO_2 to be stored for over 35 years (depending on the product) to be considered a carbon removal, limits eligibility. However, even though the captured carbon is not stored permanently, biogas and methane producers, as well as manufacturers of biochemicals and biopolymers using CO_2 as a feedstock, still contribute to reducing emissions by displacing fossil-based carbon. The framework's limited recognition of CCUS activities represents a missed opportunity to value and support short-term carbon storage and sustainable, circular materials.

Market Stability Reserve (EU Decision 2015/1814)

This is a key mechanism within the EU ETS-I, introduced in 2015 and operational since January 2019 (EUR-lex 2024z4), aimed at stabilising the carbon market by addressing the imbalance between the supply and demand of emission allowances. It strengthens the resilience of the EU ETS-I by automatically adjusting the supply of allowances to maintain a stable carbon price and ensure the system functions efficiently. The mechanism reduces the surplus of allowances, which can lead to low carbon prices that diminish the incentive for companies to invest in low-carbon technologies. By holding back allowances from auction, it tightens supply, potentially driving up carbon prices. This contributes to a predictable and credible framework that encourages long-term investments in clean energy technologies and aligns with the EU's climate goals. The mechanism is subject to regular reviews to adjust its operation based on market conditions or updated climate policy objectives. For example, starting in 2023, allowances exceeding the number auctioned in the previous year are cancelled to prevent long-term oversupply (EC, 2024h).

Assessment: This mechanism is relevant to CooCE as it may indirectly impact the capture of CO_2 from biogas production and other industrial sources for conversion into bioproducts, thereby contributing to carbon emissions reduction. By supporting higher and more stable carbon prices, the mechanism strengthens the business case for industries to invest in CCUS technologies, which help reduce emissions and lower costs within the carbon market. Additionally, it promotes the transition to a circular economy by encouraging the closure of the carbon loop. However, the mechanism introduces long-term uncertainty regarding the availability and price of allowances, which could complicate or delay investment planning. A key concern is that its focus on emissions reduction does not adequately incentivise the short- to medium-term reuse of captured carbon. A significant challenge for CCUS technologies, such as those used by CooCE, is that they often occupy a regulatory gray area in terms of how emissions savings are accounted for within *ETS-I*, as the captured CO_2 is eventually re-released. This makes it more difficult for CCUS projects to compete with other emissions reduction strategies.

4.4.5 Policy Area: Research and Innovation

Horizon Europe (COD 2018/ 0224)

This is the EU's flagship funding programme for research and innovation, aimed at fostering the creation and dissemination of advanced knowledge and technologies. Its primary goal is to facilitate collaboration and enhance the impact of research and technology projects, particularly those focused on improving energy efficiency and addressing global challenges such as the climate crisis. The programme is closely aligned with the UN Sustainable Development Goals (EUR-lex, 2024z5) and supports projects that align with the EU’s strategic priorities, especially in areas such as the European Green Deal (including climate action and clean energy), digital transformation, and resilience. With a budget of EUR 93.5 bn for the

2021-2027 period, legal entities in the EU and associated countries can apply for funding (EC, 2024i). The programme also provides significant support for research and innovation in CCUS technologies, such as those in CooCE, fostering collaboration between member states, industries, and research institutions to accelerate the development and deployment of CCUS solutions.

Innovation Fund (Directive EC 2003/87)

This directive was introduced to support member states in advancing innovation in low-carbon technologies and processes, including CCUS. Funded through revenues from ETS-I, it facilitates the development of large-scale CCUS projects in energy-intensive industries and carbon removal technologies (EUR-lex, 2024z6; EC, 2024j).

4.4.6 Key UK Policy Instruments Relevant to CCUS/CooCE

Since departing the EU in early 2020, the UK has enacted its own, independent regulatory frameworks that contain important instruments for CoocE and wider CCUS development. The most relevant statutory instruments that apply to the whole of the UK (rather to each of its four countries) are introduced and discussed next, focusing on their enabling or hindering role in the implementation and scaling up of the CooCE concept to sustainable commercial ventures.

The Gas Safety (Management) Regulations - GS(M)R (1996/2021)

This suite of instruments governs the safe management of gas systems and appliances. It is designed to ensure the safe conveyance and use of natural gas within the UK, focusing on the health and safety of consumers and the general public. These regulations set standards for the quality of gas and the management of gas supply, with specific provisions to address risks related to gas leaks, carbon monoxide poisoning, and explosions. The regulations also ensure that gas transported in the UK gas system is fit for purpose, safe to use, and compatible with gas appliances. It establishes standards for gas quality that include limits on gas composition to maintain operational safety and prevent damage to equipment. It also aims to ensure that gas transmission and distribution networks are managed safely, from the point of entry (e.g., gas terminals, storage facilities) to the point of use (e.g., homes and businesses). In 2021, the UK government introduced amendments to instrument to allow for more flexibility in the composition of gas that can be injected into the grid, particularly the integration of biomethane and hydrogen into the gas network, to help decarbonise the gas grid. The changes allow for biomethane produced from anaerobic digestion or carbon capture processes to be injected into the gas grid with more flexible gas quality requirements. Biomethane, produced from waste materials, is now widely accepted in the gas grid with more flexible gas quality requirements (UKGOV, 2024a).

Assessment: this legislation is highly relevant to biomethane produced via CCUS as it governs the quality, safety, and management of gas that is injected into the UK's gas network. Since biomethane produced via CCUS is intended for injection into the gas grid, compliance with this legislation is essential for its safe distribution and use. The biomethane must meet quality specifications (i.e. methane content), limits on impurities and odorisation (i.e. biomethane must be odourised for leak detection) before it can be injected into the grid. It must also be compatible with existing infrastructure, so it must have the same characteristics as natural gas (e.g., similar combustion properties), it must undergo regular testing and meet all health and safety regulations. This legislation ensures that as renewable gases such as captured carbon biomethane become more common, they can safely enter the gas network while supporting the UK's net-zero goals. However, the legislation was designed with a focus on natural gas. This limits flexibility for renewable gases such as biomethane to the extent that producers will have upgrade their processes to meet the requirements on gas composition, which could be expensive, thus limiting economic viability of carbon captured biomethane, slowing its integration into the gas grid.

Renewable Transport Fuel Obligation - RTFO (2007/ 2024)

The RTFO is a cornerstone of the UK's strategy to reduce carbon emissions from the transport sector by promoting the use of renewable fuels such as bioethanol, biodiesel, and biomethane. Its key features include placing obligations on fuel suppliers, creating a market for Renewable Transport Fuel Certificates (RTFCs), and supporting the development of advanced biofuels. It has been recently amended to increase overall targets setting the obligation at 12.4% for 2022, with targets expected to rise to 14.6% by 2032. The instrument also introduced a *Development Fuels Mandate* (DFM) which requires that a portion of the RTFO obligation be met through fuels with development fuels (i.e. with superior environmental benefits or from non-food sources) targeting aviation, maritime, and heavy-duty vehicles, thereby expanding support for biomethane and aviation fuels to stengthen the UK's commitment to achieving net-zero emissions by 2050. The instrument also includes provisions for double counting for certain advanced biofuels that are derived from waste materials or sustainable feedstocks, such as biomethane from waste. The RTFO also includes sustainability criteria to ensure that biofuels do not contribute to negative environmental impacts (UKGOV, 2024b).

Assessment: The RTFO is highly relevant to CooCE's since it obligates fuel suppliers to ensure that a specified percentage of the fuel they provide is sourced from renewable sources, such as biomethane, thereby creating incentives and a direct market demand for this low-carbon transport fuel. Besides, captured carbon biomethane qualifies under the mechanism as a renewable fuel suitable for transport applications (e.g. heavy goods vehicles and public transportation). Moreover, biomethane produced from waste materials or from carbon capture is eligible for double counting under this mechanism, so fuel suppliers would receive double the number of *RTFCs* for each unit of biomethane they use or supply, making it a highly attractive fuel option. Captured carbon biomethane could also be classed as sustainble under the RTFO, as it is produced from waste materials (e.g. agricultural or food waste) and does not compete with food crops. However, there are concerns that the RTFO does not explicitly prioritise or provide distinct incentives for CCU-based biomethane over traditional biomethane; about the lack of direct financial support or specific funding mechanisms (e.g. targeted subsidies or incentives) for the deployment of CCU technologies in the biomethane sector which may slow the adoption of CCU technologies; and lack of clarity regarding the role of of captured carbon biomethane under the *DFM*, with no explicit incentives or regulatory guidance to prioritise or promote the use of captured CO_2 for producing advanced biofuels such as biomethane.

The UK Climate Change Act (2008/2019)

This landmark piece of legislation legally binds the UK to reducing its greenhouse gas emissions and transitioning to a low-carbon economy and remains a critical legal framework for the UK's climate and energy transition. It was the world's first legally binding climate change legislation and has since been amended to reflect increasing urgency in tackling climate change. The original 2008 Act set a legally binding target for the UK to reduce its greenhouse gas emissions by 80% by 2050, compared to 1990 levels, but the legislation was amended in 2019, increasing this target to net-zero emissions by 2050, making the UK the first major economy to enshrine a net-zero target in law. It introduced a system of five-year carbon budgets that cap the total amount of greenhouse gases the UK can emit during each five-year period, serving as a stepping stone towards the long-term goal. It covers all sectors of the economy, including energy, transport, agriculture, and industry, to ensure that emission reductions are spread across the entire economy, and also includes mechanisms for promoting investment in CCUS and renewable energy and for ensuring government accountability for emissions (UKGOV, 2024c).

Assessment: This legislation is relevant to CooCE since its net-zero emissions target provides a strong policy signal for deploying low-carbon energy sources such as CooCE's biomethane, whose production can result in negative emissions since CO_2 from organic waste can be captured and stored or utilised in various applications, helping offset emissions from other sectors. Also, the carbon budget in this legislation sets an ongoing incentive to scale up biomethane production because of its low-carbon profile, which is crucial for meeting mid-term targets such as the 78% emissions reduction by 2035 (set in the sixth carbon budget). The instrument further encourages the use of organic waste for energy production, aligning with circular economy principles, as biomethane production from agricultural waste and municipal solid waste is a key requirement for reducing methane emissions from landfills while simultaneously producing renewable energy. The instrument also aligns with bioeconomy strategies that promote the use of bio-based feedstocks and bio-based chemicals, such as biosuccinic acid, and the principles of reusing carbon emissions to create valuable products, reducing the overall environmental impact of industrial processes. This law indirectly supports the production of PHAs/PHBs by promoting bio-based and biodegradable plastics which align with the UK's goals of reducing plastic waste and transitioning to more sustainable materials. However, there is concern about the limited focus on the bioeconomy, particularly in biomaterial sectors, the lack of specific incentives for bio-based chemicals (e.g. biosuccinic acid) and overall slow implementation in CCU technology support.

UK Energy Act (2013/2023)

This a comprehensive piece of legislation that was introduced to reform the UK's energy market, promote low-carbon energy production, and ensure the country's energy security. The Act is a cornerstone of the UK's energy transition and plays a critical role in meeting the nation's net-zero emissions target by 2050. It was revised recently, with amendments to bolster the focus on carbon capture technologies, hydrogen development, and renewable energy, and to address the need for grid modernisation and support the integration of emerging technologies and enhancing carbon reduction mechanisms. It contains a series of measures and mechanisms to help achieve its aims, including: the *Electricity Market Reform* to attract investment in low-carbon energy and ensure the security of electricity supply; the *Contracts for Difference* mechanism that provides long-term price stability for low-carbon electricity generators; the *Carbon Price Floor*, to help reduce carbon emissions from the UK's power generation sector; support for carbon capture and storage and nuclear power; and provisions to enhance energy efficiency in homes, businesses, and public infrastructure and to protect consumers (UKGOV, 2024d).

Assessment: this legislation is relevant to captured carbon biomethane, biosuccinic acid, and PHA/PHB bioplastics because it provides a legislative framework that supports CCUS technologies, low-carbon energy production, and the development of sustainable materials. Its provisions help foster innovation and investment in CCUS projects, ensuring that biomethane producers can integrate carbon capture into their processes, whilst also providing a mechanism that offers long-term price stability for low-carbon energy sources. This instrument also encourages integration of CCUS in industrial processes for producing bio-based chemicals (e.g., biosuccinic acid) and bio-based polymers (PHAs/PHBs) obtained from captured CO_2 to replace their fossil-based counterparts. By using captured CO_2, producers can benefit from policy support that encourages the reduction of emissions in chemical manufacturing, whilst reducing reliance on fossil-based plastics and promoting the circular economy. However, the legislation contains no direct financial incentive or specific subsidy targeted at integrating CCUS technologies into biomethane production, neither is biomethane from CCUS included in long-term price stability mechanism available to other renewable energy sources. This law also lacks a specific focus on promoting bio-based chemicals and bio-based biopolymers, even when produced using captured CO_2, and does not sufficiently address the role that captured carbon bioplastics can play in reducing dependence on fossil-based plastics, which may hinder the expansion of CCUS take up in the chemicals sector.

Carbon Capture, Usage, and Storage (CCUS) Innovation Programme (2017)

Although not a legally binding policy instrument, this initiative is included here since it clearly focuses on CCUS. The programme was launched as part of the UK government's broader efforts to support the development and deployment of CCUS technologies. It aims include: to promote the research, development, and demonstration of technologies that capture, store, or reuse CO_2 emissions from industrial processes and energy production; help the UK meet its net-zero emissions target by 2050 by reducing carbon emissions from industries that are difficult to decarbonise through other means (e.g. heavy industry, chemicals, cement, steel, and power generation); demonstrate the potential of CCUS in sectors such as power generation, industrial processes, biomethane production, and hydrogen production; encourage partnerships between industry, research institutions, and academia to develop innovative CCUS solutions. The programme has increasingly focused on the role of CCUS in supporting the development of the hydrogen economy and biomethane production, increasing support for projects developing technologies that turn captured CO_2 into useful products (e.g. bio-based chemicals, fuels and building materials), and advancing the commercialisation of CO_2-derived products, including bioplastics (e.g. PHAs/PHBs) and carbon-neutral fuels, supporting the UK's circular economy goals (UKGOV, 2024e).

Assessment: this programme is highly relevant to the development of biomethane, biosuccinic acid, and PHAs/PHBs bioplastics obtained through CCUS. Its encourages the development of carbon capture technologies that can be integrated into biomethane production, allowing the capture of CO_2 during biogas upgrading and reusing it to produce more biomethane or other industrial uses and provides funding for research and demonstration projects that explore novel ways to reduce emissions in biomethane production. It also promotes the use of bio-based feedstocks and encourages sustainable chemical production (e.g. biosuccinic acid) that reduces the reliance on fossil fuels. It further supports the use of captured CO_2 in creating sustainable materials, including bioplastics (e.g. PHAs/PHB), which fits within the broader aim of promoting carbon utilisation to develop new low-carbon products that help reduce plastic waste and environmental impact. However, the primary focus of the programme on large-scale industrial projects and CCUS hubs overlooks smaller, more localised biomethane production, with producers finding it difficult to access adequate funding and support under the current framework, thereby limiting innovation and slowing expansion of renewable gas production in rural or decentralised areas. The programme has also failed to prioritise the development of bio-based chemical production using captured CO_2 (e.g. biosuccinic acid) leading to missed opportunities to develop sustainable, bio-based chemicals and bioplastics that can replace fossil-derived counterparts. Also, the PHAs/PHBs bioplastics sector, which could benefit significantly from CO_2 capture and utilisation, receives limited direct support through this programme, although PHAs/PHBs, produced from bio-based feedstocks and CO_2 have strong potential as sustainable alternatives to conventional plastics, but lack of support limites the prospects for the bioplastics industry to scale up and compete with conventional, fossil-based plastics.

The Environment Act (2021)

This is a landmark piece of legislation designed to protect and enhance the environment in the UK after the UK's exit from the EU. It provides the legal framework for addressing air quality, biodiversity, water resources, and waste management, among other environmental priorities. It aims to support the UK's net-zero emissions target by 2050 and ensure long-term environmental sustainability, through a a framework for setting legally binding, ambitious, and long-term environmental targets across four key areas: air quality; water resources; biodiversity; waste reduction and resource efficiency and the government sets specific targets for each area and progress must be reported regularly. The Act includes new measures to reduce waste and promote resource efficiency, including: Extended Producer Responsibility, which requires producers to take more responsibility for the environmental impact of their products, particularly in relation to packaging and plastic waste; the cost of managing the end-of-life stage of products will increasingly fall on producers rather than local government; *Deposit Return Schemes* for drinks containers, where consumers pay a deposit that is refunded when the container is returned for recycling; *the Plastic Packaging Tax*: which implements taxes and other measures to reduce the production and use of single-use plastics and non-recyclable materials (UKGOV, 2024f).

Assessment: this legislation is relevant to the CooCE concept as far as it covers aspects of its CCUS technologies and its products that help achieve its goals. Thus, for instance, its focus on waste management, resource efficiency, and carbon reduction helps bolster waste-to-energy and encourage and encourage a circular economy, promoting the reuse of organic waste for renewable energy production rather than sending it to landfill (i.e., biomethane produced from waste feedstocks). Similarly, the emphasis on waste reduction and resource efficiency supports the production of bio-based chemicals (e.g., biosuccinic acid) and bio-based polymers (e.g., PHAs/PHBs bioplastics) which provide a low-carbon alternative to petroleum-based chemicals, thereby helping in the decarbonisation of the chemical industry. However, this piece of legislation does not provide any specific incentives for CCUS integration in biomethane production, neither does it provide sufficient support to bio-based chemical industries, placing only limited emphasis on promoting bioplastics as a sustainable alternative to fossil-based plastics.

UK Emissions Trading Scheme - UK ETS (2021)

This is a market-based mechanism designed to reduce GHG emissions by putting a price on carbon, that is, to incentivise decarbonisation by making it more expensive for companies to emit GHGs while offering financial benefits for companies that reduce their emissions below their allocation. It operates in a similar fashion as the EU ETS-I. It came into effect on January 1, 2021, and is an integral part of the UK's strategy to meet its legally binding net-zero emissions target by 2050 under the UK Climate Change Act. It covers energy-intensive industries, power generation, and aviation. It also aims to prevent carbon leakage (the risk of companies relocating to countries with less stringent carbon regulations) and it allocates free allowances to some industries in energy-intensive sectors (e.g. steel and cement) where international competition is high. In 2022, the UK government committed to tightening the cap further to align with the UK's net-zero target by 2050 and in 2023, it proposed reducing the emissions cap at a faster rate from 2024 to meet the 78% reduction target by 2035, as set by the sixth carbon budget. The UK government is also considering the potential expansion to other sectors (maritime shipping and waste management), and the introduction of *Carbon Border Adjustment Mechanism* (similar to the EU's) in and is currently in discussions about the possibility of linking the mechanism with the EU ETS-I (UKGOV, 2024g).

Assessment: This mechanism is highly relevant to CCUS-based production of biomethane, biosuccinic acid, and PHAs/PHBs bioplastics because of its role in pricing carbon emissions and promoting low-carbon technologies. Through this system, biomethane producers are incentivised to capture CO_2 emissions during production, reducing their overall emissions and potentially generating emission credits that can be traded or sold within the *ETS* market. Biomethane projects can also benefit from free allowances provided to certain sectors under the scheme to prevent carbon leakage, ensuring their competitiveness while adopting low-carbon technologies. Additionally, the mechanism promotes the use of low-carbon alternatives to fossil fuels in power generation and heating. By reusing CO_2 in the production of biosuccinic acid, producers can reduce their reliance on fossil-based inputs and generate carbon credits for lowering emissions. Moreover, the scheme enables low-carbon materials, such as PHAs/PHBs, to help the plastics industry reduce carbon emissions by phasing out fossil-based plastics in favor of biodegradable alternatives made from captured carbon. The *UK ETS* also aligns with circular economy principles by encouraging waste reduction and material reuse, since biodegradable and compostable PHAs and PHBs provide an end-of-life solution for plastic products, reducing landfill waste and emissions. However, key issues about the effectiveness of the mechanism include concerns over carbon pricing volatility; limited coverage of smaller bio-based industries and need for clearer integration with PHAs/PHBs bio-based plastics.

UK Green Gas Support Scheme – GGSS (2021)

This is a government initiative designed to support the production and use of biomethane for injection into the national gas grid, contributing to the decarbonisation of the heating sector. It is a critical part of the UK's efforts to decarbonise heating by providing financial support for biomethane production from sustainable waste feedstocks (e.g. waste-to-energy biogas projects). It offers long-term long-term tariff-based financial support for biomethane producers who inject biomethane into the national gas grid to cover the costs of biomethane production and make it economically competitive with natural gas. It also provides a a tiered tariff structure, where different levels of biomethane production receive different rates (e.g. higher production volumes receive lower tariffs to ensure fair and cost-efficient support), and and emphasises the use of waste-based biomethane to support the transition to low-carbon gas. Recent updates have included tariff adjustments, enhanced sustainability criteria, and discussions around integrating CCUS technologies to further reduce emissions. The GGSS is funded through a *Green Gas Levy*, to ensure that biomethane production goes on expanding while maintaining cost-effectiveness for consumers (UKGOV, 2024h).

Assessment: this scheme is highly relevant to captured carbon biomethane as it provides a financial framework and policy support for the production of low-carbon biomethane from sustainable sources and incentivises the potential use of CCUS to further reduce GHG emissions, by providing tariff-based support to biomethane producers. Also, the GGSS can make the production of captured carbon biomethane financially viable by providing long-term, guaranteed tariffs, helping producers offset the costs of implementing carbon capture technologies.
The scheme also places emphasis on the use of waste-based feedstocks (food waste, agricultural residues, sewage sludge) for biomethane production which CCUS technologies can incorporate to create more sustainable biomethane, ensuring that waste is not only turned into renewable energy but also used in a way that removes CO_2 from the atmosphere, thereby also aligning with the UK's circular economy principles (e.g. reducing waste, cutting emissions, and creating valuable renewable gas). However, the scheme does not yet provide specific financial incentives or dedicated support for the integration of CCUS technologies into biomethane production, nor does it sufficiently recognise or differentiate carbon-negative biomethane produced through CCUS from traditional biomethane production.

4.4.7 Stakeholders Perspectives on CooCE/CCUS Regulatory Issues

Stakeholders at the workshop and those who participated in the survey raised various issues relating to policy instruments and regulatory frameworks for CCUS that were also addressed in the policy assessment. Most notably, they observed a general lack of policy instruments designed specifically for CCUS chains, including instruments that account for CO_2 content in bioproducts and standards for commercial use of bioproducts (e.g., food packaging). Those that do exist are seen to lag behind those for other renewable energy sectors and to focus exclusively on carbon sequestration and storage to the detriment of CCUS infrastructure and markets. The survey results also highlight the perception amongst a great majority of respondents (87%) of the importance of developing regulatory frameworks specific to CCUS.

A SWOT exercise contained in the online survey revealed the perceptions of respondents about the CooCE concept and CCUS more wildely as regards policies and regulations. Table 4 shows the more salient contributions. Respondents thought that the concept may be received well by politicians as it is in line with decarbonisation agendas, it can help boost environmental policy formulation and social acceptance, and may also instigate cooperation between stakeholders. On the other hand, though, it may fail to obtain widespread support due to lack of interest or understanding by politicians, weakening or slowing down policy formulation that enables industrial-scale deployment, as well as being exploited for political gain only.

Table 4 SWOT of Regulatory and Policy Issues for CooCE/CCUS

Strengths	***Weaknesses***
- likely to have support in liberal democracies - likely to be more accepted by the public - in line with decarbonisation agenda - policy makers will applaud - promotion of green policies	- lack of support from many institutions - difficult to push through legislation to deploy at meaningful scale - too hard for legislators to understand - will be exploited for political gain
Opportunities	***Threats***
- may pave the way for more environmental policy - will drive change - promotion of partnerships between academia and industry - integration in policy formation	- lack of proper political support - slow legislation and uncertain MRV (measure, reporting, verification) - need synchronisation with other countries - insufficient backing to influence policy making - disinterest

Source: Online survey (2023)

It is well-established that technological innovations, such as CCUS, rely on supportive policy frameworks and instruments to facilitate their successful deployment and broader adoption (BEIS, 2019; Naims, 2020; Kircher, 2021; Greenfield, 2022). Several countries have already implemented comprehensive legal and regulatory frameworks for CCUS (BEIS, 2019; Greenfield, 2022), while recent policy shifts, such as the 2019 European Green Deal, outline strategies for directing resources towards CCUS research and pilot projects (Bolscher et al., 2019; JCR, 2022). However, there remains a critical need for more coherent, integrated, and coordinated policy development to support CCUS technologies and the bioproducts derived from them (Naims, 2020).

Clearly, EU member states will have different interests and approaches to developing CCUS, which will be conditioned by their own historical development trajectories that will have produced their current energy mixes, economic priorities and levels of technological development, all of which may make it challenging to achieve harmonisation and consistency in legislation. The multiple stages involved in CCUS means that different policies and regulations may apply to each stage, leading to fragmentation across the entire value chain. Similarly, as CCUS is applicable to various sectors, each of which may have unique features and issues that make it difficult to develop consistent regulatory frameworks. Also, the relative recency and complexity of CCUS technologies means a lack of precedent in terms of regulatory frameworks, leading to uncertainties and inconsistencies in emerging legislation, as do potential interpretational differences of CCUS (Bolscher, et al., 2019; JCR, 2022). Yet, despite the perception that regulatory frameworks lack consistency, stakeholders at the workshop thought that there is scope for influencing legislative processes to incorporate CCUS chains whilst enhancing circularity and lowering CO_2 emissions, which would be further strengthened by taxing carbon and operating credit schemes at regional and global scales.

A combination of factors may hinder the formulation and advancement of effective policies to bolster CCUS development and market expansion. These include technological complexity of both CCUS and bioproduct technologies that demand substantive multi-stage investment (research; development; deployment); doubts about formulating policies because of concerns with potential risks linked to CO_2 storage and unforeseen consequences of bioproduction; lack of public demand for supportive policies due to poor or no understanding of CCUS and bioproducts; lack of a strong business case for the economic viability of CCUS and bioproducts, even though the bio-based origin of products may justify a higher seling price compared to fossil-based options; technologies tend to evolve much more rapidly than the pace of policy development and enactment; the need for engagement of all stakeholders in policy-making is essential to the success of CCUS and bioproducts, yet deliberations can be time consuming, thereby slowing down the whole process (Naims, 2020; UNECE, 2021; Greenfield, 2022). Stakeholders at the workshop also noted the absence of funding and investment mechanisms for bioproducts, whose higher prices that result form subsidisation of fossil fuels and from exclusion of negative externalities in conventional fossil counterparts remain central challenges to the development of effective regulations and policies for the bioeconomy/bioproducts (Morone and Imbert, 2020; Kircher, 2021; Gould, et al., 2023).

Finally, the SHDB provides indicators for risks related to governance which ultimately may jeopardise the transparent and effective transposition or application of regulatory frameworks and the law more widely. These are shown on Table 5. As can be seen, the overall risk of corruption and fragility in the legal system is low for Denmark, for the other three CooCE countries the risk level is assessed as medium.

Table 5 Risks to Governance

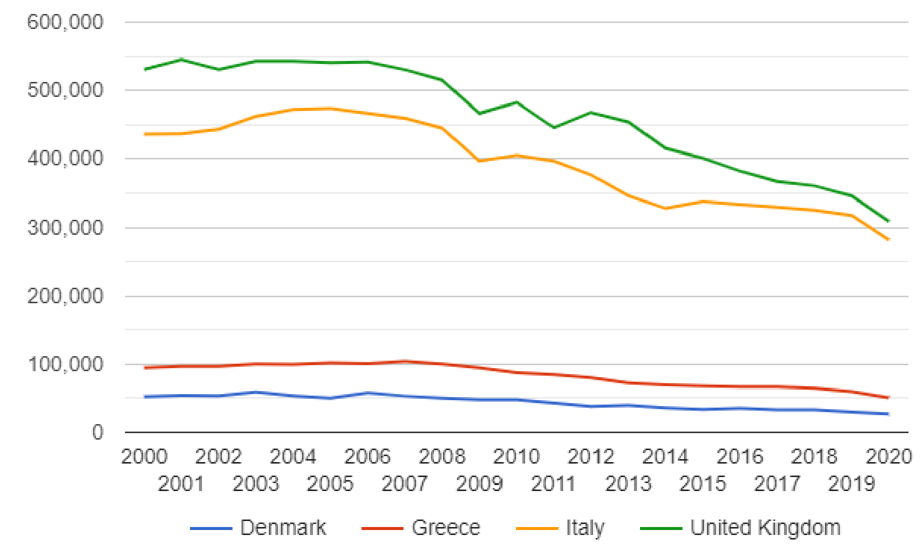
CooCE countries/ Sectors	*Chemicals/plastics*	*Electricity*	*Gas*	*Transportation*	*Water*
	Overall risk of corruption and fragility in the legal system				
Denmark	L	L	L	L	L
Greece, Italy, UK	M	M	M	M	M

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; Y= yes; risk level colour is as used in the SHDB

4.5 CO2 point source

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
CO_2 point source	Availability of feedstock	National	Feedstock	*Qualitative* Literature Workshop *Quantitative* Secondary databases Survey

The CooCE project initially focuses on the capture of CO_2 from biogas plants for processing and converting into biofuels and chemicals and polymers for use in the chemicals and bioplastics sectors (although parameters for capture from industrial plants have been set out in other CooCE research activities, e.g., carbon capture from lime producing plant). In this case the CO_2 captured is potentially readily available for CooCE's specific purposes from 20,000 biogas plants operating in the EU (EBA, 2023), the largest producer of biogas region in the world (EIA, 2023). As seen previously, in 2022, the number of biogas plants in CooCE countries were: Denmark, 123; Greece, 75; Italy, 1800; UK, 1100 (EBA, 2023). Figure 19 shows the volume of CO_2 emissions from fossil fuels burning and cement manufacturing in CooCE countries to help gauge potential availability. As the graph shows, emission levels are much higher in the UK and in Italy than in Denmark and Greece and have also declined more markedly between 2010-2019.



Source: The Global Economy (2024) https://www.theglobaleconomy.com//rankings/Carbon_dioxide_emissions/

Figure 19: Carbon Dioxide Emissions in CooCE Countries

Nevertheless, increased competition for CO_2 may help reduce overall availability (i.e., capture for upgrade to biomethane), and CO_2 availability will vary according to location, type of biomass feedstock, production capacity, and regulatory frameworks, with the cost of capture being a significant factor. Availability in the EU specifically may be affected by two existing mechanisms. The EU ETS-I, the carbon-trading system that requires companies (power plants, industrial facilities, airlines) to hold allowances to cover their emissions, which can then be traded to reduce their GHG emissions. Companies deploying CCUS to reduce their emissions may require fewer allowances, which may potentially lower demand for allowances in the ETS market. There is also the EU MSR, which helps address supply-demand imbalances in the carbon market by adjusting the total number of allowances in circulation according to market conditions. CCUS projects that effectively reduce emissions can generate carbon credits that help stabilise carbon markets but also impact the overall supply and demand dynamics within the carbon credit market. Moreover, the increased deployment of CCUS technologies is likely to influence policymaking towards adjusting emission reduction targets, allocation of allowances, or other parameters that will further impact CO_2 availability.

Stakeholders at the workshop noted potential a shortage of CO_2, which clearly could affect the availability of CO_2 for capture, thus jeopardising CCUS projects, particularly if there is increased demand for both established and emerging uses (e.g., listed by Pieri, et al., 2018). These include: heavy CO_2 emitting industrial processes reducing their emissions significantly or transition to cleaner technologies; competing uses of CO_2 in food and beverage applications, amongst other industrial uses; limited supply or increased demand for CO_2 pushing up prices; availability of suitable infrastructure for capturing and transporting CO_2; lack of sufficient policy support for CCUS; continuous development of renewable energy technologies leading to decreasing emissions from energy generators. Still, numerous industrial processes emit substantial volumes of CO_2 as a byproduct thereby potentially providing continuous and substantive supply (e.g., energy generation, cement production, chemicals manufacturing), while demand for CO_2 is also still relatively lower compared to the total emissions from various industries (IEA, 2023).

The survey results shows that two thirds (66%) disagreed with the prospect that increased demand by CCUS may lead to shortages of CO_2, and about as many (67%) did not think that CCUS technologies can help decarbonise fossil sectors through sector integration to supply of CO_2. Nearly as much (64%) also thought that carbon capture itself is still the single major barrier to the wider application of CCUS. Responses from the SWOT workshop illustrate a variety of views on the CooCE concept/CCUS as regards the use/availability of CO_2. For some, it was likely to have only a limited effect on CO_2 emissions reductions for climate change (*'it will not make a real dent in the CO_2 reduction'*), whilst for others availability was not an issue ('probably *low volume of CO_2 use'*), although that could well depend on the product pathway chosen (biofuels; biochemicals; biopolymers). Some did acknowledge that geography can be a limiting factor *('possibility of not having enough CO_2 in some regions*) that would therefore affect '*sequestration availability'* with further implications *('volume of CO_2 that can be stored or used'*). Some also thought that CCUS will open '*new complex markets for biogas producers'* and that it will require *'major tax incentives'*.

CooCE is being developed for capturing CO_2 from biogas plants and other industrial-scale emitters within CooCE countries and more widely in the EU. This would obviate the construction of new plants and attendant infrastructure, and issues relating to community acceptance, especially in rural locations. For instance, one challenge is building pipelines for transportation of the biogas or liquified gas to storage sites, particularly if these are located at great distance from the capture plants. Also, local communities may oppose the construction of CCUS and storage infrastructure because of concerns about changes to the local landscape, environmental impacts, and health and safety issues (the 'NIMBY' syndrome).

The SWOT exercise contained in the online survey recorded what respondents thought about the enviromental contribution and impacts of the CooCE concept and of CCUS more generally. Their views are shown on Table 6.

Table 6 SWOT of Environmental Issues for CooCE/ CCUS

Strengths	***Weaknesses***
- CO^2 capture and alternative offsets - much lower environmental impact - different side effects than amine systems - moving closer to a green environment - lower emissions	- needs energy to make it happen, so just more energy transfers and losses - slow pace of uptake - benefit likely to have negligible impacts on climate change

- sustainable and climate positive - decarbonisation	- essentially just a different form of solar power that has a niche market; there are more advantageous routes to achieve the same ends - smaller contribution that other solutions - potential contamination of product/biohazard - the technology will not make a real dent in CO_2 reduction - makes a good story but may not impact the environment hence misleading - slight impact on helping environmental impacts of climate change
Opportunities	***Threats***
- great reduction in long-term environmental damage - new supply chains would help lower carbon footprint of existing supply chains - addition to carbon mixture	- lack of information about the immediate effect on the environment - can this be sustained long term? - hazards - requirement for robust safety measures to mitigate biohazards

Source: Online survey by the authors (2023)

As can be seen, several positive features of CooCE regarding the environment were noted by the stakeholders. These include the capture of CO_2 itself and therefore the averted release of emissions which helps lower impacts and long-term environmental damage, helping make CCUS sustainable and climate positive as well as contributing to wider decarbonisation, and the creation of supply chains that may also help reduce the carbon footprint of existing ones. Yet, these were countered by various issues of concern as regards environmental impacts. This includes a lack of knowledge on immediate environmental effects and a perception that impacts in terms of lowering CO_2 emissions will be negligible or smaller than other solutions, thus limiting the scope for helping staving off climate change. There was also concern about hazards/biohazards and ensuring that measures will be taken to mitigate for them.

4.6 Community Participation

No Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Community participation	Social acceptance of • infrastructure • technologies • products • other involvement	National Local	All	*Qualitative* Workshop *Quantitative* Secondary databases Survey

This parameter relates to opportunities for community participation in different stages of CCUS projects such as CooCE. Participation may entail an array of forms, such as involvement in project design and implementation, business ownership and operation and labour force participation. But it may also relate more widely to public perception and social acceptance of various project features, particularly where projects have not yet been implemented (such as CooCE, which is being developed at the demonstration stage). These include project aims, feedstocks, processing technologies, intermediate and final products, infrastructure, health and safety and impacts. Lack of knowledge, awareness or understanding of CCUS can lead to mistrust and opposition by local communities which will likely bear the brunt of risks, disruptions and other negative impacts and may also be sceptical about a fair distribution of benefits. Thus, public perception of CCUS is crucial for its successful deployment since it informs social acceptance (the extent to which it is endorsed or rejected by stakeholders and society at large), and this can exert strong influence on policy and industry and impact on development and deployment (Jones et al., 2017; Lynch, et al., 2017; Arning, et al., 2019; UNECE, 2021; McLaughlin et al., 2023).

A SWOT exercise contained in the online survey captured the views of respondents on social issues related to societal acceptance of the CooCE concept and of CCUS more broadly. A sample of their contributions is shown on Table 7. As can be seen, positive aspects of CooCE/CCUS relate to its role in social sustainability (health, social cohesion, job creation), and being more socially acceptable than extant energy systems. Yet, social acceptance may be thwarted by lack of awareness of and communication on CCUS, lack of immediate benefits and improvements, the limited scope of social impacts, safety issues, views in the political realm (waste of resources; enablers of fossil fuels), and the 'NIMBY syndrome'.

Table 7 SWOT of Social Issues for CooCE/CCUS

Strengths	***Weaknesses***
- it makes a good story - sustainable societies that lead to social cohesion - likely to have support in liberal democracies - may be more acceptable than amine systems - positively viewed/likely to be more acceptable - healthier planet - people will applaud	- lack of immediate benefits prevents public acceptance - conservatives may view this as a waste of resources to fix a problem that doesn't exist; liberals may view it as enabling the fossil fuels industry - acceptability - too small to have major social impact - acceptance of biotech - logistics (safety) - less known
Opportunities	***Threats***
- creation of a sustainable society - new jobs in the sector	- lack of apparent and immediate improvements leads to low acceptance by the general public - NIMBY - how long will the concept last? - awareness - lack of communication to improve social acceptance
Source: Online survey by the authors (2023)	

The online survey also gave respondents the opportunity to express their opinion on economic issues related to the CooCE concept and CCUS more widely which have implications for community involvement and development as well as social acceptance. Their comments are shown on Table 8. As can be seen, CooCe is seen positively for helping reduce dependence on the volatile oil market, creating local economic benefits where it is deployed (including jobs), reducing costs (overall; infrastructure), producing value-added bio-commodities, potentially achieving economies of scales or expanding in a niche market. On the other hand, CooCE is also seen as being expensive (high start up, capital, development and scaling up costs), offering both high and low short term profitability (depending on contingencies) thus failing to attract commited investors who may opt for alternative technologies at lower cost options, hence major tax incentives will be required, whilst policy issues (regulations) and the 'NIMBY syndrome' may also thwart industrial-scale deployment of CooCE.

Table 8 SWOT of Economic Issues for CooCE/CCUS

Strengths	***Weaknesses***
- reduced dependence on petroleum which is highly volatile [prices] - local economic benefits where technology is deployed - cost of capture reduction on infrastructure - benefits from producing valuable products - jobs and adaptation avoidance	- expensive - higher short-term gains leading to scepticism - likely high startup expenses/high upfront investment - scaling/scalability - capital costs - unlikely to attract investors

- very favourable cost-benefit ratio - reduce costs	- smaller contribution than other solutions - bio succinic acid - costly to develop and scale up - will need major tax incentives
Opportunities	***Threats***
- jobs - long-term stability; independent from the petroleum market - packaging - increased adoption would lead to economies of scale - niche	- short-term lower profitability, leading to abandonment of project - lower cost options - regulators - NIMBY - is this the best cost saving method? How quickly will new infrastructure appear on the horizon? What are the maintenance costs long-term? - other technologies are proven with higher capture capacity so investors will not back up projects - sustainability - insufficient data to drive investment decisions - not many viable projects so few will get funded

Source: Online survey by the authors (2023)

The final SWOT exercise contained in the survey enabled respondents to comment on techonological issues related to the CooCE concept and to CCUS that also have repercurssions for community involvement and social acceptance. Table 9 shows the responses obtained. As it shows, promising features of CooCE are novel process technology for addressing carbon emissions (e.g. capture of biological CO_2) which can help advance further the state of art in research, thus paving the way for further innovation and energy efficiency improvement, as well as helping lower costs. However, there are doubts at to whether CooCE's technologies can be deployed at industrial scale and speedily enough to make a significant contribution to curbing emissions, exactly because of their novel design features (i.e. biorector size; microbial strains), as well as potential issues with feedstock variability (i.e. geographical availability), and impacts on technical skill pools (e.g. talent transfer to larger projects).

Table 9 SWOT of Technology Issues for CooCE/CCUS

Strengths	***Weaknesses***
- advance state of the art/new ideas - novel process technology that promotes further innovation; innovative technology to address common problem - speed - good area for research - lowering costs - energy	- not proven or at scale to be impactful - novel technology leads to slower implementation - not sure that this technology can be deployed at scale - scaling and unknown consequences - feedstock variability - bigger CCUS projects likely to absorb industry, commercial and technical talent - probably a low volume use of CO_2 - less developed - design - longer processing times may require larger bioreactors
Opportunities	***Threats***
- if successful, paving the way for further innovative technological approaches - niche - needs more research - discovery of more efficient processes - technological advancement - innovation	- complexity of novel technologies may lead to slow in project development - not proven - innovation - shelf life of storage facility of 5 years before infrastructure needs change (25/50 years) - impacts of failure to nurture efficient microbial strains

Source: Online survey by the authors (2023)

4.7 Rural development and infrastructure

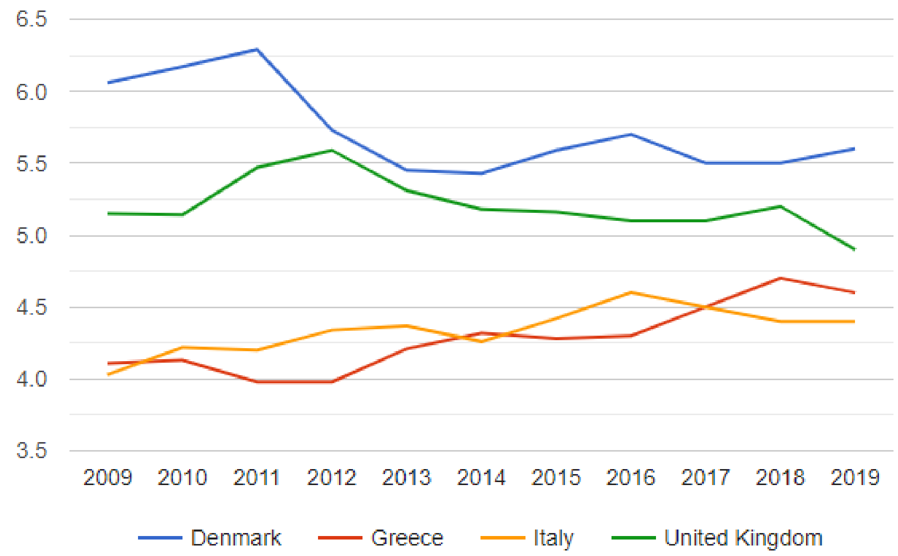
Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Rural development and Infrastructure	Access to • Sanitation • Water • etc	National Local	All	*Qualitative* SHDB Workshop *Quantitative* Secondary databases Survey

As biogas plants are commonly situated in rural areas, CCUS projects will present significant challenges and have implications for rural development and infrastructure. The extensive infrastructure required for CCUS includes processing installations, energy supply systems, storage facilities, pipelines, and transportation networks for moving captured CO_2 and hydrogen, as well as roads for transporting end products such as biofuels, chemicals, and bioproducts (IEA, 2020). Without thorough planning and active involvement of local communities in the decision-making process, the construction of CCUS infrastructure could lead to competition for rural resources such as land and water, disrupt agricultural activities, and negatively impact natural landscapes and biodiversity, including both flora and fauna (McLaughlin et al., 2023). CooCE proposes to capture carbon on-site for upgrading into biomethane by removing CO_2, which therefore obviates the need for biogas transportation but biomethane and CO_2 transportation and storage do raise potential risks about the impact of leakages along with the perceived toxic nature of CO_2 raises central concerns about the risks both to human health and the environment (Jones, et al., 2017; Arning et al., 2019). Indeed, safety related to CooCE's infrastructure was noted by stakeholders at the workshop and in the online survey as an important issue to be addressed, including communicating on immediate environmental impacts, hazards and biohazards, and sound risk assessment and management and safety measures.

The parameter 'rural development and infrastructure' was assessed using indicators from the SHDB for CooCE countries and sectors. These indicators gauge the level of risk related to lack of access to these infrastructural services within a country. The SHDB data showed that risk of access to an improved source of drinking water and to sanitation (urban and rural) and electricity were low across the CooCE sectors in all four countries (SHDB, 2024). This is important since the proportion of the population living predominantly in rural areas in CooCE countries, although declining, it is still notable, being highest in Italy (29%), followed by Greece (20%), the UK (16%) and Denmark (12%)(see Table 3, section 4).

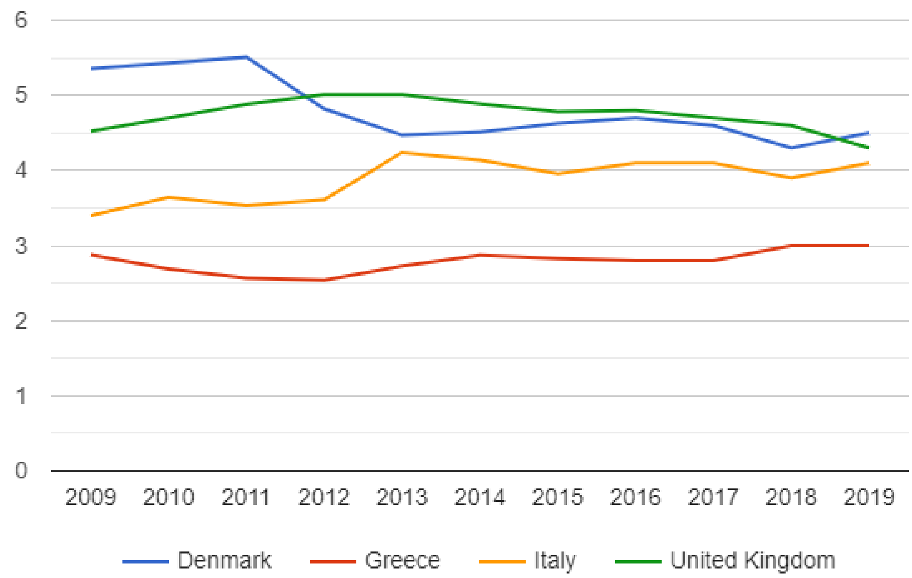
A further indicator relating to rural infrastructure is the quality of roads. Figure 20 shows the ranking for quality of roads in CooCE countries on average scores over the decade (2009-2019). As can be seen, CooCE countries rank above the middle of the scale. Denmark is ranked highest amongst all CooCE countries both at the begining and end of the period with throughs and peaks along the way, although it ended at a lower score than at the begining. The UK is the second highest ranking country, with scores that moved in a similar fashing as Denmark, ending at a lower ranking than at the start and at on a downward trend. Greece ranked third, with scores rising and declining over the period but climbing up markedly until about 2018. Italy was the lowest ranking in quality of roads, althoguh the scores picked up quite markedly throughout up until 2018. Road quality is important as road transportation is an integral feature of the

CooCE concept (i.e., the transportation of biogas, biofuels, and other intermediate and finished products), although it may also necessitate further infrastructure (e.g. pipelines; railways).



Source: The Global Economy (2024) https://www.theglobaleconomy.com//rankings/roads_quality/
Figure 20 Quality of roads in CooCE countries (1=low; 7=high)

Railways are also an important component in rural infrastructure and is likely to be one of the means of transportation used in CooCE countries to carry intermediate and final products. Figure 21 illustrates the ranking for quality of railways in CooCE countries on average scores over the decade 2009-2019. The ranking scores for three of the countries are placed above the mid-scale, bar Greece. The graph shows that Denmark ranked the highest early in the decade but declined somewhat by the early 2010s, being overtaken by the UK until about 2018, but rising again as the highest ranking at the end of the decade. Italy ranked third, although her scores rose markedly up until the mid-2010s and then more or less stabilised thereafter. Greece was the last ranked country in terms of railroad infrastructure quality, which declined early in the period, but improved towards the mid of the decade and further at the end.



Source: The Global Economy (2024) https://www.theglobaleconomy.com//rankings/railroad_quality/
Figure 21 Quality of railroad infrastructure (1=low; 7=high)

4.8 Job Creation and Wages

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Job creation and wages	• Jobs created • Wages paid according to national/regional regulations (minimum wage)	National Local	All	*Qualitative* Literature SHDB Workshop *Quantitative* Secondary databases Survey

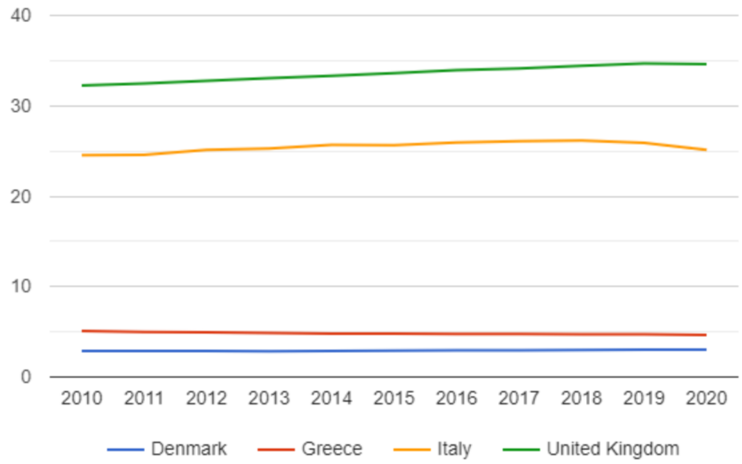
A first key indicator is GDP per capita, which serves as a useful measure of a country's overall economic environment and can influence the availability and quality of jobs. In general, a higher GDP per capita tends to create more favorable conditions for job creation and improvement in job quality, although other factors such as education, labour market policies, and social welfare systems also play significant roles in shaping employment opportunities (EC, 2021). A higher GDP per capita often correlates with increased investment in education and skills development, as well as infrastructure (e.g., transportation, energy), which are critical for fostering innovation, technological advancement, and the creation of new industries and job opportunities in sectors such as construction, engineering, biotechnology, and renewable energy. Furthermore, higher per capita GDP can enhance the quality of jobs by providing better benefits, job security, and working conditions, as economic growth typically leads to improvements in social safety nets and labor standards (EC, 2022). Data for this indicator for CooCE countries is shown in Table 10, for three separate years over a decade. As can be expected, the value of GDP per capita varies across the countries and over time, although it has increased over the period in all four countries. As can be seen, Denmark has had the highest rate, which is also much higher than that for the whole of the EU. The UK has the second highest rate, which is also higher than the EU rate. Italy comes behind, with rates nearer those for the EU, whilst Greece has the lowest per capita GDP which is also markedly lower than the rate for the EU. Hence, the data suggests that higher per capita GDP countries may offer more readily favourable conditions for implementing CooCE, whereas in medium and lower per capita GDP countries perhaps the implementation of CooCE itself could help drive wider economic development.

Table 10 Real GDP per capita in CooCE countries

Real GDP per capita (PPS)	*Denmark*	*Greece*	*Italy*	*UK*	*EU27*
2012	44 110	16 940	26 160	30 190	25 110
2019	48 920	17 780	27 230	32 910	28 050
2022	51 600	18 619	28 250	39 079	28 920

Sources: EUROSTAT (2024) Online data codes: sdg_08_10; https://doi.org/10.2908/SDG_08_10
Statista (2024) https://www.statista.com/statistics/970672/gdp-per-capita-in-the-uk/

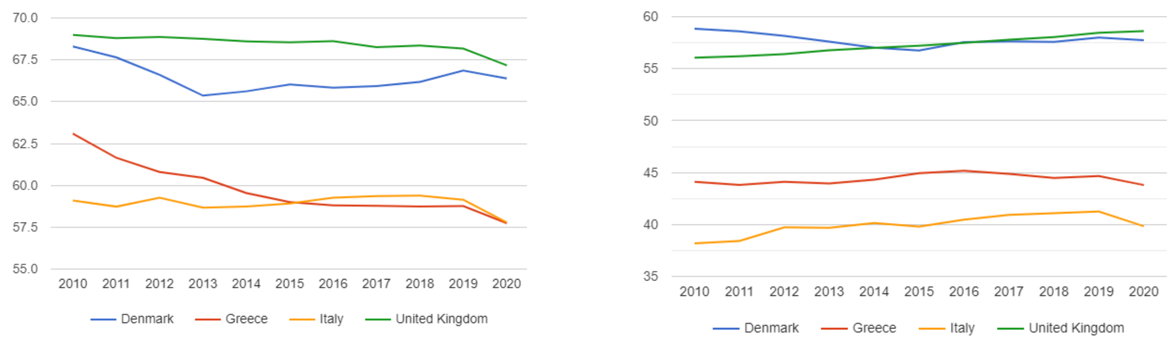
The next indicator is the size of the labour force, shown in each of the CooCE countries in Figure 22 covering de decade between 2010-2020. As the diagram shows, the labour force has expanded continuously in the UK, and for the best part of the decade in Italy too. But there was little change in the size of the labour force in both Denmark and in Greece over the period.



Source: The Global Economy (2024) https://www.theglobaleconomy.com/compare-countries/

Figure 22 The labour force in CooCE countries, 2010-2020 (million people)

Another indicator is labour force participation by gender. Figure 23 shows the rates of gender participation in the four CooCE countries for the 2010-2020 decade. A notable feature of the data shown in the diagrams is nearly a reversal of rates of participation over the period which declined for men, but increased for women in Italy, and the UK. At the start of the period, in the UK, the rate for men was 69% and 56% for women, whereas in 2020 it had declined to 67% for men and risen to 58% for women. In Greece, at the start of the decade, the rate for men was 63%, and for women 44%, but at the end of the period, it had decreased for men to 58%, although for women, the rates hovered around the 44% mark throughout the period. In Italy, at the start of the period, the rate for men was 59% and 38% for women, dropping to 58% for men and rising to 40% for women in 2020. Denmark was an exception to these trends, with rates for men dropping from 68% in 2010 to 65% in 2013 but picking up to 66% at the end of the decade. A similar trend was observed in the rate for women, which dropped from 59% in 2000 to 57% in 2015, rising thereafter to 58% in 2020.



Rates for men Rater for women

Source: The Global Economy (2024) https://www.theglobaleconomy.com/compare-countries/

Figure 23 Labour force participation rate by gender, 2010-2020 (%)

Another important labour market indicator is the gender split according in the economic sectors. Table 11 shows the employment rates by gender in sectors relevant to CooCE in the four countries. In *agriculture*, Greece stands out as employing a similar proportion of both men and women (9% of total employment each) which is also the highest of all countries where, despite the much lower rates, men predominate over women in the sector. Clearly, *agriculture* is a relevant sector for CooCE, since it may provide many of the feedstocks for biogas production, and it also raises issues around land ownership and its implications (i.e., small, or large-scale farming; men or women landowners). Men also dominate in *industry* and in *construction*, except in the UK where the difference in rates is less marked, which also points to the importance of these sectors in the other CooCE countries. Conversely, though, there is parity or near parity in participation by gender in the *professional, scientific, and technical activities*, except in Italy, where women actually predominate.

Table 11 Sectoral Employment by Gender (%)

Year/country	Denmark		Greece		Italy		UK	
	M	W	M	W	M	W	M	W
Agriculture								
2022	3	1	9	9	5	2	1	.5
Industry								
2022	17	8	15	8	13	3	6	2
Construction								
2022	11	1	6	1	11	1	6	1
Professsional, Scientific and Technical Activities								
2022	9	9	8	9	9	13	5	4
Total Employment Across all Sectors								
2022	1 486.4	1 377.8	2 321.0	1 709.2	12 884.4	9 528.1	17 087.0	16 002.0

Sources: EUROSTAT (2024) Online data code: lfst_r_lfe2en2; DOI: 10.2908/lfst_r_lfe2en2; ONS (2024) Key: M= Men; W=Women

Turning to pay rates, Table 12 shows the mean annual gross earnings by men and women in 2018 (latest available data) in relevant sectors in the four CooCE countries. As can be seen, men were earning more than women in all sectors across all countries. Within countries, in Denmark, men and women alike earned the highest wages in the *electricity and gas sector,* and men and women alike earned the lowest wages in *industry and construction*, although the same rate was paid to women in *transportation and storage.* In Greece, men earned the highest rates in *professional, scientific, and technical activities*, and women did so in *transportation and storage*, wheres men and women alike earned the lowest rates in *industry and construction*. In Italy, men and women earned the most in *electricity and gas*, but men earned the least in *transportation and storage*, and women, in *industry and construction*. Finally, in the UK, men and women both earned the most in *professional, scientific, and technical activities*, and both earned the least in *transportation and storage*.

Table 12 Mean Annual Gross Earnings in CooCE countries by economic activity and gender, 2018

	Denmark	Greece	Italy	UK
Electricity and Gas (Euros)				
Men	87 343	31 892	50 419	55 933
Women	69 242	23 416	43 650	40 431
Industry and Construction (Euros)				
Men	67 697	22 147	37 490	44 989
Women	60 890	19 794	31 819	35 882
Transportation and Storage (Euros)				
Men	68 929	30 540	33 366	40 983
Women	60 890	25 938	31 837	35 665
Professional, Scientific and Technical Activities (Euros)				
Men	85 314	32 779	49 979	61 200
Women	65 253	22 276	37 197	43 345

Source: EUROSTAT (2024) Online data code: EARN_SES18_27; DOI:10.2908/earn_ses18_27

Another economic indicator linked to paid employment is low wage earners as a proportion of all employees. The data for CooCE countries is shown in Table 13. As can be seen, Greece has the highest proportion of low-wage earners, whilst Denmark has the lowest. In Denmark, Greece and the UK, the highest proportions of low-wage earners worked in *manufacturing*, whereas in Italy the low-paid workforce were found in *transportation and storage*.

Table 13 Low-wage Earners as a Proportion of all Employees by economic activity, 2018 (%)

2018 Low-wage earners as a proportion of all employees by economic activity (%)			
Denmark	*Greece*	*Italy*	*UK*
Electricity and gas			
1.15	6.59	0.58	1.19
Manufacturing			
2.98	19.55	4.04	10.67
Transportation and Storage			
2.31	11.22	8.57	7.54
Professional, Scientific and Technical Activities			
4.0	12.61	4.25	5.06

Source: EUROSTAT (2024) Online data code: earn_ses_pub1n; DOI: 10.2908/earn_ses_pub1n

Regarding wages still, indicators from the SHDB were used to assess the level of risk related to wage issues in CooCE sectors in the four CooCE countries. The results are shown in Table 14. As can be seen the risk that these sectors would pay workers below wage benchmarks (i.e. Living Wage, 'Sweatfree' Wage, Minimum Wage) was assessed as low across the sectors and countries, except for electricity in Italy, for which no data was available.

Table 14 Assessment of Risks Linked to Wage Issues

Risks to Wages Issues	Overall country-sector risk that average wage is below the benchmarks				
	Risk that sector's average wage is below Living Wage				
	Risk that sector's average wage is below 'Sweatfree' Wage				
CooCE countries/ Sectors	***Chemicals/plastics***	***Electricity***	***Gas***	***Transportation***	***Water***
Denmark, Greece, UK, Italy	L	L	L	L	L
	Risk that Sector average wage is below country Minimum Wage				
Denmark, Greece, UK	L	L	L	L	L
Italy	L	ND	L	L	L

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; Y= yes; risk level colour is as used in the SHDB

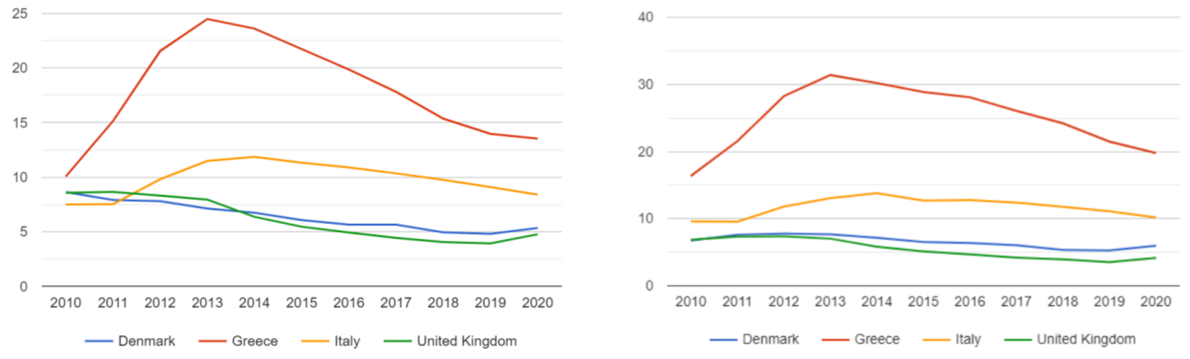
Indicators from the SHDB were used to assess the level of risk of lack of access to employment benefits. Table 15 shows the results of the risk assessment to access to paid annual leave, sick leave and parental leave. As can be seen, Denmark was the only CooCE country where risk of lack of access to social benefits was assessed as low.

Table 15 Risks of Access to Social Benefits from Employment

CooCE countries/ Sectors	***Chemicals/plastics***	***Electricity***	***Gas***	***Transportation***	***Water***
	Overall Social Benefits (paid annual leave; sick leave; parental leave)				
Denmark	L	L	L	L	L
Greece, Italy, UK	M	M	M	M	

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; risk level colour is as used in the SHDB

Unemployment is a further indicator of labour market dynamics that is important consider, since it points to potentially available pools of labour that can be engaged in various stages of value chains created by projects such as CooCE. Figure 24 shows the unemployment rates for men and women in CooCE countries. As can be seen, there is great similarity in the trends for both men and women. The rates for both men and women had increased markedly in Greece and Italy from early to mid-decade, declining thereafter, although ending slightly higher than at the start. By contrast, the unemployment rates for men in Denmark and the UK decreased throughout the decade, whilst for women, they changed little until the mid-decade but declined thereafter.



a) Rates for men b) Rates for women

Source: Source: The Global Economy (2024) https://www.theglobaleconomy.com/compare-countries/

Figure 24 Unemployment Rate by Gender, 2010-2020 (%)

The SHDB was used to assess the unemployment issues in the CooCE sectors across all four countries, with the results shown in Table 16. As the table illustrates, the 'hotspots' are the risk of very high levels of unemployment in Greece and Italy in all CooCE sectors, and also high risk of overal unemployment. Further highlights are medium levels of unemployment in Denmark across all sectors, and of vulnerable employment in Greece, Itally and the UK across all sectors.

Table 16 Risk of Unemployment in CooCE sectors and countries

CooCE countries/ Sectors	*Chemicals/plastics*	*Electricity*	*Gas*	*Transportation*	*Water*
	Overall Unemployment Risk				
Denmark, UK	L	L	L	L	L
Greece, Italy	H	H	H	H	H
	Unemployment Level				
Denmark	M	M	M	M	M
Greece, Italy	VH	VH	VH	VH	VH
UK	L	L	L	L	L
	Vulnerable Employment				
Denmark	L	L	L	L	L
Greece, Italy, UK	M	M	M	M	M
	Unemployment Programs in Place				
Denmark, Greece, Italy, UK	L	L	L	L	L

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; risk level colour is as used in the SHDB

One further indicator related to the labour market is sectoral skills availability, which can be gauged from the skills shortage index , which is shown on Table 17 for CooCE countries in 2019. Negative values represent skills surplus, whilst and positive values represent skills shortage. As can be seen, the UK skills shortage was rather marked in the UK, particularly in *Training and Education*, whilst Greece had the most skill surplus across the sectors, except in *Training and Education*, where there was a shortage of skills. In Denmark, there was also a noticeable shortage of skills in all sectors, except in transportation, with the shortage being most marked also in *Training and Education.* The picture was rather more mixed in Italy, with shortages in Transportation and also in *Training and Education*, but surpluses in all other sectors, particularly *Resource Management*. Understanding the skill gaps and training needs in these sectors is important to ensure that local populations have the requisite skills to access the employment opportunities that the implementation of CooCE may create, including mobilising groups from amongst the unemployed who may posses tranferable skills. The data in Table 17 suggests that both Greece and Italy might be more readily accommodate the implementation of the CooCE concept in terms of skills requirements in three sectors (e.g. Engineering, Mechanics and Technology; Resource Management; Scientific Knowledge).

Table 17 Index of Skills Shortage (2019)

Sector	*Denmark*	*Greece*	*Italy*	*UK*
Engineering, Mechanics and Technology	0.213	-0.132	-0.017	0.12
Production and Processing	0.228	-0.142	-0.03	0.034
Transportation	-0.31	-0.333	0.026	0.04
Resource Management	0.003	-0.326	-0.759	0.116
Scientific Knowledge	0.399	-0.104	-0.03	0.273
Training and Education	0.524	0.21	0.659	0.501

Source: OECD (2024) https://data-explorer.oecd.org/

A final indicator of relevance is the the proportion of people at risk of poverty or social exclusion, since this population may be more vulnerable to the potential negative impacts of CCUS projects such as CooCE (e.g. displacement, environmental pollution, etc), or may conversely, also benefit from training and employment opportunities associated with CooCE's implementation. Table 18 shows the proportion of this population in CooCE countries at two points in time. As can be seen, Greece had the highest proportion of people at risk of poverty and social exclusion in the two years, followed closely behind by Italy, and by the UK, with Denmark showing the lowest proportion, which was also below the rate for the whole of the EU.

Table 18 Persons at risk of poverty or social exclusion in CooCE countries, 2022 (%)

Year/Country	*Denmark*	*Greece*	*Italy*	*UK*	*EU-27*
2015	18.6	32.4	28.4	23.1	23.9
2022	17.3	26.3	24.4	22.0	21.6

Sources: EUROSTAT (2024) Online data code: ilc_peps01n ; DOI: 10.2908/ilc_peps01n ; JRF (2024)

Clearly, the implementation of CooCE will help create jobs through its supply and value chains across various activities: planning, design, construction, procurement, manufacturing, operations, transportation and distribution, sales, legal, technical, professional, and financing services. However, estimating the number of direct and indirect jobs that a CooCE-based biogas capture plant and its associated processes may create is challenging due to the numerous context-specific and intersecting variables that apply to both existing and new-build plants. These variables include factors such as location, plant size and capacity, workforce size, skills requirements, capital and operational costs, market demand, policy and regulatory frameworks, local environmental conditions, health and safety standards, and the extent of community engagement. Additionally, there is potential for job creation within related industries, such as chemicals manufacturing, waste management facilities, and supply chains that support the biogas and CCUS. For instance, Eadson et al. (2022) report that high-level estimates by the UK government indicates that the deployment of CCUS in Britain can potentially help lead to the creation of some 50,000 jobs (mainly in construction) and up to 6,000 highly skilled, high-waged low-carbon jobs in planned CCUS clusters when they become operational. Previous estimates indicate that between 1,000-2,500 jobs may be created during construction in each new CCUS power plant installation and a further 200-300 jobs created in operation and maintenance (including between 40-100 jobs in the plant itself) and the associated supply chain (TUC, 2014). However, in general, the focus of such estimates is on CCS, rather than CCUS (i.e., the utilisation phase seems generally absent from such analyses) such as CooCE.

Nevertheless, whilst is undoubted that CooCE will help create employment, other issues, besides jobs number, will need close consideration during project planning, design and implementation at the local level, as they impact community well-being with implications for social sustainability: quality of jobs, employment stability (i.e. permanent or temporary), wage levels, social benefits from employment, and upskilling opportunities. In particular, efforts should be made to engage labour from local communities and, where necessary, to collaborate with local training institutions to promote upskilling to enable engagemetn of the local workforce.

4.9 Gender Equity

No Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Gender equity	Inclusion of women	National	Feedstock Transport Storage	*Qualitative* SHDB

Gender equity refers to the processes that produce gender equality, that is, that produce equality of outcomes regarding access to and enjoyment of a range of opportunities, such as economic participation and decision-making, regardless of gender (UNWOMEN, 2024). Gender equality is one of the 17 Sustainable Development Goals (Sustainable Development Goal number 5) for achieving a better and more sustainable future for humanity. Specifically, SDG5 aims to eradicate all forms of discrimination against women and ensure their full and effective participation and equal opportunities in all facets of social life (UNWOMEN, 2024). Gender equity and equality therefore are integral to any discussion about sustainability.

Regarding the sphere of work, the ILO has set out conventions relating to equality of treatment at the workplace which address gender equality issues, two of which are highly pertinent to CooCE. There is the Discrimination (Employment and Occupation) Convention (1958), which safeguards against discrimination of the basis of race, colour, sex, religion, political opinion, national extraction, or social origin. There is also the Equal Remuneration Convention (1951) prescribes equal remuneration for men and women for work of equal value.

The previous examination of parameters has already the disparate that exists between men and women on several indicators in CooCE sectors and countries. This was seen in relation to labour market participation and income earning (parameter 'job creation and wages'). Analysis of further indicators reveal more inequalities between men and women, such as the gender employment gap (the difference between the employment rates of men and women). Table 19 shows the gender employment gap in CooCE countries along with the average for the EU27 in three years over the 2012-2022 decade. As the data shows, at the start of the period, the gap was widest in Italy, followed closely by Greece and then by the UK, whereas in Denmark the gap was the narrowest, being multiple times lower than the other countries. Halfway through the period, the gender employment gap only increased in Denmark, although it remained the lowest amongst the countries. At the end of the period, the gap increased only in Greece, declining in Denmark and the UK, and stabilising in Italy. Denmark is the only country where the gap is well below the rate the EU27 in all three years, whereas, by contrast, the rate for the other three countries were much higher than the rate for the EU27.

Table 19 Gender Employment Gap in CooCE Countries

Year/Country	*Denmark*	*Greece*	*Italy*	*UK*	*EU27*
2012	6.4	20.1	20.5	19.6	11.8
2017	7.8	18.6	19.7	18.4	11.3
2022	5.4	21.0	19.7	14.4	10.8

Sources: EUROSTAT (2024) Online data code: sdg_05_30: DOI:10.2908/sdg_05_30; ONS (2024a)

A further indicator of gender inequality is the gender pay gap (the difference in average gross hourly earnings between women and men). Table 20 shows the gender pay gap in CooCE groups along with the average rate for the EU27 for two years. As can be seen, in 2018, the gap was smallest in Italy, with a much lower rate than that for the other CooCE countries and the average rate for the EU, followed by Italy and Greece, being widest in the UK. In 2022 (except for Greece, for which there was no data), the gap remained smallest in Italy, whilst rates dropped markedly in the UK, and decreased also in Denmark (although remaining above the rate for the EU in both cases).

Table 20 Gender Pay Gap in CooCE Countries and Sectors (%)

Year/Country	*Denmark*	*Greece*	*Italy*	*UK*	*EU27*
2018	14.8	10.4	5.5	19.8	14.4
2022	13.9	10.4	4.3	14.4	12.7

Sources: EUROSTAT (2024) Online data code:earn_gr_gpgr2; DOI: 10.2908/earn_gr_gpgr2; ONS (2024b)

A final indicator of relevance is the UN GII. This index reflects gender-based disadvantage in reproductive health, empowerment, and the labour market, ranging from 0, where women and men fare equally, to 1, where one gender fares as poorly as possible in the three dimensions (UNDP, 2024). Table 21 shows the GII values for CooCE countries for three years over the 2002-2022 decade. As the data shows, the gap in gender inequality has been closing across the countries over the period, being narrowest in Denmark, followed by the UK and Italy, but widest in Italy.

Table 21 Gender Inequality Index for CooCE Countries

Year/Country	*Denmark*	*Greece*	*Italy*	*UK*
2002	0.062	0.216	0.187	0.211
2012	0.042	0.125	0.115	0.162
2022	0.009	0.120	0.057	0.094

Sources: UNDP (2024)

The SDBH was also used to assess the risk of risk of gender inequality in CooCE countries and sectors. The results are shown in Table 22. As can be seen, the overall risk of gender inequality was assessed as low across all sectors and countries. But whilst Global Gender Gap Index was assessed as low in Denmark and the UK, in Greece and Italy it was assessed as medium.

Table 22 Risk of Gender Inequality in CooCE Countries

CooCE countries/ Sectors	*Chemicals/plastics*	*Electricity*	*Gas*	*Transportation*	*Water*
	Overall Gender Equality Risk				
Denmark, Greece, Italy, UK	L	L	L	L	L
	The Global Gender Gap Index				
Denmark, UK	L	L	L	L	L
Greece, Italy	M	M	M	M	M

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; Y= yes; risk level colour is as used in the SHDB

4.10 Labour Conditions

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Labour conditions	ILO conventions and human rights: • child Labour • trafficking • forced labour • right to organise	National	All	*Qualitative* Literature SHDB *Quantitative* Secondary databases Survey

This parameter focuses on issues related to labour conventions and human rights. Labour and working conditions are largely regulated by national legislation that may incorporate elements from the conventions and policies drawn up and overseen by the ILO. The representatives of governments, employers and workers are brought together through the ILO to jointly shape policies, programmes, and standards. The ILO has also developed mechanisms for overseeing enforcement and ratification of conventions, protocols, and recommendations by member states. The most relevant and overarching conventions that cover labour themes relevant to CooCE are shown on Table 23, along with the year of ratification.

Table 23 ILO Conventions Applicable to CooCE Countries

No	Convention and Year Issued	Year of Ratification			
		Denmark	Greece	Italy	UK
Freedom of Association, Collective Bargaining, and Industrial Relations					
87	Freedom of Association and Protection of the Right to Organise (1948)	1951	1962	1958	1949
98	Right to Organise and Collective Bargaining (1949)	1955	1962	1958	1950
135	Workers' Representatives Convention (1971)	1978	1988	1981	1973
Forced Labour					
29	Forced Labour (1957)	1932	1952	1934	1931
105	Abolition of Forced Labour Convention (1957)	1958	1962	1968	1957
Equality of Opportunity and Treatment					
100	Equal Remuneration (1951)	1960	1975	1956	1971
111	Discrimination (Employment and Occupation) (1958)	1960	1984	1963	1999
Migration for Work					
97	Migration for Employment Convention	NR	NR	1952	1951
143	Migrant Workers (1975)	NR	NR	1981	NR
Elimination of Child Labour and Protection of Children and Young Persons					
138	Minimum Age (1973)	1997	1986	1981	2000
182	Worst Forms of Child Labour (1999)	2000	2001	2000	2000
190	Violence and Harassment (2019)	NR	2021	2021	2022

Source: ILO (2024) Key: NR: not ratified

The ratification of these conventions nonetheless, the SHDB was used to to assess risks of lack enforcement of labour conventions at country level or in CooCE countries and sectors. The results are shown in Table 24. As can be seen, the risk of lack of enforcement of labour laws and conventions was low in all four counries in transportation, and medium for all countries in the electricity and water sectors. In the gas sector, it was low except in Denmark, and in chemicals/plastics it was low for Italy and the UK, but medium for Greece and Denmark.

Table 24 Risk of Lack of Enforcement of Labour Laws and Conventions

Labour Laws and Conventions					
CooCE countries/ Sectors	***Chemicals/plastics***	***Electricity***	***Gas***	***Transportation***	***Water***
	Risk of lack of enforcement of labour laws and conventions				
Denmark	M	M	M	L	M
Greece	M	M	L	L	M
Italy	L	M	L	L	M
UK	L	M	L	L	M

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; risk level colour is as used in the SHDB

The SHDB was also used to to assess risks of excessive working time in the CooCE sectors across the countries, with results shown on Table 25. The overall risk of excessive working time was assessed as low for Denmark and the UK, and middle for Italy, but high for Greece. The risk of working above 48 hours per week was assessed as medium for the UK, but low for the other three countries. Further, the risk of lack of regulations on working time or their implementation was assessed as low for Denmark and the UK, and as medium for Greece and Italy.

Table 25 Risks Related to Working Time

Excessive Working Time					
CooCE countries/ Sectors	***Chemicals/plastics***	***Electricity***	***Gas***	***Transportation***	***Water***
	Overall risk excessive working time				
Denmark, UK	L	L	L	L	L
Greece	H	H	H	H	H
Italy	M	M	M	M	M
	Risk of working >48 hours per week				
Denmark, Greece, Italy	L	L	L	L	L
UK	M	M	M	M	M
	Lack of regulatory framework for working hours and its implementation				
Denmark, UK	L	L	L	L	L
Greece, Italy	M	M	M	M	M

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; risk level colour is as used in the SHDB

A further issue regarding work is the use of child and forced labour, which was also assessed with use of the SHDB. Table 26 shows the results on the risk that child labour and forced labour may be found in the CooCE sectors across the four countries. Regarding the risk of child labour, the risk of presence of child labour was assessed as medium for Greece in all sectors, and as low in all sectors in the remaining countries. The risk of forced labour was found to be medium for Italy in all sectors, low for the UK in all sectors, and high for Greece in all sectors. For Denmark, the risk of forced labour was low in electricity, gas, and water, but medium in chemicals and transportation. A further risk assessed was the presence of trafficked persons across CooCE sectors in all countries. As can be seen, the risk was low only in the UK, and medium in the other countries.

Table 26 Risk of Use of Child and Forced Labour

CooCE countries/ Sectors	***Chemicals/plastics***	***Electricity***	***Gas***	***Transportation***	***Water***
	Overall country-sector risk of child labour				
Denmark, Italy, UK	L	L	L	L	L
Greece	M	M	M	M	M

	Overall country-sector risk of forced labour				
Denmark	M	L	L	M	L
Greece	H	H	H	H	H
Italy	M	M	M	M	M
UK	L	L	L	L	L
	Risk of trafficking in persons				
Denmark, Greece, Italy	M	M	M	M	M
UK	L	L	L	L	L

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; risk level colour is as used in the SHDB

A final issue of importance relates to risks migrant workers face in CooCE countries and sectors. The UN defines a migrant worker as "a person engaged in a remunerated activity in a state of which he or she is not a national", although this definition excludes certain types of migrants (e.g. employees of international organisations, government officials, investors, refugees stateless persons, students and trainees, non-national non-resident seafarers and workers on an offshore installation). Migrant workers contribute to their host country economy and the remittances they send home help boost the economies of their countries of origin, but are often vulnerable to exploitation, discrimination, violence and poor working conditions (David et al., 2019). The SHDB was used to assess overall risks to migrant workers, which include the risk that conventions and policies are not ratified for the protection of migrant workers and evidence-based risk to migrant workers). As can be seen in Table 27, the results show that overall risks relating to migrant workers are very high in all sectors in three CooCE countries, except for Denmark, where the are assessed as medium.

Table 27 Risks to Migrant Workers

CooCE countries/ Sectors	*Chemicals/plastics*	*Electricity*	*Gas*	*Transportation*	*Water*
	Overall risk regarding migrant workers				
Denmark	M	M	M	M	M
Greece, Italy, UK	VH	VH	VH	VH	VH

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; Y= yes; risk level colour is as used in the SHDB

4.11 Health and Safety

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Health and safety	• Compliance with occuptional health and safety regulations • Occupational health and safety risks	National Local	All	*Qualitative* Literature SHDB *Quantiative* Secondary databases Survey

This parameter examines occupational health and safety regulations and risks. All four CooCE countries have national OSH legislation and strategies in place to address health and safety at work which were also recently reviewed (Schmits-Felten and Lieck, 2019). In addition, all four have ratified the ILO convention on inspections at the workplace (Table 28) to ensure the enforcement of the legal provisions that apply to working conditions and the protection of workers while at work, including safety, health, and welfare of workers (ILO, 2024).

Table 28 ILO Labour Inspection Convention

No	Convention and Year Issued	Year of Ratification			
		Denmark	Greece	Italy	UK
81	Labour Inspection Convention (1947)	1958	1955	1952	1949

Source: ILO (2024) https://normlex.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_INSTRUMENT_ID:312226

In general, the higher the number of processes involved and the higher the complexity of systems, the higher occupational health and safety risks and hazards. The CooCE concept is to be implemented along three pathways to obtain distinct products based on the extraction of CO_2 from biogas (biofuels, BioSA and PHAs), which involves capture, diverse conversion processes, as well as transportation, storage and use. Table 29 shows data on non-fatal accidents at the workplace in CooCE sectors in the four CooCE countries at two points in time to give a sense of change. As can be seen, the data paints a rather mixed picture. The highest figures for non-fatal accidents were recorded for men in *Transportation and Storage* in Italy, followed relatively close by the UK, which were multiple times those for other countries for both men and women. The same largely apply to the figures for men working in the *Land transportation and Transport via Pipelines* in Italy, which were also much higher than those for the UK, the second highest amongst the countries, and the highest for women working in this sector across the four countries. Similarly, Italy had the highest number of men working in *Manufacture of Rubber and Plastic Products* and was followed again by the UK, a pattern that is also observable for figures in *Manufacture of Chemicals and Chemicals products*. Finally, Italy also had the highest figures of all countries for non-fatal accidents involving men and women in *Professional, scientific, and technical activities*, although the data points to a declining trend.

Table 29 Non-fatal Accidents at Work in CooCE countries by Sector and Gender (N)

	Denmark		*Greece*		*Italy*		*UK*	
Year/Gender	M	W	M	W	M	W	M	W
Electricity/ gas								
2016	67	11	65	12	705	79	427	28
2021 (UK 2018)	106	15	68	6	419	39	437	25
Land transportation and transport via pipelines								
2016	1 767	223	121	18	12 726	658	8 962	3 452
2021 (UK 2018)	2 435	376	193	12	12 884	695	7 789	2 971
Manufacture of chemicals and chemical products								
2016	97	45	16	5	1 192	196	503	89
2021 (UK 2018)	171	74	22	7	1 015	166	489	55
Manufacture of rubber and plastic products								
2016	223	65	41	4	3 189	392	1 665	202
2021 (UK 2018)	251	125	49	6	3 098	387	1 515	211
Professional, scientific and technical activities								
2016	448	285	30	21	3 101	1 741	404	529
2021 (UK 2018)	761	437	40	19	1 851	929	412	552
Transportation and storage								
2016	3 218	727	343	62	25 192	4 961	22 088	5 950
2021 (UK 2018)	4 176	820	361	51	24 572	4 648	20 693	5 618

Source: EUROSTAT (2024) Online data code:hsw_n2_01; DOI:10.2908/hsw_n2_01

The SHDB also allowed for assessing occupational injuries and fatalities in CooCE sectors and countries. Table 30 shows that overall risk for occupational injuries and fatalities (which includes many other issues) was assessed as medium. The most relevant issues listed in the table were assessed as low, apart from exposure to mechanical forces.

Table 30 Risk of Occupational Injuries and Fatalities

CooCE countries/ Sectors	Chemicals/plastics	Electricity	Gas	Transportation	Water
	Overall risk of occupational injuries and fatalities				
Denmark, Greece, Italy, UK	M	M	M	M	M
	Occupational road injuries and fatalities related risk				
Denmark, Greece, Italy, UK	L	L	L	L	L
	Occupational poison related injuries and fatalities				
Denmark, Greece, Italy, UK	L	L	L	L	L
	Occupational related fire/heat injuries and fatalities				
Denmark, Greece, Italy, UK	L	L	L	L	L
	Occupational related exposure to mechanical forces injuries and fatalities				
Denmark, Greece, Italy, UK	M	M	M	M	M

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; Y= yes; risk level colour is as used in the SHDB.

Occupational health risks and hazards associated with the CooCE concept were also assessed with use of the SHDB, and relate directly to physical, chemical, and biological factors in the environment and related behaviours. As the SHDB does not allow for differentiating the risks for specific products or technologies, the risks are assessed for CooCE's sectors and countries. Table 31 shows the risk levels for a number of issues. As can be seen, 'hotspots' are risks of cancer and COPD (very high in all CooCE sectors across the countries), and overall occupational and health risks (high across all countries and sectors).

Table 31 Occupational Health Risks and Hazards

CooCE countries/ Sectors	Chemicals/plastics	Electricity	Gas	Transportation	Water
	Overall occupational toxic and health				
Denmark, Greece, Italy, UK	H	H	H	H	H
	Occupational noise				
Denmark, Greece, Italy, UK	L	L	L	L	L
	Occupational cancer				
Denmark, Greece, Italy, UK	VH	VH	VH	VH	VH
	Occupational asthma				
Denmark, Greece, Italy, UK	L	L	L	L	L
	Occupational COPD				
Denmark, Greece, Italy, UK	VH	VH	VH	VH	VH
	Occupational Pneuma (respiratory)				
Denmark, Greece, Italy, UK	M	M	M	M	M
	Occupational infectious disease				
Denmark, Greece, Italy, UK	L	L	L	L	L

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; Y= yes; risk level colour is as used in the SHDB

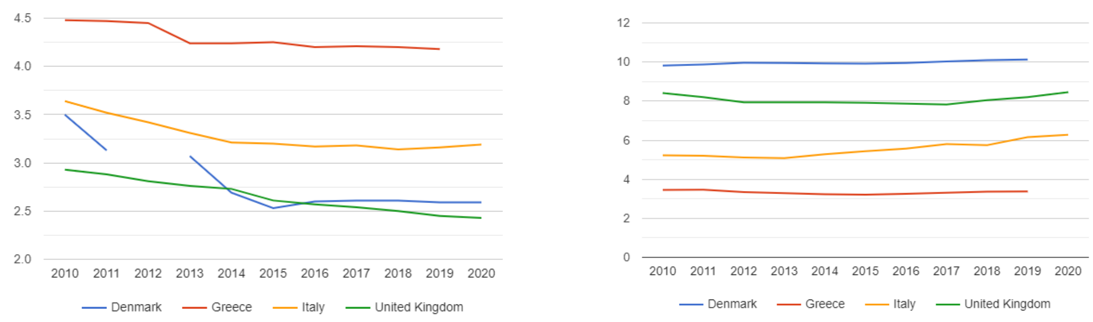
Further indicators of interest in the context of health safety relate to healthcare provision. Table 32 shows data for per capita health spending and health spending as a percentage of GDP at two points in time in CooCE countries. The data shows that Denmarks led with the highest figures for health spending per capita and as percentage of GDP in 2016 and in 2021, whilst Greece had the lowest expenditure in Euros in both years which were also well below the average for the EU as a whole (48% in 2016 and 44% in 2021). Regarding health spending at percentage of GDP, Denmark spent the most in 2016, whilst Greece spent the least. In 2021, the UK spent the most, followed closely by Denmark, whereas Greece had the lowest expenditure of all CooCE countries, which were also below the proportion of the EU. Yet, the trend across the board is for increased expenditure on health.

Table 32 Health Expenditure in CooCE Countries

Health Expenditure in CooCE Countries					
	Denmark	*Greece*	*Italy*	*UK*	*EU 27*
Health spending per capita (EUROS)					
2016	5 066.91	1 368.10	2 440.53	3 662.83	2 806.46
2021	6 223.01	1 576.75	2 837.00	4 765.20	3 562.06
Health spending at % of GDP					
2016	10.25	8.45	8.73	9.73	9.96
2021	10.82	9.17	9.38	12.36	10.87

Source: EUROSTAT (2024) Online data code:tps00207; DOI:10.2908/tps00207;
WHO (2024) https://www.who.int/data/gho/data/indicators/indicator-details/GHO/current-health-expenditure-(che)-as-percentage-of-gross-domestic-product-(gdp)-(-)

Yet other health indicators of interest are those health service delivery, such as availability of hospital beds and healthcare staff. Figure 25a shows the trend for hospital beds availability in CooCE countries between 2010-2020. As can be seen, the trend is for decreasing numbers of beds per 1000 population across the board. Greece has provided the highest levels (4.48 at the start of the decade, and declining to 4.18 in 2020), whilst in general the UK has provided the lowest levels (2.93 in 2010, ending at 2.43 in 2020). Figure 25b shows the availability of nurses per 1 000 population for the four countries. It can be seen that Denmark has the highest levels of provision, in contrast to Greece, which has the lowest. In Denmark in 2010, the figure was 8.2 and in 2020 it stood at 10.13. In the UK, it started the decade at 8.41, ending at 8.46 in 2020. In Italy, the figure stood at 5.23 in 2010, and ended the decade at 6.28, the highest growth of all countries. In Greece, the figure was 3.45 in 2010, ending the decade at 3.38, the only country to show a decline over the period.



a) Hospital beds per 1 000 people b) Nurses per 1 000 people
Source: The Global Economy (2024) https://www.theglobaleconomy.com/compare-countries/
Figure 25 Health Service Delivery (2010-2020)

Finally, the SHDB was used to assess risks related to access to healthcare infrastructure and staff in CooCE countries. Table 33 shows the levels of risks to access to hospital beds and nurses and midwives. As can be seen, risk for access to hospital beds were assessed as medium for Denmark and the UK across the sectors, but low for Greece and Italy in all sectors. The risk to access to staff was assessed as low for Denmark and medium for the UK, but high for both Greece and Italy. The overall risk to access to health care is thus assessed as medium.

Table 33 Risks to Access to Healthcare

CooCE countries/ Sectors	***Chemicals/plastics***	***Electricity***	***Gas***	***Transportation***	***Water***
Overall risk related to access to health care					
Denmark, Greece, Italy, UK	M	M	M	M	M
Risk of access to hospital beds					
Denmark, UK	M	M	M	M	M
Greece, Italy	L	L	L	L	l

	Risk of access to nurses/midwives				
Denmark	L	L	L	L	L
Greece, Italy	H	H	H	H	H
UK	M	M	M	M	M

Source: SHDB (2024) Key: L= low; M=Medium; H=High; VH= Very High; ND= No Data; Y= yes; risk level colour is as used in the SHDB

4.12 Competition with other sectors

Parameter	Characteristics/ criteria	Assessment Level	Supply chain stage	Data type and source
Competition with other sectors	Competition and negative impacts on other industries and sectors	National Local	Feedstock Process Products	*Qualitative* Literature Workshop *Quantitative* Survey

The CooCE concept may encounter varying levels of competition from established and emerging uses of CO2 as feedstock in sectors such as chemicals, construction materials, food, medical applications, and cooling systems, which could drive up prices and affect availability. However, the overall demand for CO2 remains relatively low compared to total emissions across industries (IEA, 2023). In its demonstration phase, the CooCE concept is focused on capturing CO2 from biogas plants and upgrading it into biomethane for renewable energy production, including electricity, heating, and transportation fuels such as CNG and LNG. This positions CooCE in direct competition with biomethane plants both upstream (for feedstock sources such as agricultural residues and organic waste) and downstream (in the energy market). Increased competition could lead to various challenges, such as local job losses due to the closure of smaller or less efficient plants, especially in rural areas; rising feedstock prices that smaller plants may struggle to afford; market instability and CO_2 price volatility that disproportionately affects smaller plants with limited resources; reduced social cohesion as tensions arise between different stakeholders (e.g., small versus large producers, or local communities versus external investors); and decreased public support due to real or perceived negative impacts. Although stakeholders at the workshop acknowledged that CO_2 capture could create new revenue streams for biogas producers, they also expressed concern that competition for renewable energy could pose a significant threat to the CooCE concept (see D5.4).

One way CooCE might compete with renewable energy is by offering a pathway for power plants and industrial facilities to reduce their carbon emissions and footprint without necessarily pushing for a complete phase-out of fossil fuels (Jones et al., 2017; IEA, 2020; Naims, 2020). However, integrating renewable energy into certain industries (e.g. steel and cement production) remains particularly challenging, and their emissions may not be easily mitigated by increased reliance on renewable energy or improved efficiencies. In these cases, CCUS solutions such as CooCE can present a cost-effective alternative (Pieri et al., 2018). Despite the fact that nearly two-thirds (64%) of stakeholders surveyed believe that CCUS investments are currently not viable for most industrial sectors, energy production (including energy, gas, biofuels, and oil) was identified as the most promising sector for developing CCUS value chains in the next decade (35% of all sectors). Nevertheless, CooCE may also contribute to increased competition with renewable energy technologies—particularly for funding, subsidies, incentives, and resources—that offer cleaner and more sustainable long-term solutions, as well as with other sectors such as transportation (Jones et al., 2017; IEA, 2020; Naims, 2020).

Competition between CooCE's other bioproducts (i.e biosuccinic acid and PHAs/PHBs) and their fossil-based counterparts may likely help drive down prices for bio-based and fossil-based chemicals and polymers alike. But rising demand for bioproducts stemming from both EU regulations promoting bio-based materials and circular economy principles may drive down production costs due to economies of scale, making biosuccinic acid and biopolymers more cost-competitive than fossil-based alternatives, enhancing CooCE's economic viability, and the environmental benefits of its products lower carbon footprint.

5. 'Hotspots' in CooCE's product system and countries

This section introduces a further assessment that draws on the SHDB to identify the hotspots in the CooCE product system in CooCE countries. This entailed the use of the Combined Social Hotspot Index, which integrates the results of analysis of all risks levels within the CooCE product system in the four countries, providing an overall index of the risks that enables for easy visualisation of the hotspots across them. Figures 26-30 show the combined social hotspot index for CooCE countries and sectors.

Figure 26 Social Hotspot Index for chemicals

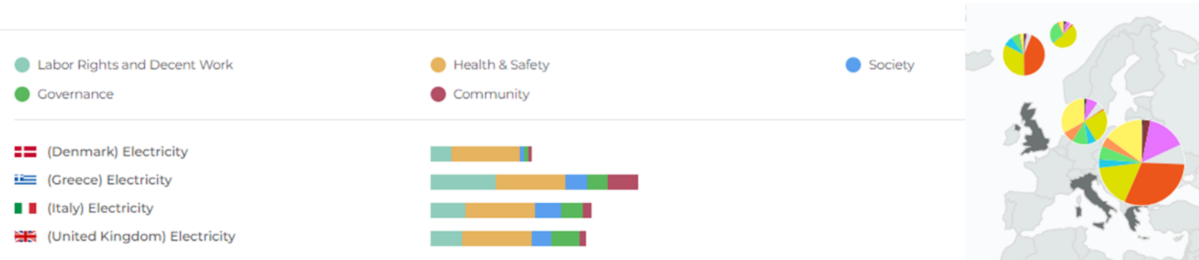


Figure 27 Social Hotspot Index for electricity

Social Hotspot Index for gas

Figure 28 Social Hotspot Index for gas

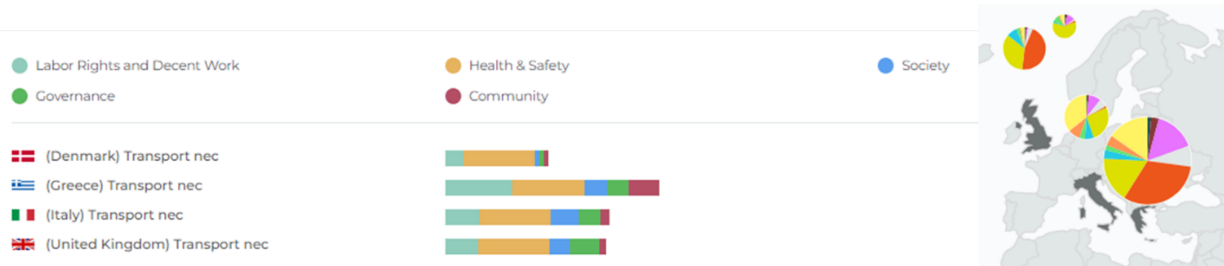


Figure 29 Social Hotspot Index for transport

Figure 30 Social Hotspot Index for water

As the image shows, *Health and Safety* and *Labour Rights and Decent Work* are the main hotspot themes across the sectors in the four CooCE countries in the combined social hotspot index. Implementers of CooCE will need to pay careful attention to them to ensure the prevention or minimisation of negative impacts and the lowering of risks in their industrial and business activities.

6. Overall Social Sustainability Assessment of CooCE

This section introduces the overall assessment of the social sustainability of CooCE. The assessment focuses on the potential impacts, risks or benefits associated with implementing the CooCE concept (i.e. CO_2 capture to produce biomethane, biochemicals and biopolymers for manufacturing bioplastics and biopackaging) in three EU countries and in the UK. The results of the SIA and SLCA parameters are assessed against the criteria shown in Table 34. The overall assessment is shown in the matrix in Table 35, which provides a synoptic view of the key issues and actions, and along with further comments.

Table 34 Criteria for the Overall Social Assessment

Impact	*Type*	*Evaluation*
Direct	D	Where the project itself produces the impact
Background	B	Where local conditions influence implementation of the project
Positive	+	Project likely to produce a benefit
Negative	-	Project likely to produce impact that will not be of social benefit to country/local community
Neutral	N	Project produces no impact at all

Risk	*Benefit*	*Type*	*Evaluation*
L	L	Low	According to the data and indicators examined, and the likelihood of a problem emerging in the future even where the impact was assessed as positive
M	M	Medium	
H	H	High	
VH	VH	Very High	

The colours assigned to risks reflect that of a ‘traffic light’ system: green means it is viable (‘proceed’); yellow is for warning (‘caution’); red is for not viable (‘stop’). The same colours are used for the benefits, but in reverse. Mitigating measures are suggested for potentially negative impacts

Table 35 CooCE: Overall Social Sustainability Assessment

No	Parameter	Characteristics/Criteria	Type	Impact	Risk	Benefit	Actions/Mitigation	Observations
1	Trade of feedstock (carbon)	Incentives	B	+	M	H	Provision of state incentives and subsidies and more efficient/effective financial mechanisms to make CO_2 capture and use viable in initial stages;	Limited funding and incentives for development and deployment of CCUS technologies (e.g. the CooCE concept)
		Barriers	B	-	M		Design of standardised methodologies for measuring/certifying carbon capture; develop specific regulatory frameworks and the market for captured carbon; coordinated efforts between policymakers, industry players, and researchers to create standardised protocols, reduce costs, and ensure regulatory support for captured carboncarbon markets	CCUS not fully integrated into the ETS-I (mechanism does not fully recognise CO_2 use as a valid offset mechanism); limited dedicated infrastructure for CO_2 CTS; inconsistent carbon pricing
2	Identification of stakeholders along the supply chain	Producers Regulators Business Traders Researchers	D	+	L	H	Mapping of all stakeholders (local, regional, national) and ensuring their engagement in all stages of implementation of the CooCE at the local level	Key local level stakeholders (unions; cooperatives; associations) to work collaboratively to help establish CooCE chains (market expansion)
3	Policies and regulations	International National	B	- +	M	VH	Ensure stable, coherent, and interconnected policies for energy, transport, and platform biochemicals to encourage investment in the CooCE concept; devise policies specific to CCUS; amend existing EU policy instruments (e.g. *CEAP, CRCF, ETS-I, FuelEU Maritime, PWD, RED III, TEN-E, WDF);* advocate for policies that support the circular economy and prioritise the use of captured CO_2 to	Extensive EU policy framework for energy, transport and platform biochemicals but many gaps (no specific legislation for CCUS nor bioproducts obtained through it); normative instruments need to be transposed properly/timely by member states to enable and support the scaling up of CooCE into successful commercial ventures;

							reduce competition with other CO_2 sources;	
		Enforcement	D	+	L	H	Timely and effective transposition of EU policies by member states and enactment of all national policies	Risk to governance medium in Greece, Italy, and UK across all CooCE sectors
4	CO_2 point source	Availability of feedstock (CO_2)	B	- +	M	H	Full intergration of CCUS into the EU ETS-I; development of suitable infrastructure for CO_2 CTS	increased competition for CO_2 may reduce availability but this vary by location, type of biomass feedstock, production capacity, and regulatory frameworks
6	Community participation	Acceptance of • feedstocks • techno-processes • products Other involvement	D	-+	M	H	Ensure engagement of local stakeholders in CooCE implementation; awareness-raising campagins on CCUS safety and environmental impacts (e.g. CO_2 leakages; use of water and chemicals; biodegradability)	NIMBY syndrome; poor knowledge about CCUS and bioderadability of products; concerns about impacts on human health and the environment
8	Rural development and Infrastructure	• Roads • Sanitation • Water	B/D	-+	M	H	Build/upgrade/expand infrastructure: capture plants, processing installations, energy supply, pipelines, storage facilities, roads and rail for transporting CO_2,hydrogen and bioproducts (intermediate/final) where quality and safety (human health and environment) should be paramount considerations	Quality of roads and railroads declining in Denmark and the UK but improving in Greece and Italy; CooCE requires CTS infrastructure; increased demand for CooCE's biomethane may help expand infrastructure networks but also create create competition for rural resources (land, water)
9	Job creation and wages	Labour involved in techno-processes (CO_2 capture and upgrading; compression; transportation; storage)	D	-+	M	H	Prioritise local labour pool for employment/new employment opportunities created by CooCE whenever possible; enable skilling/upskilling of labour	Population at risk of poverty or social exclusion higher than EU average in Greece and Italy; very high risk of unemployement in CooCE sectors in Greece and Italy
		Wages paid according to national/regional regulation (minimum wage)	D	+	M	H	Monitor enforcement of legislation to ensure appropriate wage remuneration	Proportion of low-wage earners highest in Greece, lowest in Denmark across CooCE sectors; but low risk in all CooCE countries that average wage levels are below

								benchmarks (Living Wage, Sweat-free Wage)
10	Gender equity	Inclusion of women	**D**	**+**	**M**	**H**	Ensure equality of opportunity or enhanced opportunity to access resources and services to be able to participate in the implementation of CooCE (e.g.jobs, business ownership, supporting services, etc)	Indicators of economic activity by gender shows that men are generally more economically active than women in all CooCE countries, although gender employment and pay gaps have been narrowing
11	Labour conditions	Conventions on • child labour • forced labour • right to organise	**D**	**-+**	**M**	**H**	Monitor enforcement of legislation for labour protection to prevent excessive working time and exploitation of migrant workers	CooCE countries are signatories of most ILO conventions but there is a medium risk of lack of enforcement of labour laws and conventions in four sectors in all countries; high risk of excessive working time and of forced labour in Greece in all CooCE sectors; very high risk for migrant workers in Greece, Italy and the UK across all sectors
12	Health and safety	Compliance with health and safety regulations at the different stages of the chain	**D**	**+**	**H**	**H**	Monitor enforcement of legislation for health and safety at the workplace to minimise risk of injuries and occupational hazards	All CooCE countries have legislation in place for Health and Safety at the workplace and are long-standing signatories of the Labour Inspection Convention; very high overall occupational toxic and health risks in all four CooCE countries and sectors; medium overall risk regarding access to health care
13	Competition with other sectors	Competition and negative impacts on other industries and sectors	**D**	**-**	**M**	**L**	Take action to mitigate disruption of any established uses for CO2 (e.g. biogas for biomethane upgrading); CooCE developers can collaborate with established CO_2 users through partnerships and joint ventures to supply captured CO_2 for their existing processes, thus creating synergies that can help both sides optimise CO_2 use	CooCE may face some competition for CO_2 for its products (biomethane; biochemicals and biopolymers) as well as unfavourable competition with fossil fuels (subsidies and prices)

7. Overall Policy Assessment

The EU policy arena contains myriad instruments that are applicable to CooCE concept, to varying degrees (section 4.4.; also Appendix III). The policy assessment showed that many can play an enabling or supporting role to the successful commercial deployment of CooCE at industrial scale, through CO_2 capture and its conversion into valuable bioproducts, thereby contributing to the diverse goals set out in various policy agenda (energy, climate, industry, transport) that ultimately all aim to help mitigate or stave off climate change. Yet, despite the EU's ambition to achieve climate neutrality by 2050, the regulatory framework supporting CCUS remains fragmented and underdeveloped, raising pressing economic, technological, and environmental issues that impact the widespread implementation of CooCE /CCUS in the EU (Kourmentza et al., 2017; Pieri et al., 2018; Bolscher et al., 2019; Turnau et al, 2019; IEA, 2019, 2020; UNECE, 2021; Chen et al., 2022; ETC, 2022; Greenfield, 2022; JCR, 2022; Ramirez et al., 2022; Thielges et al., 2022; Borchardt et al., 2023; Dziejarski et al., 2023; Gowd et al., 2023; Storss et al., 2023; Vicente et al., 2023; Kumar et al., 2024; Peres et al., 2024; Talus and Maddahi 2024). The most relevant of these are discussed here with added recommendations to help develop a more integrated, supportive and robust framework for CCUS/CooCE. Challenges from overarching instruments are discussed first, followed by issues arising from instruments relevant to each of CooCE's bioproducts.

7.1 Challenges from Overarching EU Policy Instruments

Lack of Comprehensive Legal Framework for CCUS

Challenges: There is currently no unified or comprehensive EU regulatory framework for CCUS. Instead, CCUS is governed by various pieces of legislation, each focusing on different aspects such as emissions reduction, environmental protection, innovation, and infrastructure. Key legislations include the *ETS-I*, the *TEN-E Regulation*, the proposed *CRCF*, and the *Innovation Fund*. These current directives, regulations, and funding programs cover aspects of CCUS but lack an integrated approach.

Recommendations: Create a comprehensive legal framework that includes specific policies for all aspects of CCUS and aligns cross-sector regulations to ensure consistency and coherence for projects such as CooCE.

Lack of Integration of CCUS with Circular Economy Policies and the WDF

Challenges: CCUS is not yet comprehensively incorporated into the EU's circular economy policies, which means it misses out on potential synergies with recycling and waste management initiatives. The 2023 update to the *CEAP* prioritises recycling and waste reduction but still falls short of integrating CCUS into circular carbon economies, limiting its recognition in industrial sectors. Meanwhile, the revised *WDF* continues to regard CCUS as a valid method for waste treatment and recycling that adds value to waste, but this limits its potential in industries producing CO_2 as a byproduct of waste treatment.

Recommendations:

- Integrate CCUS into circular economy strategies, aligning its technologies with waste reduction and recycling goals
- Revise the WDF to acknowledge CCUS as a legitimate waste management solution, enabling industries to capture and utilise CO_2 instead of treating it as waste

- Explicitly include CCUS in circular economy frameworks, especially in sectors that can reuse captured CO_2 as a raw material.

Unclear Definition and Lack of Recognition of CCUS in EU Energy Policies

Challenges: CCUS lacks a clear definition and recognition in several EU climate and energy policies, preventing it from consistently qualifying under renewable energy or emission reduction schemes. The *REDIII* fails to specify how CCUS technologies contribute to renewable energy targets and does not explicitly acknowledge CO_2 reuse from industrial processes.

Recommendations:

- Establish a clear definition of CCUS within EU legislation acknowledges its role in circular carbon economies
- Amend the *REDIII* to explicitly include CCUS technologies that use renewable energy for CO_2 conversion, allowing these projects to contribute to renewable energy targets.

Misalignment of CCUS with the ETS-I

Challenge: The EU *ETS-I* focuses mainly on emissions reduction, providing limited support for CCUS due to its emphasis on CO_2 reuse. Despite the recent revision enhancing carbon pricing, it still fails to fully acknowledge CO_2 utilisation as a valid offset mechanism. Consequently, CCUS projects are excluded from financial incentives available to CCUS, potentially discouraging investment in them.

Recommendation: Revise the *ETS-I* to better support and encourage CCUS by offering credits for CO_2 utilised in CCU processes, acknowledging it as a legitimate carbon offset method.

Inconsistent CO_2 Accounting Methodologies for CCUS

Challenges: The variety of CO_2 accounting methods across EU member states and sectors, combined with a lack of unified accounting rules for CO_2 emissions, create uncertainty about CCUS's role in carbon neutrality targets. The 2023 revision of the *Energy Union Governance Regulation* fails to offer clear guidelines for CO_2 emissions accounting related to CCUS, leading to inconsistencies across member states.

Recommendations:

- Develop a standardised CO_2 accounting framework across the EU that specifically includes provisions for CO_2 used in CCUS processes
- Ensure CO_2 utilisation is recognised within climate action plans under the *Energy Union* framework.

Regulatory Barriers for Cross-Border CO_2 Transport

Challenges: Discrepancies in the legal and regulatory treatment of CO_2 transport and utilisation across borders hinder the development of transnational CCUS projects. The *TEN-E* regulation primarily supports energy infrastructure for electricity and gas, but CCUS projects often lack adequate CO_2 transportation networks. The recent update to the *TEN-E* regulation still does not provide enough support for CO_2 transport, especially in cross-border scenarios where CCUS projects may benefit from shared CO_2 pipelines.

Recommendations:

- Harmonise regulations for cross-border CO_2 transport to ease the implementation of CCUS projects throughout the EU and simplify cross-border permitting and operations

- Revise the *TEN-E* regulation to include and prioritise CO_2 transport infrastructure, particularly cross-border CO_2 pipelines, ensuring robust support for CCUS projects.

Inconsistent Carbon Pricing

Challenge: Variations in carbon pricing across member states under the *Effort Sharing Regulation* create market distortions that impact the viability of CCUS projects.

Recommendation: Introduce a consistent carbon price floor across the EU to ensure CCUS projects enjoy stable and predictable carbon market conditions.

Unclear Position of CCUS in the FuelEU Maritime Regulation

Challenge: The revised *FuelEU Maritime* regulation fails to clearly outline the role of CCUS in decarbonising maritime transport, thereby missing potential applications for captured CO_2.

Recommendation: Revise the regulation to incorporate provisions for CCUS technologies that can mitigate maritime emissions by utilising alternative fuels derived from captured CO_2, such as biomethane.

Challenges in Achieving Carbon Removal Certification

Challenge: the recently introduced *CRCF* does not yet fully recognise the role of CCUS in carbon removal, as it focuses primarily on long-term storage.

Recommendation: Update the framework to encompass CCUS technologies that facilitate the long-term use of CO_2 within circular carbon economies.

Lack of comprehensive EU legislation for biobased, biodegradable, and compostable plastics

Challenges: Without a clear legal framework, companies producing bioplastics from captured carbon face uncertainty regarding regulation and classification, deterring investment and hindering market development. The absence of comprehensive legislation leads to inconsistencies in certification and labelling standards, making it challenging for such bioplastics to be recognised as sustainable alternatives. Current EU incentives for sustainable materials primarily support bio-based and biodegradable products, potentially sidelining captured carbon bioplastics , which may not qualify for the same financial or policy support despite their environmental benefits. The lack of comprehensive EU-level regulation slows the development of standards for the quality and sustainability of carbon captured bioplastics, limiting producers' ability to demonstrate compliance and market their products. The *CEAP* emphasises biodegradable and compostable plastics but lacks specific guidelines for integrating captured carbon bioplastics into the circular economy. Additionally, varying regulations across EU member states lead to market fragmentation, making it difficult for captured carbon bioplastics to scale up across the EU.

Recommendations:

- Establish clear regulatory definitions and standards for bioplastics, distinguishing between biobased, biodegradable, compostable, and products made from captured carbon to provide certainty for producers and investors
- Harmonise certification and labelling schemes across the EU to ensure carbon captured bioplastics are recognised under existing or new bioplastic certifications, such as those for biodegradability or compostability
- Amend EU policies to include captured carbon bioplastics within the scope of financial incentives and circular economy strategies to ensure that they are treated equally with biobased alternatives

- Accelerate the development of EU-wide standards for bioplastics covering biodegradability, compostability, and environmental performance metrics, such as the carbon footprint of captured carbon materials.
- Amend the *CEAP* to include provisions for carbon captured bioplastics, aligning them with principles of circularity, particularly in packaging and other high-use sectors.
- Establish a harmonised regulatory framework for biobased and biodegradable plastics, including captured carbon bioplastics, across all member states to ensure a consistent market.

Limited Funding and Financial Support Mechanisms

Challenges: Lack of funding mechanisms hampers the deployment of CCUS technologies. While *Horizon Europe* supports innovation, it doesn't sufficiently address the specific challenges CCUS faces, such as cost-effective scalability and technological development.

Recommendations:

- Expand EU funding programs, such as *Horizon Europe* and the *Innovation Fund*, to specifically support large-scale CCUS pilot projects, showcasing their commercial viability and scalability
- Increase dedicated funding for CCUS research within *Horizon Europe*, focusing particularly on pilot projects that enhance cost-effectiveness and scalability.

Research and Development Gaps

Challenge: Despite the promise of CCUS technologies, there are still considerable R&D gaps, especially in terms of cost-effectiveness and scalability.

Recommendation: Boost R&D funding to enhance the cost-efficiency and scalability of CCUS technologies, focusing especially on public-private partnerships.

7.2 Challenges from EU Policy Instruments Covering Biomethane

Challenges: The *REDIII* primarily targets biogas from organic sources for renewable energy, but it does not explicitly include biomethane produced from CCUS, limiting its eligibility for renewable energy incentives; the *ETS-I* does not provide clear carbon credits or financial incentives for converting captured CO_2 into biomethane, affecting the profitability and market competitiveness of this technology; the *FuelEU Maritime Regulation* focuses on reducing the carbon footprint of maritime fuels, but lacks specific guidelines on how CCUS-derived biomethane can aid in decarbonising maritime transport; the *TEN-E regulation* supports the development of energy infrastructure across Europe but does not adequately address the infrastructure needs for biomethane produced from CCUS, particularly for injection into natural gas grids; the *Hydrogen Strategy* promotes hydrogen produced from renewable energy sources but does not fully integrate the potential role of biomethane from CO_2 and renewable hydrogen; the *Guarantees of Origin* system under the *REDIII* does not clearly account for biomethane produced from CCUS, complicating its certification and labelling as a sustainable or low-carbon fuel; differences in biomethane support schemes and regulatory frameworks across EU member states lead to market fragmentation, making it difficult for biomethane produced from CCUS to compete across Europe; public awareness and understanding of the environmental benefits of CCUS-derived biomethane are still very limited, as current EU communication strategies do not adequately promote it as a sustainable solution for the energy transition.

Recommendations:

- Amend the *REDIII* to explicitly recognise biomethane from captured CO_2 as a renewable energy source, making biomethane from CCUS eligible for subsidies and inclusion in national renewable energy targets.
- Modify *ETS-I* to allow biomethane from CCUS to earn carbon credits, incentivising industries to capture CO_2 for producing renewable gases such as biomethane, thereby enhancing economic viability
- Revise the *FuelEU Maritime* regulation to include biomethane from CCUS as a recognised low-carbon fuel for maritime applications, creating a clear pathway for its adoption in shipping and other maritime industries
- Extend the *TEN-E* regulation to include the development of infrastructure for the injection and transport of CCUS-derived biomethane, ensuring it can be integrated into existing gas networks
- Integrate biomethane into the *Hydrogen Strategy* as a complementary low-carbon energy carrier, particularly in sectors where hydrogen and biomethane can be used interchangeably or together
- Revise the *Guarantees of Origin* framework to include biomethane from CCUS, ensuring it can be certified and marketed as a renewable and low-carbon energy source
- Harmonise biomethane regulations across member states to ensure that captured carbon biomethane has consistent market access and can benefit from uniform support mechanisms throughout the EU
- Increase public awareness campaigns and industry education efforts on the benefits of biomethane from CCUS, positioning it as a crucial element for decarbonising transport and heating.

7.3 Challenges from EU Policy Instruments Covering BioSuccinic Acid

Challenges: the *CEAP* does not explicitly recognise captured carbon chemicals, such as biosuccinic acid, as contributors to circularity, a regulatory gaps might prevent producers from benefiting from incentives aimed at promoting circular materials and reducing carbon emissions in industrial sectors; the *ETS-I* mechanism does not currently offer carbon credits for the utilisation of CO_2 in producing biosuccinic acid, limiting access to financial incentives for industries adopting CCUS technologies and making it less economically viable compared to other carbon reduction options such as CCUS; the *REACH* regulation does not clearly differentiate between biosuccinic acid produced from CCUS processes and conventionally produced chemicals, creating uncertainty around labeling, compliance, and market acceptance; biosuccinic acid produced from CCUS technologies may not be fully recognised under the *REDIII*, restricting its inclusion in sectors that aim to increase their use of renewable or low-carbon inputs; the *WDF* directive does not provide clear end-of-life management guidelines for CCUS-derived chemicals, such as biosuccinic acid, especially in terms of recyclability and integration into waste management systems, which could lead to improper disposal and missed opportunities for recycling; the *Bioeconomy Strategy* aims to promote the use of renewable resources in the production of chemicals but does not explicitly include CCUS-derived chemicals such as biosuccinic acid, limiting the scope for integrating CCUS technologies into broader bioeconomy frameworks, particularly in relation to chemicals and materials.; the *PWD* and other related bioplastics policies do not adequately recognise biosuccinic acid as a key building block for biodegradable or recyclable materials, preventing the full integration of CCUS-based biosuccinic into bioplastic and sustainable packaging industries; the *CRCF* focuses mostly on long-term carbon storage, overlooking the role of biosuccinic acid produced via CCUS as a form of carbon removal, thus limiting the ability of companies to claim carbon credits for producing biosuccinic acid; low public and industrial sector awareness of CCUS-based biosuccinic acid, partly due to the lack of EU policies explicitly promoting its use, hinders market acceptance and limits the potential for industrial-scale adoption.

Recommendations:

- Amend the *CEAP* to include biosuccinic acid and other captured carbon biochemicals, promoting their adoption across industries that can utilise renewable alternatives
- Modify the *ETS-I* to provide credits for capturing and utilising CO_2 in the production of biosuccinic acid, creating stronger market incentives for CCUS adoption in the chemical industry
- Establish clear regulatory pathways under *REACH* for captured carbon biochemicals, ensuring that biosuccinic acid from captured CO_2 benefits from streamlined regulatory approval and labelling as a sustainable alternative
- Revise the *REDIII* to include captured carbon biosuccinic acid as part of the renewable materials mix, particularly for industries relying on biobased chemicals
- Amend the *WDF* to include specific provisions for captured carbpm biochemicals, ensuring their incorporation into recycling and waste treatment frameworks
- Update the *Bioeconomy Strategy* to recognise captured carbon biosuccinic acid as a renewable chemical that can contribute to decarbonisation efforts across various industrial sectors
- Revise packaging and bioplastic legislation to acknowledge the role of biosuccinic acid in producing sustainable, recyclable packaging materials, especially as a precursor to bioplastics such as polybutylene succinate
- Expand the *CRCF* to include CCUS-derived biosuccinic acid as a valid form of carbon removal, allowing companies to earn carbon credits for using captured CO_2 in chemical production
- Increase awareness through campaigns about the benefits of biosuccinic acid produced from CCUS, promoting its integration into high-demand industries such as packaging.

7.4 Challenges from EU Policy Instruments Covering PHAs/PHBs

Challenges: Current EU legislation does not explicitly recognise captured carbon PHAs/PHBs, creating a regulatory gap, and the lack of clear definitions for these bioplastics makes it difficult for manufacturers to market them as sustainable; bioplastics are subject to fragmented and inconsistent standards across EU member states, presenting certification challenges for captured carbon PHAs/PHBs, especially around biodegradability and compostability, an inconsistency that may exclude them from incentives and labelling schemes available to other bioplastics; captured carbons PHAs/PHBs are not explicitly recognised in the *CEAP* as contributing to circularity, which could limit their uptake in circular economy initiatives and prevent clear pathways for their contribution to EU waste reduction and material reuse goals; the *ETS-I* incentivises carbon reduction projects but does not offer financial incentives for the utilisation of captured CO_2 in producing PHAs/PHBs bioplastics, weakening their economic feasibility; waste legislation, such as the *WFD*, does not provide clear guidelines for the disposal or recycling of captured carbon PHAs/PHBs, an ambiguity that confuses waste management operators, potentially leading to improper disposal or incineration; the *Single-Use Plastics Directive* aims to reduce plastic pollution but does not provide specific exemptions for captured carbon PHAs/PHBs bioplastics, limiting their market potential under the same restrictions as fossil-based plastics; the *PWD* does not explicitly address captured carbon bioplastics in its recycling targets or material requirements for packaging, leaving PHAs/PHBs in a regulatory limbo regarding their role in reducing packaging waste; the *CRCF* focuses on long-term carbon storage with limited recognition for captured carbon PHAs/PHBs bioplastics as a valid form of carbon sequestration, hence limiting the ability of companies to claim carbon credits for producing these materials; the *Horizon Europe* funding framework offers limited targeted funding for R&D of captured carbon PHAs/PHBs bioplastics, potentially restricting innovation in scaling up production and improving their cost-effectiveness.

Recommendations:

- Establish specific regulatory frameworks for captured carbon bioplastics to ensure they are included under existing or new sustainability standards

- Harmonise standards across the EU to make captured carbon PHAs/PHBs eligible for certifications in biodegradability, compostability, and carbon footprint reduction, providing clear market pathways
- Amend the *CEAP* to explicitly cover captured carbon PHAs/PHBs bioplastics, particularly in sectors prioritising plastics recycling and biodegradability, such as packaging
- Adjust the *ETS-I* to offer carbon credits for CO_2 used in bioplastic production, encouraging companies to produce PHAs/PHBs through CCUS processes
- Update the *WFD* to include specific end-of-life management protocols for captured carbon PHAs/PHBs, such as recycling, composting, and biodegradation
- Revise the *Single-Use Plastics Directive* to provide exemptions or incentives for captured carbon PHAs/PHBs biodegradable bioplastics, considering their lower environmental impact compared to fossil-based plastics
- Review the *PWD* to recognise captured carbon bioplastics as part of sustainable packaging solutions contributing to the EU's packaging waste reduction goals
- Expand the *CRCF* to include captured carbon bioplastics as a form of carbon removal, allowing producers of PHAs/PHBs to claim carbon credits
- Increase dedicated funding within *Horizon Europe* for captured carbon bioplastics to support the technological development of PHAs/PHBs.

The Way Forward: enabling industrial-scale and sustainable deployment of CCUS in the EU

The implementation of CCUS technologies in the EU faces several significant policy stumbling blocks that must be addressed to unlock their full potential and enable their sustainable industrial-scale deployment. Inadequate incorporation of CCUS in key climate policies, regulatory fragmentation and instability, insufficient financial support, and market barriers are the main challenges hindering the widespread adoption of CCU. Harmonising regulations across member states, providing targeted financial support, and integrating CCU more explicitly into climate and circular economy frameworks will be crucial to overcome these obstacles. Addressing these policy deficiencies will not only facilitate the deployment of CCUS but also contribute to the EU's broader decarbonisation and sustainability goals.

7.5 Challenges from Overarching UK Policy Relevant to CCUS/CooCE

As with the EU, the UK policy arena contains a range of instruments that are applicable to CooCE's concept. The assessment of central instruments showed that they can play enabling role to the successful industrial scale deployment of CooCE through CO_2 capture and its conversion into valuable bioproducts, thereby contributing to the diverse goals set out in environment, energy, climate, industry, transport policy agenda. However, the assessment showed that the regulatory framework relevant to CCUS remains fragmented and underdeveloped, raising pressing economic, technological, and environmental issues that impact the widespread implementation of CooCE /CCUS in the UK (Kourmentza et al., 2017; UKGOV, 2018; Allen and Hammond, 2019; BEIS, 2019a, b; IEA, 2020; Dickson et al., 2021; Bywater et al., 2022; Eadson et al., 2022; LSE/GI 2023; Vicente et al., 2023; Kumar et al., 2024). The most relevant of these are discussed, here with added recommendations to help develop a more integrated, supportive and robust framework for CCUS/CooCE. Challenges from overarching instruments introduced first, followed by issues arising from instruments relevant to each of CooCE's bioproducts.

Challenges: There is a lack of comprehensive and clear regulatory frameworks for CCUS, particularly for the reuse of captured CO_2 in products such as chemicals and fuels; financial mechanisms and incentives specifically targeting the use of captured CO_2 in products are limited; the carbon price under existing carbon emissions trade mechanisms, such as the UK ETS, is not robust enough to incentivise investment in costly CCUS infrastructure, making capturing and reusing of CO_2 less financially rewarding than offsetting emissions; there is a also a shortage of adequate shared infrastructure for transporting and utilising CO_2 across multiple industries.

Recommendations:

- Create detailed regulations specifically for CCUS projects, outlining the legal, environmental, and operational requirements, such as permitting processes, environmental impact assessments, and safety standards for CO_2 deployment across the sectors
- Establish dedicated funding streams for CCUS technologies under the *GGSS* and the *CCUS Innovation Programme*, along with other financial incentives, such as capital grants, tax credits, and enhanced carbon credits for captured carbon products to support industrial-scale deployment of CCUS.

7.6 Challenges from UK Policy Instruments Covering Biomethane

Challenges: The policy framework for captured carbon biomethane is fragmented, involving multiple regulatory bodies and schemes (e.g., ETS, GGSS), a complexity that can delay project approvals and increase compliance costs, thus discouraging investment; the costs of capturing and utilising CO_2 are high, and existing subsidies do not sufficiently cover the capital investment required for CCUS infrastructure; there are no clear guidelines or consistent standards governing the utilisation of captured CO_2 for producing biomethane, which can deter investment in this technology; biomethane produced from captured carbon generally requires substantial upfront investment, but its short-term economic viability is uncertain, especially if carbon prices do not justify the costs of implementing CCUS technologies; policies supporting innovation in renewable energy often prioritise carbon capture and storage over capture and utilisation. This limits the potential for reusing captured CO_2 in biomethane production and constrains its contribution to advancing the circular economy.

Recommendations:

- Streamline the various regulatory requirements affecting biomethane and CCUS integration to align regulations across different schemes
- Provide additional financial incentives, such as capital grants and tax relief, or enhanced support under existing schemes for biomethane producers incorporating CO_2 capture to help bridge financial gaps
- Develop clear regulatory standards for using captured CO_2 in biomethane production.
- Increase the carbon price under the *UK ETS* to reflect the true cost of carbon emissions, making CCUS projects more economically attractive
- Provide carbon credits or offset opportunities specifically for industries that integrate CO_2 capture in biomethane production
- Encourage more demonstration projects focused on CCUS technologies in biomethane production through targeted funding under existing innovation schemes.

7.7 Challenges from UK Policy Instruments Covering Biosuccinic Acid

Challenges: Producing biosuccinic acid through CCUS is still cost-prohibitive due to the high capital investment required for CO_2 capture technologies and the fermentation processes to convert CO_2 into biosuccinic acid; current financial support mechanisms aren't robust enough to attract investment in CCUS-based production; the existing regulatory framework lacks clear definitions for CO_2 utilisation processes in chemical manufacturing, including biosuccinic acid production; current policies do not sufficiently promote bio-based chemicals as part of the UK's circular economy and decarbonisation goals; biosuccinic acid, as a bio-based platform chemical, lacks targeted incentives to replace fossil-based chemicals under existing legislation.

Recommendations:

- Expand targeted financial mechanisms, such as grants, tax credits, and enhanced carbon credits, for industries incorporating CCUS technologies in chemical production, including biosuccinic acid
- Adapt the GGSS to offer incentives for low-carbon chemicals
- Develop a comprehensive regulatory framework that clearly defines processes and standards for CO_2 utilisation in chemical manufacturing (e.g., biosuccinic acid production) to provide producers with legal certainty
- Increase the carbon price under the ETS or offer specific carbon credits for industries utilising captured CO_2 for producing biosuccinic acid.

7.8 Challenges from UK Policy Instruments Covering PHA/PHB bioplastics

Challenges: Producing PHA/PHB bioplastics through CCUS involves significantly higher costs than conventional plastics due to the expensive substrate materials and advanced fermentation and CO_2 utilisation technology require; there is limited policy guidance or financial support specifically for CCUS in bioplastic production; current financial mechanisms do not provide sufficiently strong carbon pricing to incentivise the use of captured CO_2 in bioplastic production; production of captured carbon PHA/PHB bioplastics is still under development (e.g. biomass fermentation and scalability), which impacts costs and efficiency, thereby lowering the competitiveness of these bioplastics.

Recommendations:

- Expand the *CCUS Innovation Programme* to introduce specific grants and tax credits for projects utilising captured CO_2 to produce PHA/PHB bioplastics, helping to offset high production costs and bolster innovation
- Establish clear, legally binding standards for CO_2 utilisation in PHA/PHB bioplastics production, including the necessary permits, monitoring systems, and compliance requirements for CCUS projects within the plastics industry
- Strengthen the UK ETS by raising the carbon price or offering carbon credits specifically for industries adopting CCUS technologies in bioplastic production to enhance the financial viability of carbon-negative production.

8. Conclusion and Recommendations

This document presents an assessment of the potential socio-economic impacts and risks associated with integrating the CooCE concept into a value chain, as well as an analysis of the relevant policy instruments that significantly affect CooCE. Social sustainability assessment, one of the four pillars of the sustainability framework applied to CooCE, focuses on the social dimension, which is often overlooked in supply chain analyses due to the complexity and nature of the data required. The methodology used for assessing the social sustainability of biorefineries represents a novel approach, combining SLCA and SIA that draws on a variety of data sources. This integrated method leverages both quantitative and qualitative data, enabling a comprehensive evaluation of the potential socio-economic impacts or risks associated with implementing novel bio-technological processes and establishing value chains at the local level.

The successful establishment and sustainable operation of CooCE capture plants and technological processes will be contingent on a complex interplay of factors, conditions, and dynamics across multiple scales. Addressing this complexity necessitates methodologies tailored to the specific characteristics of each carbon capture plant's location, alongside its broader socio-economic and policy context. This includes conducting comprehensive feasibility and impact assessments of the entire supply chain and adhering to frameworks (e.g., the Equator Principles). While the sustainability assessment provided here is not a substitute for these in-depth studies, it underscores both the potential positive and negative impacts, risks, and benefits of implementing CooCE across various socio-economic, policy, and cultural settings within the EU (as summarised in Table 35). CooCE can contribute to socially sustainable development by creating local employment and income opportunities and promoting social well-being and quality of life throughout its value chain, provided that it adequately addresses or mitigates critical 'hotspot' issues such as gender equity, health and safety, labour conditions, and competition for inputs and products. However, the realisation of these positive impacts will largely depend on the degree of integration within its value chain and the influence of policy frameworks that shape the socio-economic conditions within which CooCE will operate. These frameworks will affect access to CO_2, the role of CooCE in achieving decarbonisation targets in key sectors such as energy, transport, and industry, and its competitiveness against fossil-based commodities. These factors form the basis for the recommendations that follow.

Ensuring and Enabling Stakeholder Engagement

As seen previously (section 4.3), a range of stakeholders were identified in the four CooCE countries that will need to work together (and alongside others) to drive the successful implementation of CooCE in them. Indeed, it will be crucial to bring together a multitude of key stakeholders who usually operate in different market sectors (e.g. gas, chemicals, energy, transportation, industry) to cooperate in multi-disciplinary partnerships for discussions and knowledge exchange on CCUS issues, to develop synergies, to foster and accelerate research and techno-innovation for the market take-up of CooCE's technologies and products. Indeed, the social sustainability of CooCE will necessarily require engaging stakeholders through a variety of established and novel methodologies (e.g., workshops, interviews, surveys, focus groups, etc) to help identify and address the gamut of pivotal issues related to CCUS supply/value chains, particularly those that hinge on local dynamics (e.g., community involvement, gender equity, health and safety and working conditions, and adequate remuneration). Effective stakeholder engagement will require a pro-active approach that prioritises early, transparent, and inclusive communication to help build trust, allay doubts, align interests, and foster cooperation. Although it may not always be possible to align or reconcile different the interests and perspectives, stakeholder engagement should be strived for to the greatest extent for the benefit of most.

Leveraging local labour markets and promoting gender equity

Producers and investors involved in implementing CooCE should prioritise recruiting labour from local communities whenever possible, and in rural areas, particularly for low-skilled or unskilled positions, as highly skilled roles may be more challenging to fill locally. CooCE implementers should also provide appropriate working conditions and strictly enforce all necessary regulations to ensure the health and safety of the workforce, paying special attention to 'hotspot' issues to avoid or mitigate them. The CCUS industry (as in many others that require personnel with a background in science and technology) may face gender imbalances, with women underrepresented in technical and

leadership roles. To address this, CooCE implementers should ensure equal employment opportunities for both men and women, along with fair access to income-generating activities, training, upskilling, and career development. They must also ensure equitable wages, including closing any gender pay gaps. Furthermore, CooCE offers a valuable opportunity for producers and businesses to promote gender equality through capacity-building programs such as summer schools, internships, and apprenticeships.

Improving Regulatory Frameworks and Designing Policies for CCUS in the EU and the UK

The strong emphasis on decarbonisation in policy agendas in the EU and the UK can help boost the development of CCUS chains such as CooCE. However, persistent challenges to the implementation of CCUS techno-innovations include regulatory frameworks that lack clarity, integration, stability, consistency, and coherence, lack of adequate enforcement or transposition in a timely manner, whilst many lack instruments tailored specifically to CCUS technologies and products. Both the policy assessment and feedback from CooCE stakeholders highlight the lack of policy instruments specifically designed for CCUS chains, products, and bioproducts. This includes a lack of mechanisms to account for CO_2 content in bioproducts, difficulties in enforcing standards for the commercial use of bioproducts (e.g., food packaging), and insufficient funding and investment mechanisms for developing CCUS biotechnologies and bioproducts. Existing policies are heavily focused on carbon sequestration and storage, often overlooking the development of CCUS infrastructure and markets.

Addressing these policy and regulatory challenges requires coordinated efforts from stakeholders across a wide spectrum: government, industry, business, NGOs, local communities, and others. These interest-groups must collaborate to influence legislative processes, underscore the potential of CCUS to enhance circularity and reduce CO_2 emissions to help stave off climate change, advocate for the creation of policy instruments specific to CCUS, as well as pressing for the integration of CCUS into cross-sectoral policy frameworks. In addition, project developers and funders should develop targeted communication strategies to address knowledge gaps amongst industry leaders about policy instruments for CCUS and all sectors that it encompasses to help accelerate CCUS diffusion and take-up.

Enhancing CooCE's social and policy sustainability

The social and policy assessment presented here reveals that CooCE's techno-processes and products have a role to play contributing to the wider policy goals of lowering carbon emissions from different economic sectors to address climate change. The prospects for CooCE are promising insofar as it offers an interim solution to the seemingly intractable challenge of achieving zero carbon emissions across the economy in the near future, at least in the EU and the UK. Its proposed biomethane can be used for transportation and for energy, and its biochemicals and biopolymers as intermediate products in an array of applications in several industries. However, the social and policy sustainability of CooCE hinge on addressing the weaknesses, threats and challenges identified here, with approaches that ensure the equitable distribution of its benefits, and a commitment to balancing social considerations with economic opportunities and environmental impacts.

****

References

Allen, PE and Hammond, GP (2019) ‘Bioenergy utilization for a low carbon future in the UK: the evaluation of some alternative scenarios and projections’, *BMC Energy*, 1:3; https://doi.org/10.1186/s42500-019-0002-9.

Andrews, E, Lesage, P., Benoît, C, Parent, J, Norris, G, Revéret, J (2009) `Life cycle attribute assessment: Case study of Quebec greenhouse tomatoes’, *Journal of Industrial Ecology*, 13 (4): 565-578.

Afshari, H, Agnihotri, S, Searcy, C, and Jaber, M Y (2022) ‘Social sustainability indicators: a comprehensive review with application in the energy sector’, *Sustainable Production and Consumption* (31): 263-286.

Arning, K, Offermann-van Heek, J, Linsenich, A, Kaetelhoen, A, Sternberg, A, Bardow, A and Siefle, M (2019) `Same or different? Insights on public perception and acceptance of carbon’, *Energy Policy,* 125: 235–249.

BEIS (2019a) *Business Models for Carbon Capture, Usage and Storage,* London, UK: Department for Business, Energy, and Industrial Strategy: https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models; (accessed 27/03/2024).

BEIS (2019b) *Carbon Capture Usage and Storage: A Government Response*, UK Department for Business, Energy and Industrial Strategy: https://www.gov.uk/government/publications/the-uk-carbon-capture-usage-and-storage-ccus-deployment-pathway-an-action-plan; (accessed 28/03/2024).

Benoît-Norris, C, Cavan, DA, Norris, G (2012) ‘Identifying social impacts in product supply chains: overview and application of the social hotspot database’, *Sustainability*, 4: 1946–1965.

Benoît, C, Traverso, M, Valdivia, S, Vickery-Niederman, G, Franse, J, Asuero, L, Aulision, D (2013): *The methodological sheets for sub-categories in social life cycle assessment sLCA*, UNEP-SETAC.

Bolscher, H, Brownsort, P, Opinska, LG, Jordal, K, Kraemer, D, Mikunda, T, Parmiter, P, Rycroft, L, and Yearwood, J (2019) *CCUS in Europe*, EU CCUS Projects Network: https://ccussen.eu/sites/default/files/HLR%20_CCUS-in-Europe.pdf; (accessed 29/11/2023).

Borchardt, K (2023) *Carbon Capture Usage and Storage: the new driver of the EU Decarbonization Plan?* OIES Energy Comment, The Oxford Institute for Energy Studies: https://www.oxfordenergy.org/publications/carbon-capture-usage-and-storage-the-new-driver-of-the-eu-decarbonization-plan/; (accessed 03/08/2024).

Bywater, A, Heaven, S, Zhang, Y and Banks, J (2022) ‘Potential for Biomethanisation of CO2 from Anaerobic Digestion of Organic Wastes in the United Kingdom’, *Processes*, 10(6): 1202; https://doi.org/10.3390/pr10061202.

Ciroth, A, Finkbeier, M, Hildenbrand, J, Klöpffer, W, Masijn, B, Prakash, S, and Sonnemann, G, (2011) *Towards a Life Cycle Sustainability Assessment: Making informed choices on products*, United Nations Environmental Programme (UNEP): Paris.

Chen, S., Liu, J., Zhang, Q., Teng, F. & McLellan, B. C. (2022) 'A critical review on deployment planning and risk analysis of carbon capture, u2liza2on, and storage (CCUS) toward carbon neutrality', *Renewable and Sustainable Energy Reviews*, 167(9): https://doi.org/10.1016/j.rser.2022.112537.

CooCE (2024) *CooCE: harnessing the potential of biological CO2 capture for the Circular Economy*: https://cooce.eu/.

Dalal-Clayton, B, and Sadler, B (2004) *Sustainability Appraisal, A Review of International Experience and Practice*, Institute for Environment and Development: London.

David, F, Bryant, K, Larsen, JJ (2019) *Migrants And Their Vulnerability to Human Trafficking, Modern Slavery and Forced Labour*, International Organisation for Migration: Geneva; https://publications.iom.int/books/migrants-and-their-vulnerability-human-trafficking-modern-slavery-and-forced-labour; (accessed 13/07/2024).

de Luca, AI de, Iofrida, N, Strano, A, Falcone, G, Gulisano (2015) 'Social life cycle assessment and participatory approaches: a methodological proposal applied to citrus farming in Southern Italy', *Integrated Environmental Assessment Management*, 11 (3): 383-396.

Diaz-Chavez, R (2006) 'Measuring Sustainabiltiy in Peri-urban Areas: case study of Mexico City', in Simon, D and Thompson, D (eds) *The Peri-Urban Interface*: approaches to Sustainable Natural and Human Resource Use, Earthscan: London; 246 – 261.

Diaz-Chavez, R (2011) 'Assessing Biofuels: Aiming for Sustainable Development or Complying with the Market? *Energy Policy*, 39: 5763-5769; https://doi.org/10.1016/j.enpol.2011.03.054.

Diaz-Chavez, R (2014) 'Indicators for Socio-Economic Sustainability Assessment', in Ruts, D and R Janseen, (eds) *Socio-economic impacts of Bioernergy Production*, Springer: Switzerland: 17-37.

Diaz-Chavez, R and Evans, Y (2018) *Social and Policy Assessment – COSMOS: https://www.researchgate.net/publication/384066429_D75_Social_and_Policy_Assessment_of_the_COSMOS_Chain_Lead_beneficiary_Imperial_College*.

Diaz-Chavez, R and Evans, Y (2019) *Social Assessment of Underutilised Feedstocks - BIOrescue*: https://www.researchgate.net/publication/384066210_D672_Social_Assessment_of_Underutilised_Feedstocks_Project_Number_720708_Start_date_of_the_project_duration_1_st_September_2016_36_months_Organisation_name_of_lead_contractor_IMPERIAL_COLLEGE_LONDON_O.

Diaz-Chavez, R and Evans, Y (2021) *Social Sustainability Assessment - BioMates: https://www.researchgate.net/publication/384066336_Work_Package_N_o_Task_N_o_WP4_integrated_sustainability_assessment_Task_45_Deliverable_title_Report_on_Social_Sustainability_Assessment_Reviewers_Verification_Report_with_public_summary_BioMates_D_46_*.

Diaz-Chavez, R, Stichnothe, H, Johnson, K (2016) 'Sustainability Considerations for the Future Bioeconomy', in Lamers,P, Searcy, E, Hess, J R, Stichnothe, H (eds) *Developing the Global Bioeconomy:Technical, Market, and Environmental Lessons from Bioenergy*, Academic Press, pp69-90; DOI: https://doi.org/10.1016/B978-0-12-805165-8.00004-5.

Dickson, R, Mancini, EA, Garg, NA, Woodley, JM, Gernaey, KV, Pinelo, M, Liu, J, Mansouri, SS (2021) 'Sustainable bio-succinic acid production: superstructure optimization, techno-economic, and lifecycle assessment', *Energy and Environmental Science*, 6 (14): 3542-3558; https://doi.org/10.1039/D0EE03545A.

Dziejarski, B., Krzyżyńska, R. & Andersson, K. (2023) 'Current status of carbon capture, utilization, and storage technologies in the global economy: A survey of technical assessment', *Fuel*, 342: 127776; https://doi.org/10.1016/j.fuel.2023.127776.

EC (2021) *Fiscal Policy and Economic Growth in Europe: The Impact of Fiscal Consolidation and the Role of Fiscal Multipliers*, European Economy Institutional Papers 150.: https://ec.europa.eu/info/publications/fiscal-policy-and-economic-growth-europe-impact-fiscal-consolidation-and-role-fiscal-multipliers_en; (accessed 25/06/2024).

EC (2022) *Employment and Social Developments in Europe 2022*. European Commission. Available at: https://ec.europa.eu/social/main.jsp?catId=738&langId=en&pubId=8469

EC (2024a) *Revision of the Energy Taxation Directive (ETD: Questions and Answers*: https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3662; (accessed 09/05/2024).

EC (2024b) *Progress on Climate Action*: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/progress-climate-action_en; accessed 08/02/2024).

EC (2024c) *REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition*: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131; accessed 10/02/2024).

EC (2024d) *REACH Regulation*: https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en#law; (accessed 20/05/2024).

EC (2024e) *ReFuelEU Aviation*: https://transport.ec.europa.eu/transport-modes/air/environment/refueleu-aviation_en; (accessed 15 April 2024).

EC (2024f) *Common Agricultural Policy*: https://agriculture.ec.europa.eu/common-agricultural-policy_en; (accessed 03/06/2024).

EC (2024g) *Communication – EU policy framework on biobased, biodegradable and compostable plastics:* https://environment.ec.europa.eu/publications/communication-eu-policy-framework-biobased-biodegradable-and-compostable-plastics_en; (accessed 19/05/2024).

EC (2024h) *Market Stability Reserve: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/market-stability-reserve_en; (accessed 09/08/2024).*

EC (2024i) *Horizon Europe:* https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horison-europe_en; (accessed 12/07/2024).

EC (2024j) *Innovation Fund*: https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund_en?prefLang=sv; (accessed 12/07/2024).

EC (2024k) *Nature Restoration Law:* https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en; (accessed 15/08/2024).

EBA (2023) *Statistical Report 2023: Tracking biogas and biomethane deployment across Europe*, European Biomass Industry Association, Scotland House, Rond-Point Schuman 6, 1040 Brussels, Belgium.

Eadson, W, Northall, P, Johnston, A, Parkes, S, Wells, P, and While, A (2022) *South Yorkshire low carbon energy supply chains: carbon capture, utilisation and storage (CCUS) sector summary:* https://www.shu.ac.uk/centre-regional-economic-social-research/publications/sector-summary-carbon-capture-utilisation-and-storage-ccus; (accessed 01/11/2023).

EU (2023) EIP-AGRI: agriculture and innovation: https://ec.europa.eu/eip/agriculture/en/ (accessed 23/06/2024).

EUR-lex (2024a) *Proposal for a COUNCIL DIRECTIVE restructuring the Union framework for the taxation of energy products and electricity (recast)*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0563; (accessed 09/09/2024).

EUR-lex (2024b) *Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119; (accessed 08/02/2024).

EUR-lex (2024c) *Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action*: https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ:L:2018:328:TOCanduri=uriserv:OJ.L_.2018.328.01.0001.01.ENG; (accessed 08/08/2024).

EUR-lex (2024d) *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, REPowerEU Plan*; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFINandqid=1653033742483; (accessed 10/2/2024).

EUR-lex (2024e) *Regulation (EU 2022/869) of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2022.152.01.0045.01.ENGandtoc=OJ%3AL%3A2022%3A152%3ATOC; (accessed 23/06/2024).

EUR-lex (2024f) *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413andqid=1699364355105; (accessed 08/08/2024.

EUR-lex (2024g) *Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast)*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001andqid=1695186598766; (accessed 10/02/2024).

EUR-lex (2024h) Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 on establishing a carbon border adjustment mechanism: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R0956; (accessed 11/08/2024).

EUR-lex (2024i) *Directive (EU) 2024/1788 of the European Parliament and https://eur-lex.europa.eu/leal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFINandqid=1653033742483of the Council of 13 June 2024 on common rules for the internal markets for renewable gas, natural gas and hydrogen*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024L1788; (accessed 11/02/2024).

EUR-lex (2024j) *Regulation (EU) 2024/1789 of the European Parliament and of the Council of 13 June 2024 on the internal markets for renewable gas, natural gas and hydrogen*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1789; (accessed 14/07/2024).

EUR-lex (2024k) *Regulation EU (2024/1787) of the European Parliament and of the Council of 13 June 2024 on the reduction of methane emissions in the energy sector:* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AL_202401787; (accessed 14/07/2024).

EUR-lex (2024l) *Directive (EU) 2024/1785) of the European Parliament and of the Council of 24 April 2024 amending Directive 2010/75/EU of the European Parliament and of the Council on Industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC on the landfill waste*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401785; (accessed 23/05/2024).

EUR-lex (2024m) *Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401735; (accessed 19/04/2024).

EUR-lex (2024n) *Commission Regulation (EU) 2022/586 amending XVI to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH):* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32022R0586; (accessed 20/05/2024).

EUR-lex (2024o) *Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFUelEU Aviation)*: https://eur-lex.europa.eu/eli/reg/2023/2405/oj; (accessed 27/05/2024).

EUR-lex (2024p) *Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport*: https://eur-lex.europa.eu/eli/reg/2023/1805; (accessed 28/05/2024).

EUR-lex (2024q) *Regulation (EU) 2023/2405 of the European Parliament and of the Council of 14 May 2024 amending Regulations (EU) 2021/2115 and (EU) 2021/2116 as 2116 as regards good agricultural and environmental condition standards, schemes for climate, environment and animal welfare, amendment of the CAP Strategic Plans, review of the CAP Strategic Plans and exemptions from controls and penalties*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1468; (accessed 03/06/2024).

EUR-lex (2024r) *Regulation (EU) 2023/839 of the European Parliament and of the Council of 19 April 2024 amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member states for 2030, and Regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review*: https://eur-lex.europa.eu/eli/reg/2023/839/oj; (accessed 10/06/2024).

EUR-lex (2024s1) *Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869:* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1722240349976; (accessed 19/08/2024).

EUR-lex (2024s2) *Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system:* https://eur-lex.europa.eu/eli/dir/2023/959/oj; (accessed 23/04/2024).

EUR-lex (2024t) *Regulation (EU) 2023/957 of the European Parliament and of the Council of 10 May 2023 amending Regulation (EU) 2015/757 in order to provide for the inclusion of maritime transport activities in the EU emissions Trading System and for the monitoring, reporting and verification of emissions of additional greenhouse gases and emissions from additional ship types:* https://eur-lex.europa.eu/eli/reg/2023/957/oj; (accessed 25/04/2024).

EUR-lex (2024u) *Regulation (EU) 2023/857 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member states from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and Regulation (EU)2018/1999:* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R0857; (accessed 06/05/2024).

EUR-lex (2024v) *Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2019/631 as regards strengthening the CO_2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition*: https://eur-lex.europa.eu/eli/reg/2023/851/oj; (accessed 16/05/2024).

EUR-lex (2024w) *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable energy sources:* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32023L2413; *(accessed 19/05/2024).*

EUR-lex (2024x) *Proposal for a Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste:* https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/revision-eu-waste-framework-directive; (accessed 22/05/2024).

EUR-lex (2024y) *Proposal for a Regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU)2019/904, and repealing Directive 94/62/EC:https://environment.ec.europa.eu/publications/proposal-packaging-and-packaging-waste_en;* (accessed 03/07/2024).

EUR-lex (2024z1) *Directive (EU) 2015/720 of the European Parliament and of the Council of 29 April 2015 amending Directive 94/62/EC as regards reducing the consumption of lightweight plastic carrier*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32015L0720; (accessed 15/07/2024).

EUR-lex (2024z2) *Directive (EU) 2019/094 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment*: https://eur-lex.europa.eu/eli/dir/2019/904/oj; (accessed 13/02/2024).

EUR-lex (2024z3) *Proposal for a Regulation of the European Parliament and of the Council establishing a Union certification framework for carbon removals:* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0672andqid=1671116014081; *(accessed 12/08/2024).*

EUR-lex (2024z4) *Decision 2015/1814 of the European Parliament and of the Council of 6 October 2015 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme*: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2015.264.01.0001.01.ENG; (accessed 11/07/2024)

EUR-lex (2024z5) *Regulation of the European Parliament and of the Council establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination:* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018PC0435; (accessed 10/08/2024).

EUR-lex (2024z6) *Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC:* https://eur-lex.europa.eu/eli/dir/2003/87/oj; (accessed 11/08/2024).

EUROPARL (2024) *Revision of the Energy Taxation Directive (ETD)*: *https://www.europarl.europa.eu/legislative-train/spotlight-JD22/file-revision-of-the-energy-taxation-directive#:~:text=Its%20aim%20is%20to%20align,electricity%20at%20the%20lowest%20rate;* (accessed 02/08/2024).

ETC (2022) *Carbon Capture, Utilisation and Storage in the Energy Transition: vital but limited*, Energy Transitions Commission: https://www.energy-transitions.org/publications/carbon-capture-use-storage-vital-but-limited/#download-form; (accessed 22/08/2024).

Evans, Y and Diaz-Chavez, R (2023) *D5.4 – Report on CooCE Stakeholders' Workshop*, CooCE: https://cooce.eu/deliverables/.

Falcone, M and Imbert, E (2018) 'Social Life Cycle Approach as a Tool for Promoting the Market Uptake of Bio-Based Products from a Consumer Perspective', *Sustainability*, 10 (4), 1031; https://doi.org/10.3390/su10041031.

FAOSTAT (2024) Food and Agriculture Organisation Database: https://www.fao.org/faostat/en/#home.

Fortier, MP, Teron, L, Reames, TG, Munardy, DT (2019) 'Introduction to evaluating energy justice across the life cycle: A social life cycle assessment approach', *Applied Energy*, 236: 211-219.

Gowd, S. C., Ganeshan, P., Vigneswaran, V. S., Hossain, M. S., Kumar, D., Rajendran, K., Ngo,H. H. & Pugazhendhi, A. (2023) 'Economic perspectives and policy insights on carbon capture, storage, and u2liza2on for sustainable development', *Science of the Total Environment*, 883:163656; https://doi.org/10.1016/j.scitotenv.2023.163656.

Gould, H, Kelleher, L and O'Neill, E (2023) `Trends and policy in bioeconomy literature: A bibliometric review', *EFB Bioeconomy Journal*, Volume 3: https://doi.org/10.1016/j.bioeco.2023.100047.

Greenfield, C (2022) *Legal and Regulatory Frameworks for CCUS: an IEA CCUS handbook*: International Energy Agency: https://iea.blob.core.windows.net/assets/bda8c2b2-2b9c-4010-ab56-b941dc8d0635/LegalandRegulatoryFrameworksforCCUS-AnIEACCUSHandbook.pdf; (accessed 20/10/2023).

Grießhammer, R, Benoît, C, Dreyer, LC, Flysjö, A, Manhart, A, Masijn, B, Méthot, AL, Weidma, B (2006) *Feasibility study: integration of social impacts into LCA*, https://lca-net.com/publications/show/feasibility-study-integration-social-aspects-lca/; (accessed 04/11/2023).

IEA (2019) *Transforming Industry through CCUS*, International Energy Agency: https://iea.blob.core.windows.net/assets/0d0b4984-f391-44f9-854f-fda1ebf8d8df/Transforming_Industry_through_CCUS.pdf; (accessed 22/04/2024).

IEA (2020) *CCUS in Clean Energy Transitions*, International Energy Agency: https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf; (accessed 08/09/2024).

IEA (2023) *CO2 Emissions in 2022*, Paris: International Energy Agency: https://www.iea.org/reports/co2-emissions-in-2022; (accessed 25/10/2024).

ISO (2006) *ISO 14040, Environmental management, Life cycle assessment, Principles and framework,* International Organisation for Standardisation, https://www.iso.org/standard/37456.html; (accessed 23/03/2024).

ILO (2024) *International Labour Organisation*: https://www.ilo.org/.

Jäger, J , Brutschin, E , Pianta, S, Omann, I, Kammerlander, M, Sudharmma, VS , Vrontisi, Z, MacDonald, J, van Ruijven, B (2023) 'Stakeholder engagement and decarbonization pathways: Meeting the challenges of the COVID-19 pandemic', *Frontiers in Sustainability*, 3: 1063719; doi:10.3389/frsus.2022.1063719.

JCR (2022) *Carbon Capture Utilisation and Storage in the European Union: status report on technology development, trends, value chains and markets*, Netherlands: Joint Research Centre, European Commission: https://publications.jrc.ec.europa.eu/repository/handle/JRC134999; (accessed 25/10/2023).

JRF (2024) UK *Poverty: the essential guide to understanding poverty in the UK*, Joseph Rowntree Foundation, York: https://www.jrf.org.uk/uk-poverty-2024-the-essential-guide-to-understanding-poverty-in-the-uk#:~:text=Poverty%202024%20report.-Poverty%20has%20increased%2C%20close%20to%20pre%2Dpandemic%20levels,nearly%203%20in%2010)%20children (accessed 25/03/2024).

Jones, CR, Olfe-Kräutlein, B, Naims, H and Armstrong, K (2017) `The Social Acceptance of Carbon Utilisation: a review and research agenda', *Frontiers in Energy Research*, Volume 5: https://www.frontiersin.org/journals/energy-research/articles/10.3389/fenrg.2017.00011/full.

Kircher, M (2021) 'The framework conditions must be aligned to the requirements of the bioeconomy', *EFB Bioeconomy Journal,* Volume 1: https://doi.org/10.1016/j.bioeco.2021.100021.

Klöpffer (2008) 'Life-cycle based sustainability assessment of products', *International Journal of Life Cycle Assessment*, 13 (2): 89–94.

Kourmentza, C, Plácido, J, Venetsaneas, N, Burniol-Figols, A, Varrone, C, Gavala, HN, Reis, MAM (2017) 'Recent Advances and Challenges towards Sustainable Polyhydroxyalkanoate (PHA) Production', *Bioengineering*, 4:55; https://doi.org/10.3390/bioengineering4020055.

Kumar, V, Kumar, P, Maity, SK, Agrawal, D, Narisetty, V, Jacob, S, Kumar, G, Bhatia, SK, Kumar, D, and Vivekanand, V (2024) 'Recent advances in bio-based production of top platform chemical, succinic acid: an alternative to conventional chemistry', *Biotechnology for Biofuels and Bioproducts*, 17:72; https://doi.org/10.1186/s13068-024-02508-2.

Leibensperger, C, Yang, P, Zhao, Q, Wei, S and Cai, X (2021) The synergy between stakeholders for cellulosic biofuel development: perspectives, opportunities, and barriers, *Renewable and Sustainable Energy Reviews*, 13: 110613; https://doi.org/10.1016/j.rser.2020.110613; (accessed 19/02/2024).

LSE/GI (2023) *What is the UK's policy approach to carbon capture, usage and storage (CCUS)?*, LSE/Grantham Institute: https://www.lse.ac.uk/granthaminstitute/explainers/what-is-the-uks-policy-approach-to-carbon-capture-usage-and-storage-ccus/; (accessed 23/06/2024).

Lynch, DH, Klaassen, P and Broerse, JE (2017) `Unravelling Dutch citizens'' perceptions on the bio-based economy: the case of bioplastics, bio-jetfuels and small-scale bio-refineries`, *Industrial Crops and Products*, 106: 130-137.

MacDowell, N, Fennel, PS, Nilay, S, Maitland, GC (2017) 'The role of CO_2 capture and utilization in mitigating climate change‘, *Nature Climate Change*, 4(7): 243-249.

McLaughlin, H, Littlefield, AA, Menefee, M, Kinser, A, Hull, T, Sovacool, BK, Basilian, MD, Kim, J and Griffiths, S (2023) 'Carbon capture utilisation and storage in review: Sociotechnical implications for a carbon reliant world‘, *Renewable and Sustainable Energy Reviews*, 177: 113215; https://doi.org/10.1016/j.rser.2023.113215.

Morone, P and Imbert, E (2020) `Food waste and social acceptance of a circular bioeconomy: the role of stakeholders‘, *Current Opinion in Green and Sustainable Chemistry*, 23: 55–60.

Mota-Nieto, J and García-Meneses, PM (2024) 'A Stakeholder-centred narrative exploration on carbon capture, utilisation, and storage: a systems thinking and participatory approach', in *Energy Research and Social Science*, 113: 103563; https://doi.org/10.1016/j.erss.2024.103563.

Naims, H (2020) 'Economic aspirations connected to innovations in carbon capture and utilisation value chains‘, *Journal of Industrial Ecology*, 24:1126-1139.

Norris, C and Norris, G (2015) 'The Social Hotspots Database Context of the SHDB', in Murray, J, McBain, D, and Wiedmann, T (eds) *The Sustainability Practitioner's Guide to Social Analysis and*

Assessment, Common Ground: https://www.researchgate.net/publication/287215286_Chapter_8_The_Social_Hotspots_Database_Context_of_the_SHDB; (accessed 15/07/2024).

O'Brien, M, Doig, A, Clift, R (1996) `Social and environmental Life Cycle Assessment (SELCA) 'Approach and methodological development', *International Journal Life Cycle Assessment*, 1(4):231-237.

ONS (2024) *Employment and Labour Market in in the UK*: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/bulletins/genderpaygapintheuk/2023#gender-pay-gap-data; (accessed 07/05/2024).

OECD (2024) *OECD data*: https://www.oecd.org/en/data.html.

Parajouli, R, Dalgaard, T, Jørgensen, U, Adamsen, A, Knudsen, M, Birkved, Gylling, M and Schjørring, J (2015) 'Biorefining in the prevailing energy and material crisis: a review of sustainable pathways for biorefinery value chains and sustainability assessment methodologies', *Renewable and Sustainable Energy Reviews*, 43: 244 – 263.

Peres, CB, Resende, PM, Nune, LJR, Morais, LC (2024) 'Advances in Carbon Capture and Use (CCU) Technologies: A Comprehensive Review and CO2 Mitigation Potential Analysis', *Clean Technologies*, 4(4): 1193-1207; https://doi.org/10.3390/cleantechnol4040073/.

Pieri, T, Nikitas, A, Castillo-Castillo, A and Angelis-Dimakis, A (2018) `Holistic Assessment of Carbon Capture and Utilisation Value Chains', *Environments,* 5(10): https://www.mdpi.com/2076-3298/5/10/108.

Rafiaani, P, Kuppens, T, Van Dael, M, Asadi, H, Lebailly, P, Van Passel, S (2018) `Social sustainability assessments in the biobased economy: towards a systemic approach', *Renewable Sustainable Energy Review*, 82 (Part 2):1839-1853.

Ramirez Ramirez, A, El Khamlichi, A, Markowz, G. Rettenmaier, N, Baitz, M, Jungmeir, G, and Bradley, T (2022) *LCA4CCU – Guidelines for life cycle assessment of carbon capture and utilisation*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2833/161308; (accessed 23/03/2024).

Reitinger, C, Dumke, M, Barosevcic, M, and Hillerbrand, A (2011) 'A conceptual framework for impact assessment within SLCA', *International Journal of Life Cycle Assessment*, 16 (4):380–388.

Sala, S, Farioli, F, and Samagni, A (2013) 'Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment', *The International Journal of Life Cycle Assessment*, 18(9), 1653–1672.

Schmits-Felten and Lieck (2019) *National Strategies in the field of Occupational Safety and Health in the EU, European Agency for Safety and Health at Work*: https://osha.europa.eu/en/safety-and-health-legislation/osh-strategies; (accessed 04/07/2024).

SHDB (2021) *Social Hotspot Database*: http://www.socialhotspot.org/.

Spangenberg, J H (2014) 'Institutional sustainability indicators: an analysis of the institutions in Agenda 21 and a draft set of indicators for monitoring their effect', *Sustainable Development*, 22(1): 49-64.

Storrs, K., Lyhne, I. & Drustrup, R. (2023) 'A comprehensive framework for feasibility of CCUS deployment: A meta-review of literature on factors impacting CCUS deployment', *International Journal of Greenhouse Gas Control*, 125: 103878; https://doi.org/10.1016/j.ijggc.2023.103878.

Talus, K and Maddahi, R (2024) 'Carbon capture and utilization under EU law: impermanent storage of CO2 in products and pre-combustion carbon capture', Journal of World Energy Law and Business, 295-308: 295-308; https://doi.org/10.1093/jwelb/jwae009.

The Global Economy (2024) *Indicators*: https://www.theglobaleconomy.com/indicators_list.php.

Thielges, S , Olfe-Kräutlein, B, Rees, A, Jahn, J, Sick, V, and Quitzow, R (2022) 'Committed to implementing CCU? A comparison of the policy mix in the US and the EU', *Frontiers in Climate*, 4: https://doi.org/10.3389/fclim.2022.943387.

TUC (2014) *The economic benefits of carbon capture and storage in the UK*, Trade Union Congress: https://www.tuc.org.uk/sites/default/files/carboncapturebenefits.pdf; (accessed 27/10/2023).

Turnau, S, Jaspers, D, Marxen, A, Naims, H, de Bruyn, S, Bringezu, S, et al. (2019) *Identification and Analysis of Promising Carbon Capture and Utilisation Technologies, Including their Regulatory Aspects*, European Commission Directorate-General for Climate Action, and attributed to a team of experts from Ramboll, the Institute for Advanced Sustainability Studies, University of Kassel Center for Environmental Systems Research, IOM Law, and CE Delft: https://op.europa.eu/de/publication-detail/-/publication/7656142c-7083-11e9-9f05-01aa75ed71a1; (accessed 29/08/2024).

UKGOV (2024a) The Gas Safety (Management) (Amendment) Regulations 2023, UK Government: https://www.legislation.gov.uk/uksi/2023/284/contents; (accessed 13/07/2024).

UKGOV (2024b) *The Renewable Transport Fuel Obligations (Amendment) Order 2024*, UK Government: https://www.legislation.gov.uk/uksi/2024/642/contents/made; (accessed 09/07/2024).

UKGOV (2024c) *Climate Change Act 2008*, UK Government: https://www.legislation.gov.uk/ukpga/2008/27/contents; (accessed 05/06/2024).

UKGOV (2024d) *Energy Act 2023*, UK Government: https://www.legislation.gov.uk/ukpga/2023/52/contents; (accessed 12/07/2024).

UKGOV (2024e) *UK carbon capture, usage and storage,* UK Government: https://www.gov.uk/guidance/uk-carbon-capture-and-storage-government-funding-and-support; (accessed 13/07/2024).

UKGOV (2024f) *Environment Act 2021*, UK Government: https://www.legislation.gov.uk/ukpga/2021/30/contents; (accessed 08/06/2024).

UKGOV (2024g) *The Greenhouse Gas Emissions Trading Scheme (Amendment) Order 2024*, UK Government: https://www.legislation.gov.uk/uksi/2024/192/contents/made; (accessed 09/06/2024).

UKGOV (2024h) *The Green Gas Support Scheme (Amendment) Regulations 2024,* UK Government: https://www.legislation.gov.uk/uksi/2024/642/contents/made; (accessed 10/07/2024).

UNECE (2021) *Technology Brief: Carbon Capture, Use and Storage (CCUS)*, Geneva: United Nations Economic Commission for Europe.

UNDP (2024a) *UNDP data centre*: https://hdr.undp.org/data-center.

UNDP (2024b) *Human Development Index*, United Nationals Development Programme: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI; (accessed 25/04/2024).

UNDP (2024c) *Gender Inequality Index (GII)*, United Nationals Development Programme: https://hdr.undp.org/data-center/thematic-composite-indices/gender-inequality-index#/indicies/GII; (accessed 11/05/2024).

UNEP/SETAC (2009) *Guidelines for Social Life Cycle Assessment of Products*, UNEP-Paris; http://www.unep.fr/shared/publications/pdf/dtix1164xpa-guidelines_slca.pdf; (accessed 18/06/2023).

UNEP/SETAC (2020) *Guidelines for Social Life Cycle Assessment of Products and Organisations 2020*, United Nations Environment Programme: https://www.lifecycleinitiative.org/wp-content/uploads/2021/01/Guidelines-for-Social-Life-Cycle-Assessment-of-Products-and-Organisations-2020-22.1.21sml.pdf; (accessed 19/06/2023).

UNWOMEN (2024) *SDG 5: Achieve gender equality and empower all women and girls*: https://www.unwomen.org/en/node/36060#:~:text=In%20short%2C%20all%20the%20SDGs,in%20private%20and%20public%20spheres (accessed 21/03/2024).

van Heek, J, Arning, K and Ziefle, M (2017) 'Differences between laypersons and experts in perceptions and acceptance of CO_2 utilisation for plastics production', *Energy Procedia*, 114: 7212 – 7223.

Vicente, D, Proença, DN, and Morais, PV (2023) 'The Role of Bacterial Polyhydroalkanoate (PHA) in a Sustainable Future: a review on the biological diversity', *International Journal of Environmental Research and Public Health*, 20(4):2959; https://doi.org/10.3390/ijerph20042959.

Warren, P (2019) *The role of climate finance beyond renewables: demand-side management and carbon capture*, *Climate Policy,* 19(7): 861-877.

WECD (1987) *Report of the World Commission on Environment and Development: Our Common future,* Brundtland Report, United Nations: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf; (accessed 05/08/2023).

Appendix I: Definition of Indicators

Indicator	Measurement Unit	Definition/Guidance	Data Source
Environmental/Infrastructure Indicators			
CO_2 emissions	million tonnes	Those stemming from the burning of fossil fuels and the manufacture of cement, including CO_2 produced during consumption of solid, liquid, and gas fuels and gas flaring.	The Global Economy
Road quality	Scale: 1-7 1=low/underdeveloped; 7= high; extensive and efficient by international standards	An assessment of the quality of roads in any given country based on data from the WEF Executive Opinion Survey. The road quality indicator score is based on only one question. The individual responses are aggregated to produce a country score.	The Global Economy
Railroad infrastructure quality	Scale: 1-7 1=low/underdeveloped; 7= high; extensive and efficient by international standards	An assessment of the quality of the railroad system in a given country based on data from the WEF Executive Opinion Survey. The score for railroad infrastructure quality is based on only one question. The individual responses are aggregated to produce a country score.	The Global Economy
Socio-economic and health service indicators			
At risk of poverty	Percentage of total population	The at-risk-of-poverty rate is the share of people with an equivalised disposable income (after social transfer) below the at-risk-of-poverty threshold, which is set at 60 % of the national median equivalised disposable income after social transfers.	EUROSTAT
Employment rate	Percentage	The percentage of employed persons in relation to the comparable total population. For the overall employment rate, the comparison is made with the population of working-age	EUROSTAT
Gender Inequality Index	Index range from 0 (where women and men fare equally) to 1, (where one gender fares as poorly as possible in all measured dimensions)	A composite metric of gender inequality using three dimensions: reproductive health, empowerment and the labour market. A low GII value indicates low inequality between women and men, and vice-versa.	UNDP
Gender employment gap	Percentage	The difference between the employment rates of men and women. The indicator shows activity and employment status for four groups of persons: employed persons working full time, employed persons working part time, employed persons with temporary contract and underemployed persons working part time. The indicator is based on the EU Labour Force Survey.	EUROSTAT
Gender pay gap	Percentage	The difference in average wages between men and women. The unadjusted gender pay gap is calculated as the difference between the average gross hourly earnings of male and female paid employees as a	EUROSTAT ONS

		percentage of average gross hourly earnings of male paid employees.	
Gross Domestic Product (GDP) per capita	Purchasing Power Standards (PPS)	The indicator is calculated as the ratio of real GDP to the average population of a specific year. GDP measures the value of total final output of goods and services produced by an economy within a certain period of time. It is a measure of economic activity and is also used as a proxy for the development in a country's material living standards.	EUROSTAT and STATISTA
Labour force	million people	It comprises people ages 15+ who supply labour for the production of goods and services during a specified period. It includes people who are currently employed and people who are unemployed but seeking work as well as first-time jobseekers. Its size tends to vary during the year as seasonal workers enter and leave.	The Global Economy
Human Development Index	Social measurement adopted from UN	Ranking of countries' levels of social and economic development based on four criteria: life expectancy at birth, mean years of schooling, expected years of schooling and gross national income per capita.	United Nations Development Programme
Index of Skills Shortage	Positive values indicate skill shortage while negative values point to skill surplus.	The larger the absolute value, the larger the imbalance. The value of 1 represents the largest shortage and the value of -1 the largest surplus across OECD countries, skill categories and years.	OECD
Persons at risk of poverty or social exclusion	Percent of population	Persons are considered to be at risk of poverty after social transfers, if they have an equivalised disposable income below the risk-of-poverty threshold, which is set at 60 % of the national median equivalised disposable income.	EUROSTAT
Low-wage earners	Percentage	Low-wage earners are defined as those employees (excluding apprentices) earning two-thirds or less of the national median gross hourly earnings in that particular country.	EUROSTAT
Mean Annual Gross Earnings	Euros	Employees are all persons who have a direct employment contract with the enterprise or local unit and receive remuneration, irrespective of the type of work performed, the number of hours worked (full or part-time), and the duration of the contract (fixed or indefinite). Mean annual gross earnings also cover all 'non-standard payments', i.e. payments not occurring in each pay period, such as 13th or 14th-month payments, holiday bonuses, quarterly or annual company bonuses, and annual payments in kind.	EUROSTAT
Sectoral Employment	Thousands of persons or percentage	Represents the sector of the economy that the economically active populations work in	EUROSTAT

Unemployment rate by gender	Percentage	The gender share of the labour force that is without work but available for and seeking employment	The Global Economy

Appendix II: CooCE Sectors (SHDB/GTAP)

SHDB/GATP definition of sector activities	
Sector	**Definition**
Chemicals, rubber, plastics	Manufacture of chemicals and chemical products, rubber and plastics products
Electricity	Electricity; steam and air conditioning supply
Gas	Extraction of natural gas, service activities incidental to oil and gas extraction excluding surveying (part)
Transport	Land transport and transport via pipelines
Water	Water supply; sewerage, waste management and remediation activities
Source: SHDB (2024); GTAP (2024) Global Trade Analysis Project (https://www.gtap.agecon.purdue.edu/)	

Appendix III – EU Strategic Policy Instruments

Thematic area: Climate and Energy

EU Bioeconomy Strategy

This strategy aims to accelerate the deployment of a sustainable European bioeconomy through a focus on five goals: ensure food and nutrition security; manage natural resources sustainably; reduce dependence on non-renewable, unsustainable resources; limit and adapt to climate change; and

strengthen European competitiveness and create jobs. The strategy is implemented through an Action Plan centred on fourteen actions, contributing to the the European Green Deal, the circular economy and clean energy innovation strategies, which all highlight the importance of a sustainable, circular bioeconomy to achieve their objectives. Other wider aims inclulde strengthening and scaling up the biobased sectors by mobilising stakeholders to develop and deploy sustainable and biobased solutions, promote and develop standards, faciliate the deployment of new biorefineries, and develop substitutes to fossil-based materials that are biobased, recyclable and biodegradable in marine environments. The strategy also aims at orieting the rapid deployment of local bioeconomies across the EU (https://research-and-innovation.ec.europa.eu/research-area/environment/bioeconomy/bioeconomy-strategy_en;https://op.europa.eu/en/publication-detail/-/publication/775a2dc7-2a8b-11e9-8d04-01aa75ed71a1).

EU Plastics Strategy (COM 2018/28)

Concern with the impact and disposal of plastic waste had already been addressed EU legislation in the late 2000s, and again on an EU Green Paper in 2013 which included biodegradable plastics. But it gained a new impetus as a part of the new Action Plan for the Circular Economy introduced in 2015, culminating in the design and adoption of a strategy for plastics in the circular economy in 2018. The strategy highlighted that biodegradable and compostable plastics can help support the transition to a circular economy and set out the ambition that all plastic packaging should be designed to be recyclable or reusable by 2030. It also noted that alternative types of feedstock (e.g. bio-based plastics or plastics produced from CO_2 or methane) offer the same functionalities of fossil-based plastics with potentially lower environmental impacts, and that the EC would look into opportunities to support the development of alternative feedstocks in plastic production to increase market shares of plastics with biodegradable properties (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516187067621anduri=COM:2018:28:FIN).

The European Green Deal (COM 2019/640)

This comprises a set of proposals to help the EU transform its economies and societies to enable a reduction of its net GHG emissions by at least 55% by 2030 in relation to 1990 levels and become the first climate neutral continent by 2050. It is the foremost overarching EU framework. It sets out an initial roadmap of the key policies and measures, encompassing wide ranging plans and actions for various sectors, including climate, energy, transport and taxation changes. For road transport, for instance, it aims to reduce emissions from vans by 50% by 2030, and to reach 0 emissions from new cars by 2035. Road transport will be covered by emissions trading (through the ETS), putting a price on pollution, boosting the use of cleaner fuels and higher investment on clean technologies. It also envisages carbon pricing for aviation and promoting SAFs through imposing an obligation for planes to be powered by sustainable blended fuels for all departures from EU airports. It includes seven actions for the agricultural sector, including a reform of CAP (see section). It also commits to stepping up efforts to ensure legislation and policies relevant to the Green Deal are enforced and implemented effectively (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640).

EU Circular Economy Action Plan (COM 2020/98)

This instrument is one of the main building blocks of the EU's Green Deal and was recently revised to enhance its aims and agenda. It aims to enable the EU's transition to a circular economy focused on reducing pressure on natural resources and creating sustainable growth and jobs, being indispensable to the achievement of EU's 2050 climate neutrality targets. The revised instrument introduces initiatives along the entire life cycle of products, targeting the design of products, promoting circular economy processes, encouraging sustainable consumption, ensuring the prevention of waste and the keeping the use of resources within the economy for as long as possible. Measures introduced by the revised instrument include making sustainable products the norm in the EU; empowering consumers and public buyers; focusing on sectors that use most resources and that can incorporate circularity (e.g. electronics, ICT, batteries, vehicles, packaging, plastics, textiles, construction, food, water and nutrients); curbing waste; make circularity work for people, regions and cities; and lead global efforts on the circular economy (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386anduri=COM:2020:98:FIN; https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en).

EU Energy System Integration Strategy (COM 2020/299)

This instrument aims at creating a climate neutral integrated energy system that improves energy production and consumption, by establishing a comprehensive terminology for all renewable and low-carbon fuels along with an EU system for their certification based on lifecycle GHG emission savings and sustainability criteria. The system is anchored on three key goals: achieving circularity in the energy system; use of cleaner electricity; promotion of renewable and low-carbon fuels, including hydrogen, where there is no other alternative. Actions to achieve these include a more integrated energy infrastructure, making energy markets fit for defossilisation, a digitalised energy system and a supportive innovation framework (https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2020:299:FIN).

EU Hydrogen Strategy (COM 2020/301)

This strategy was adopted to accelerate the development of clean hydrogen and help decarbonise the energy sector in the EU. Hydrogen is suitable can address the limits and challenges of renewable electricity, especially in storage, heavy-duty transport and energy-intensive industries. As the cost of clean or low-carbon hydrogen remains uncompetitive, most hydrogen produced currently is fossil-based. The strategy outlines a number of key actions and presents three strategic phases in the timeline up to 2050, and key areas for action include an investment agenda, boosting demand and scale-up, regulatory framework, and research and innovation. The EC launched the European Clean Hydrogen Alliance, made up of stakeholders from industry, public authorities and civil society to help scale up production and demand for clean hydrogen in Europe. The Alliance is tasked with setting up the investment agenda and facilitate the implementation of actions (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301).

EU Methane Strategy (COM 2020/663)

This strategy sets the EU's ambition on methane emissions, aiming to curb temperature increases, improving air quality and reinforcing the EU's global leadership in the fight against climate change. It focuses on reducing methane emissions in the energy, agriculture and waste sectors, the sources of all human-related emissions. Proposed targeted action and synergy promotion are embedded in the cross-sectoral approach (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0663). Key to develiring this strategy is the EU's Regulation on Methane (EU/2024/1787) that came into force on June 2024 (introduced in section 4.1.1)

EU Climate Adaptation Strategy(COM/2021)

This strategy builds on the original 2013 strategy (COM/2013/216). It aims to step up action across the economy and society to achieve for climate resilience in 2050. It is to be implemented in concert with other European Green Deal components. It will promote sub-national, national and regional approaches to adaptation, requiring that the private and public sectors work closely together, and providing tools to support the private sector to identify risks and steer investment towards action on adaptation and resilience. Financial support is to be made available through a range of sources (e.g., ESIFs, the CAP, LIFE, etc). It highlights the urgent need for devising solutions to help farmers and land managers address climate risks (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN).

EU Solar Energy Strategy (COM 2022/221)

This instrument aims to harness solar power as a central tool in reducing reliance on fossil fuels, enhancing energy security, and achieving climate neutrality by 2050. In terms of targets, it aims to double the EU's solar power capacity by 2030 to help accelerate decarbonisation efforts. It proposes a phased-in mandatory installation of solar panels on new public, commercial, and residential buildings, and includes provisions for simplifying permitting processes, boosting access to financing, and promoting solar energy communities. It also aims to reduce dependency on non-EU solar technology supply chains by strengthening the EU's solar manufacturing capacity through building a sound supply chain for solar equipment and helping address the shortage of qualified professionals for installation, operation, and maintenance through training and upskilling workers in the solar energy sector. By integrating digital technologies, the plan intends to enhance energy efficiency, reduce emissions, and create a more resilient and adaptable energy system (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A221%3AFINandqid=1653034500503).

EU SET Plan (COM 2023/634)

This is a central instrument initiative aimed at driving the development and deployment of low-carbon energy technologies in the EU. It plays a central role in the EU's energy policy, facilitating innovation and accelerating the transition to a sustainable energy system. Initially adopted in 2007 and regularly updated, it aligns with the broader goals of the European Green Deal, the REPowerEU Plan, and the EU's climate neutrality target by 2050. It focuses on accelerating the deployment of renewable energy sources, energy efficiency solutions, and smart grid technologies to ensure a clean, sustainable, and resilient energy system. A key goals is to make renewable energy and low-carbon technologies more competitive by reducing their costs through innovation, economies of scale, and technological advancements. It also aims to foster economic growth and job creation in the green energy sector, supporting Europe's transition to a sustainable, competitive economy. also aims to foster economic growth and job creation in the green energy sector, supporting Europe's transition to a sustainable, competitive economy. It sets out ten key actions that address a range of low-carbon technologies and energy solutions (e.g. energy efficiency in buildings and industry; renewable energy technologies; renewable heating and cooling; CCUS; smart grids and energy systems; sustainable transport; energy storage; nuclear safety; and competitive renewable fuels and bioenerg. It also fosters cooperation between EU member states and regions through joint initiatives and partnerships. The plan is currently being revised to ensure a unified approach towards achieving the EU's decarbonisation goals, supporting strategic net-zero energy technologies, and building a sustainable and resilient energy future (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0634andqid=1698315020718; https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en).

dSET Plan (COM 2023/634)

This instrument embeds the EC's updated approach to modernising the SET Plan by harnessing digital technologies as enablers and accelerators of the energy transition, promoting their role in enhancing energy system efficiency, flexibility, and security, to achieve climate neutrality by 2050. It aligns with the EU's commitment to increasing renewable energy capacity, as digital tools are positioned to support the scaling up of renewable energy sources, including wind, solar, and hydropower. A major focus is on developing smart grid technologies to enable better grid management and facilitate the integration of renewable energy. It also calls for establishing a robust framework for data protection and privacy, ensuring that sensitive energy data remains secure while facilitating data exchange for energy optimisation (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0634andqid=1698315020718).

EU Grid Action Plan (COM 2023/757)

This instrument is a critical part of the EC's broader strategy to accelerate the energy transition and achieve climate neutrality by 2050. It addresses the need for modern, resilient, and smart electricity grids capable of integrating increasing shares of renewable energy, enhancing energy security, and supporting decarbonisation. Its main objective is to ensure that electricity grids across the EU are ready to accommodate large-scale integration of renewable energy sources, particularly wind and solar power, by modernising, expanding, and digitising grid infrastructure. It aims to create flexible and resilient grid systems that can handle variable renewable energy production while maintaining stable and secure energy supply. Priority focuses on grid upgrades, enhanced grid interconnections, and the adoption of smart grid technologies. It also seeks to promote electrification across sectors, especially in transport, industry, and heating, by ensuring sufficient grid capacity to support the increased demand for electricity resulting from these transitions (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A757%3AFINandqid=1701167355682; https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6044).

Thematic area: Industry and Transport and Mobility

EU Chemicals Strategy for Sustainability (COM 2020) 667

This strategy is a key component of the EU's Green Deal. It aims to protect human health and the environment from hazardous chemicals and foster innovation and sustainability in the chemicals sector. It focuses on reducing the use and presence of harmful substances, promoting safer alternatives, and strengthening the competitiveness of the chemicals industry in the EU. The primary goal is to ensure that chemicals are produced and used safely, minimising exposure to hazardous substances that can harm human health and ecosystems as well as delivering a toxic-free environment by 2050, where exposure to harmful chemicals is minimised, and safe and sustainable alternatives are promoted. It emphasises the phase-out of the most harmful chemicals in consumer products and non-essential uses, particularly those that are carcinogenic, mutagenic, reprotoxic (CMR), endocrine-disrupting, or persistent and bio-accumulative. A major focus is on driving innovation towards the development of safe and sustainable-by-design chemicals, fostering the production of substances that are non-toxic, recyclable, and have minimal environmental impact. Overall, the strategy seeks to update and strengthen EU chemicals legislation, including the REACH regulation, to better reflect scientific advances and improve protection against hazardous chemicals, whilst simplifying and harmonising regulatory processes that ensure consistency across different sectors and encourage the use of safer alternatives (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A667%3AFIN).

EU Sustainable and Smart Mobility Strategy (COM 2020/789)

This strategy is part of the EU's Green Deal and sets out the EU's roadmap for transforming its transport system to be more sustainable, efficient, and digitally integrated. It aims to ensure that transport systems in the EU become climate-neutral by 2050, while remaining competitive and inclusive. A key aim is to accelerate the deployment of zero-emission vehicles and associated infrastructure (e.g., charging stations), with a focus on electric vehicles (EVs), hydrogen, and alternative fuels. It seeks to drive the digital transformation of the transport system, making it smarter, more efficient, and interconnected through the use of digital solutions, such as automated driving, mobility as a service, and smart traffic management. It further ams to ensure safe, efficient, and reliable transport systems across the EU. This includes improving road safety, cybersecurity, and the resilience of transport infrastructure to climate change. It also aims to make transport accessible and affordable for all citisens, ensuring that urban, rural, and remote regions benefit from sustainable mobility options. The strategy includes an Action Plan (with over 82 initiatives to orient policy over four years) for achieving a 90% reduction in transport-related GHG emissions by 2050 to help the EU achieve climate neutrality set out in the Green Deal (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789; https://transport.ec.europa.eu/transport-themes/mobility-strategy_en).

EU New Industrial Strategy (COM 2021/350)

This revised strategy aims to strengthen the EU's industrial base, accelerate the transition towards climate neutrality and enhance the resilience of the economy accross the EU. Central goals include: increasing the resilience of the EU's industrial sectors, enabling them to better withstand future shocks (e.g., supply chain disruptions, economic crises, pandemics) ensuring that the EU can produce key goods and materials domestically (e.g., semiconductors, pharmaceuticals); making industries more sustainable and energy-efficient; supporting the adoption of clean technologies, circular economy practices, and renewable energy across key sectors such as manufacturing, chemicals, and steel; bolstering the EU's strategic autonomy by reducing dependence on third countries for critical materials and technologies (e.g., raw materials, batteries, hydrogen); and accelerate the digital transformation of European industry by promoting the use of digital technologies (https://commission.europa.eu/document/download/9ab0244c-6ca3-4b11-bef9-422c7eb34f39_en?filename=communication-industrial-strategy-update-2020_en.pdf; https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en).

Biobased, Biodegradable and Compostable Plastics (COM 2022/682)

This framework was introduced by the EC as part of the *Circular Economy Action Plan*. Its central aim is to ensure that biobased, biodegradable, and compostable plastics contribute to the EU's circular economy goals by supporting sustainable production, reducing waste, and improving recyclability. It encourages the use of these plastics in specific applications where they offer clear environmental benefits, while ensuring that they do not undermine existing recycling systems or create new waste challenges. It also aims to clarify the role of biobased plastics in reducing fossil fuel dependency and GHG emissions and to prevent the misuse of biodegradable plastics, particularly in scenarios where they may lead to pollution, such as being improperly disposed of in natural environments, leading to fragmentation into microplastics. Further, it encourages innovation in the development of advanced biobased materials as well as supporting the creation of sustainable markets for these plastics. A final key aim is to increase transparency and awareness among consumers and industries about the benefits, limitations, and proper use of biobased, biodegradable, and compostable plastics (https://environment.ec.europa.eu/system/files/2022-12/COM_2022_682_1_EN_ACT_part1_v4.pdf).

EU Green Deal Industrial Plan (COM 2023/62)

This is a comprehensive strategy aimed at positioning the EU as a global leader in clean technologies, supporting the green transition, and enhancing the EU's economic and strategic autonomy. By simplifying regulations, improving access to finance, fostering innovation, and developing green skills, the plan ensures that Europe's industrial base can thrive in a climate-neutral economy while maintaining global competitiveness and securing a sustainable future. The plan is designed to accelerate the EU's progress toward climate neutrality by 2050 by scaling up sustainable industries and supporting the decarbonisation of key sectors, including energy, transport, and heavy industry. It also supports the deployment of low-carbon technologies and innovation to meet the EU's climate and energy goals, particularly in reducing greenhouse gas emissions. A key aim is to simplify and streamline regulatory processes for clean technology industries. The plan proposes faster and more predictable permitting processes for the deployment of renewable energy projects, batteries, heat pumps, and other essential green technologies. It further aims to aims to help position the EU as a global leader in sustainable technologies, facilitating green trade and ensuring the bloc's standards are adopted internationally (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0062; https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en).

EU Industrial and Carbon Management Strategy (COM 2024/62)

Industrial carbon management comprises a range of technologies used for capturing, storing, transporting and using CO_2 emissions from industrial and energy production facilities, as well removing it from the atmosphere. This strategy aims to help decarbonise the EU's industrial sector while ensuring economic competitiveness, job creation, and strategic autonomy. By promoting CCUS, green hydrogen, circular economy practices, and innovation, the strategy provides a roadmap for industries to achieve climate neutrality by 2050. It emphasises a just transition, ensuring that workers and regions dependent on carbon-intensive industries are supported through the green transformation. The pivotal aim of the strategy is to decarbonise European industry, helping the EU meet its goal of climate neutrality by 2050, which involves reducing emissions across key industrial sectors, such as steel, cement, chemicals, and manufacturing, through the adoption of low-carbon technologies. It focuses on accelerating the deployment of decarbonisation technologies (e.g. CCUS), green hydrogen, and electrification of industrial processes). It also aims to aims to safeguard the competitiveness of European industries in the global market, whilst balancing decarbonisation efforts with policies that promote innovation and investment so that industries can compete globally while leading in green technologies. It further seeks to reduce the EU's reliance on fossil fuel imports by promoting the production of clean energy and supporting domestic supply chains for critical materials and decarbonisation technologies, including hydrogen and carbon management systems. It also promotes circular economy practices within industrial sectors, encouraging industries to improve resource efficiency, reduce waste, and promote recycling and reuse of materials, particularly plastics, steel, and electronics manufacturing (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2024:62:FIN; https://energy.ec.europa.eu/topics/carbon-management-and-fossil-fuels/industrial-carbon-management_en).

Thematic area: Agriculture and Forestry

Rural Development Programs

RDPs aim to strengthen the social, environmental and economic sustainability of rural areas in the EU. Member states implement national and regional RDPs, which are co-financed by EAFRD and national budgets. Under the CAP transitional regulation (due to a recent, major review of the CAP), RDPs have been extended to 2022, and as a result, during this period, many of the projects and schemes included in RDPs will continue to run until the end of 2025. From 2023 onwards, all new rural development actions will be incorporated into national CAP strategic plans which will be built around key social, environmental and economic objectives for EU agriculture, forestry, and rural areas. Each RDP must work towards at least four of the six priorities of the EAFRD, which are: fostering knowledge transfer and innovation in agriculture, forestry and rural areas; enhancing the viability and competitiveness of all types of agriculture, and promoting innovative farm technologies and sustainable forest management; promoting food chain organisation, animal welfare and risk management in agriculture; promoting resource efficiency and supporting the shift toward a low-carbon and climate resilient economy in the agriculture, food and forestry sectors; restoring, preserving and enhancing ecosystems related to agriculture and forestry; promoting social inclusion, poverty reduction and economic development in rural areas: https://agriculture.ec.europa.eu/common-agricultural-policy/rural-development_en#ruraldevelopmentprogrammes

Farm to Work (COM 2020/381)

This is a cornerstone policy of the European Green Deal. It aims to create a sustainable, resilient, and fair food system that meets the needs of both people and the planet. By promoting sustainable farming practices, reducing the use of harmful inputs, supporting healthy diets, and tackling food waste, the strategy addresses the environmental, health, and social challenges associated with the current food system. It is a critical part of the EU's vision for a climate-neutral and biodiversity-friendly Europe by 2050. The strategy addresses the entire food supply chain, from production to consumption, with a focus on reducing the environmental and climate impact of food production while ensuring food security, public health, and fair incomes for farmers. The primary aim is to transition to a sustainable food system that protects the environment, preserves biodiversity, and mitigates climate change. It also aims to reduce the environmental footprint of food production, ensuring that farming, fishing, and aquaculture practices are sustainable and less dependent on harmful inputs (e.g. fossil-based pesticides and fertilisers). The strategy supports the adoption of circular economy principles in food production, which include reducing waste, recycling agricultural inputs, and making use of by-products, and promotes the use of organic fertilisers, composting, and biogas production from food and agricultural waste (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381; https://food.ec.europa.eu/horisontal-topics/farm-fork-strategy_en).

EU Forestry Strategy (COM 2021/572)

This revised strategy aims to make forests a key part of the EU's efforts to address climate change, biodiversity loss, and sustainable economic development. By promoting sustainable forest management, expanding forest areas, enhancing resilience, and boosting biodiversity, the strategy seeks to ensure that forests continue to provide essential ecological, economic, and social benefits for current and future generations while supporting the EU's climate neutrality and Green Deal objectives. This is to be achieved by a host of actions, including: promoting a sustainable forest bioeconomy, ensuring sustainable use of wood-based resources for bioenergy, promoting non-forest based economic activities (e.g., ecotourism), ensuring forest restoration, and forest restoration and reinforced sustainable forest management for climate adaptation; reforestation and afforestation of biodiverse forests, including planting some 3bn trees by 2030, and providing incentives for forest owners and managers to improve the quantity and quality of forest (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0572; https://environment.ec.europa.eu/strategy/forest-strategy_en; https://environment.ec.europa.eu/strategy/forest-strategy_en).

Thematic area: Environment

EU Low-Emission Mobility Strategy (COM 2016/501)

This key strategy aims at lowering GHG emissions from the transport sector, one of the largest contributors to climate change in the EU. It is part of the broader effort to meet the EU's climate targets under the Paris Agreement and the 2030 Climate and Energy Framework, while also improving air quality, reducing reliance on fossil fuels, and enhancing the competitiveness of the

European economy. A central aim is to cut transport-related GHG emissions by at least 60% by 2050 compared to 1990 levels, contributing to the EU's overarching goal of achieving climate neutrality by 2050, but it targets a substantive reduction in emissions by 2030 from road, air, maritime, and rail transport to support the EU's intermediate climate objectives. It emphasises the need to improve the energy efficiency of transport systems across the EU, by adopting clean technologies, optimising vehicle performance, and making the transport system more sustainable and integrated. It also sets out measures to support the market uptake of low- and zero-emission vehicles by encouraging innovation, reducing costs, and improving their performance. It further seeks to encourage a modal shift from high-emission transport modes (e.g. private cars, aviation) to more sustainable modes (e.g. public transport, rail freight), and supports the development and deployment of alternative fuels such as electricity, hydrogen, advanced biofuels, and natural gas (https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52016DC0501; https://ec.europa.eu/commission/presscorner/detail/en/MEMO_16_2497).

A Clean Planet for All (COM2018/773)

This is the EC's strategic long-term vision for a climate-neutral Europe by 2050. It outlines the EU's path towards achieving net-zero GHG emissions by 2050, providing a comprehensive roadmap for transitioning to a sustainable, low-carbon economy while ensuring economic growth, competitiveness, and social fairness. The srategy highlights that climate neutrality is compatible with economic growth and competitiveness, and positions the green transition as an opportunity for European businesses to become global leaders in clean technologies and innovation. A central aim is to foster sustainable growth through investments in green industries, innovation, and digitalisation, ensuring that European industries remain competitive on the global stage. But this must be pursued in such a way as to ensure that it supports workers and communities, particularly those in regions dependent on carbon-intensive industries, to prevent job losses and economic decline. This will require providing financial and social support for regions undergoing structural transformations that require workforce reskilling and upskilling. The strategy promotes the circular economy by encouraging lowering resource use, improvements in material efficiency, fostering recycling practices, and designing products for reuse and long life. It also supports innovation in sustainable materials and industrial processes to minimise waste and carbon emissions. It also fosters innovation focused on the development of clean technologies (e.g. renewable energy, energy storage, hydrogen, and CCUS) (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773).

Biodiversity Strategy (COM 2020/380)

This instrument is part of the EU's Green Deal and aims to halt biodiversity loss, restore ecosystems, and promote sustainable use of natural resources. It sets ambitious goals to halt and reverse biodiversity loss in the EU by 2030. By protecting and restoring nature, transforming agriculture and fisheries, reducing pollution, integrating biodiversity into business, and securing financing, the strategy aims to create a nature-positive economy. It also emphasises the importance of global leadership in addressing biodiversity loss at an international scale. It proposes legally binding restoration targets that require, for instance, planting 3 bn trees by 2030, enhancing agroforestry, and restoring free-flowing rivers by removing river barriers and restoring 25,000 km of rivers. It also aims to transform agriculture and fisheries to make them more sustainable and harmless to biodiversity. This includes a commitment to reduce the use of chemical pesticides by 50% and fertilisers by 20% by 2030. A further central aim is to supports clean air and water legislation and promotes a zero-pollution goal for water bodies, marine environments, and soils (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338anduri=CELEX:52020DC0380; https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en).

8th Environment Action Programme (EU Decision 2022/591)

This is the EU's framework for environmental policy from 2021 to 2030, coming into force on 2 May 2022 . It is closely aligned with the European Green Deal and aims to accelerate the EU's transition towards climate neutrality, sustainability, and resilience. This program builds on previous environment action programs while addressing new environmental challenges and setting a long-term vision for a sustainable future. It emphasises adapting to the impacts of climate change by improving the EU's resilience to climate-related risks (e.g. extreme weather events, sea-level rise, biodiversity loss). Central aims include halting and reversing the decline in biodiversity and ecosystem degradation by 2030; promoting the circular economy to reduce resource use, minimise waste, and increase recycling; fostering sustainable production and consumption patterns to reduce pressure on natural resources and ecosystems; reducing pollution from chemicals, plastics, industrial emissions, and other pollutants that harm human health and the environment; improving environmental governance by enhancing the implementation, monitoring, and enforcement of environmental legislation; improving coordination among EU institutions, national governments, and local authorities, along with active engagement with stakeholders, including civil society, businesses, and scientific communities (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022D0591; https://environment.ec.europa.eu/strategy/environment-action-programme-2030_en).

Zero-Pollution Action Plan (COM 2021/400)

This key initiative of the EU's Green Deal aims to create a toxic-free environment by 2050. The plan seeks to eliminate harmful pollution from air, water, soil, and consumer products, while protecting human health and ecosystems. It sets out a comprehensive framework for reducing pollution across sectors and regions, ensuring that the EU meets its sustainability and climate goals. It includes actions to reduce emissions from industry, transport, and agriculture, ensuring compliance with WHO air quality guidelines. It also aims to reduce nutrient losses by 50% and the use of chemical pesticides by 50% by 2030 to protect soils from contamination and degradation, and minimise the presence of harmful substances in consumer products (e.g., cosmetics, toys, food packaging, textiles). It encourages the phasing out of toxic chemicals. It addresses the health impacts of pollution, with a particular focus on reducing the health burden associated with poor air quality, contaminated water, and exposure to hasardous chemicals. A further aim is to promote innovation in green technologies, digital solutions, and smart mobility systems to reduce pollution from transport, industry, and energy production (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400andqid=1623311742827; https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en;