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Policy review for biomass value chains in the European bioeconomy

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ABSTRACT

The main aim of this paper is to review existing European policies relevant to the biomass value chains and examine how their main objectives support or align with the five core objectives (pillars) identified under the 2018 Bioeconomy Strategy. The paper also discusses key challenges that restrict the compliance of the policies to the Strategy, identifies policy gaps and provides recommendations for future policy formation.

A structured review was conducted of over ninety policies relevant to the biomass, bioprocessing and biobased products. The value chain approach was used as a tool to harmonise these sectors under a common bioeconomy framework and provides an understanding of how key activities and challenges are being addressed. Several gaps were identified in relation to these challenges in each stage, at land use stage a lack of European-wide harmonised characterisation of marginal land and integration among sectoral policies targeting soil quality and financial measures incentivising the uptake of sustainable soil improvers. At the biomass production stage, inadequate policy support was found for waste mobilisation and valorisation. Furthermore, there is a lack of policy provisions and financial support improving collaborations among value chain actors to overcome the complexity associated with harmonising biomass logistics and conversion processes. Finally, regarding the end use stage, policy interventions targeting the distribution and standardisation of the wide, available range of biobased products and services remain limited. Based on this gap analysis, a set of recommendations was produced outlining ways in which policy measures can be updated through introducing either financial, regulatory or information provisions, or formulating novel policies altogether. These recommendations were made following the value chain analysis approach, which addresses specific challenges in relation to the five core objectives of the Bioeconomy Strategy, with the aim of further increasing the level of coherence among sectoral policies.
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1. Introduction

Climate change and global population rise are intensifying pressure on the environment and further depleting natural resources. The European Bioeconomy Strategy 2018-2030 (EC, 2018a) [1], issued in 2012 and updated in 2018, recognises these challenges and highlights the need for a transition to resource-efficient production and consumption, reduction and valorisation of waste streams, and change in consumer behaviour (Morone, 2016) [2]. The Strategy highlights the cross-cutting nature of the bioeconomy through its five core objectives which address inter-connected societal challenges*: ensuring food security, managing natural resources sustainably, reducing dependence on non-renewable resources, mitigating and adapting to climate change,* and *creating jobs and maintaining European competitiveness* (EC, 2012a; EC, 2018a) [3,4].

These cross-cutting objectives imply that challenges are interlinked among sectors which produce and process biomass (agriculture, forestry, waste, marine, bio-based industries) and there is a need to adjust, align and harmonise relevant policies to address the prevailing barriers that hinder biobased economy market development. This can lead to a higher level of coherence [5], reduce competition for biomass resources, as well as improve ecosystem services and climate change mitigation. According to the 2012 Bioeconomy Strategy review [6], policy coherence has improved

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over the years between EU research and innovation policy and other EU policies relevant to the bioeconomy (e.g. CAP, EU Biodiversity Strategy 2020, Circular Economy Action Plan, European Structural and Investment Funds [7], and EC, 2011a [8]), however coherence is lacking in providing '*a regulatory framework for bio-based products and markets, high risk investments, and knowledge on biomass supply and demand*'. There is also an indication that policy coherence lacks in sectoral policies such as forestry bioeconomy policies, which causes inefficiencies (Ladu et al., 2020) [9].

The strategy has also been criticised for its greater emphasis on market and technology and for neglecting the multiple benefits of biomass production including greenhouse gas (GHG) emissions reduction, increased resource efficiency, improved food security, and EU competitiveness (Bugge et al., 2016; Scordato et al., 2017; De Besi and McCormick, 2015; Hausknost et al., 2017; Brunori, 2013; Ramcilovic-Suominen and Pülzl, 2018 as cited in Ronzon et al., 2020) [10]. Based on shortcomings identified in the review, the updated Bioeconomy Strategy 2018 has been revised and further enhanced to reinforce the coherence across sectoral policies by supporting their synergy in addressing issues mentioned above.

This paper reviews ninety (90) existing policies in the European Union relevant for biomass, bioprocessing and biobased products, examines their core objectives, instruments and measures, and assesses how they address biomass value chain challenges. This paper does not present an integral review of all policies governing the bioeconomy, however, it details and analyses policies targeting biomass mobilisation, processing and valuation as end-products through the value chain approach which contextualises how these sectors work together and evaluates gaps based on key challenges. Concerning the value chain stages of land use and biomass production, the paper focuses on agricultural, forestry and waste sectors while conversion and end use stages are concerned with non-food bio-based sectors. The work seeks to improve understanding of the relevance of the current policy regime to the five objectives of EU bioeconomy and provide recommendations for reinforcing sectoral integration and overcoming existing barriers.

2. Methodology

The methodology in this paper is comprised of two stages, i) policy landscaping and ii) policy gap analysis and recommendations (see Fig. 1). The work follows the value chain approach and analyses the policies relevant for biomass mobilisation, processing and valuation as end-products across land use, biomass production, conversion and end use stages.

Value chain analysis allows decision makers to understand policy related challenges and operational details of different activities at each stage of the biomass value chain and tailor future policy accordingly. It also enables them to identify the roles of stakeholders and communicate specific actions and interventions required to overcome challenges (Ronzon and Sanjuan, 2020) [10]. This process can improve understanding of strengths and opportunities and create value both within and across stages. Additionally, value chain analysis helps gain insights to technological, environmental and socio-economic challenges (Schmitz, 2005) [11] for both established and emerging bio-based value chains (EC , 2011a; Bellu, 2013) [8,12,13]. This allows policy makers to prioritise and focus measures and resources on certain stages of the value chain to perform better and achieve policy objectives.

Stage 1: Policy Landscaping

Policy landscaping presents a structured review of current EU policies (see Table A-E in the Annex) with relevance to the biomass, bioprocessing and biobased products groups them by value chain stage, and examines their relevance with the five objectives of the EU Bioeconomy Strategy (EC, 2018a). The policies are analysed for each value chain stage and activity as well as the main issues they regulate based on their scope, objectives and instruments, which include regulations, financing mechanisms and soft measures (Panoutsou and Singh, 2020) [14].

- Regulatory instruments define rules to control actions and include quota obligations, product standards and certifications, tax exemptions and reductions, targets and qualifying criteria for incentives, feed-in-tariffs, and green procurement.
- Financing mechanisms support investments and value chain operations and include feedstock premiums, capital grants, technology and feedstock related premiums, tax incentives, user charges, and research funds.
- Soft measures include the promotion and dissemination of best practices and successful lessons learnt, capacity building, and awareness raising, among others.

The value chain stages for the landscaping process are: i) land use, ii) biomass production, iii) conversion and iv) distribution and end-use.

The structured review of these policies provides both an understanding of policy objectives and measures in place as well as the level of harmonisation between policy objectives and the five core objectives of the 2018 Bioeconomy Strategy.

The analysis improves understanding on how policies confined within certain sectors can complement each other to achieve the common goal of establishing sustainable and resource efficient bioeconomy value chains. Key data sources used for the landscaping include i) S2Biom [15], ii)Biomass Policies [16,17], iii)

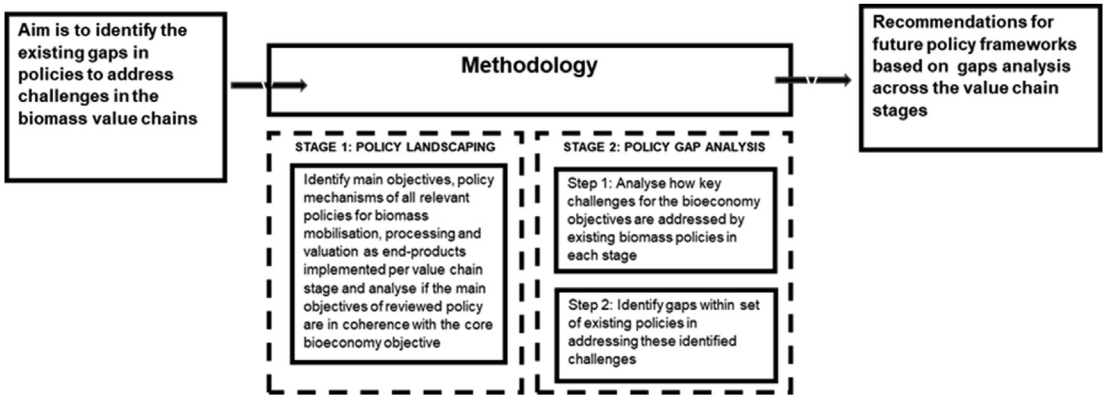


Fig. 1. Methodology.

European climate and energy policy databases [18] and iv) the European Bioeconomy Knowledge for policy portal [19].

Stage 2: Policy Gap Analysis

The second section identifies and presents challenges for each value chain stage in relation to the five core objectives of the 2018 Bioeconomy Strategy and analyses the gaps in current biomass, bioprocessing and biobased product policies to address and overcome these challenges (Panoutsou and Singh, 2020; Panoutsou et al., 2020) [20,21]. Following this, the paper concludes with recommendations for future policy development.

Policy coherence is also referred throughout the paper as a principle of policy analysis across value chain stages (May et al., 2006) [22] to support policy recommendations that are consistent with the five bioeconomy objectives, and improve the value chain perspective among policy makers (Mertens et al., 2019) [23]. This will allow policy makers to incorporate and optimise key elements from sectoral policies while reducing competition of interests and resources (Jordan et al., 2006; Akhtar-Schuster et al., 2011) [24,25].

3. Policy landscaping

Policies that directly impact the development of the European bioeconomy from the resource supply side derive from the agricultural, forestry and waste sectors. They include **Common Agricultural Policy (CAP) 2021-2027** [26], **A Farm to Fork Strategy COM (2020/381)** [27], **EU Forest Strategy** [28], **new EU Biodiversity Strategy 2020** and **Waste Framework Directive (WFD) 2008/98/EC** [29]. On the demand side, relevant sectors include energy, transport, and chemical industries, where key policies include the **Renewable Energy Directive (RED II)**, **Fuel Quality Directive (FQD) (2009/30/EC)** [30], and **EU REACH (1907/2006)** [31]. Bioeconomy value chains are also influenced by policies from cross cutting areas like climate change, environment, research and innovation. The **European Green Deal** [31], **new Circular Economy Action Plan 2020** [32], **Effort Sharing Decision (ESD)** [33], and **Roadmap to Resource Efficient Europe** [35] are a few of those which cut across multiple value chain stages.

Policies included in this section are discussed in detail for selected, key value chain stage activities, although these can vary across research and policy initiatives (Fig. 2). A detailed list of these policies and the key issues they regulate per value chain stage is presented in Figs. 3–6 and and tables in the Annex (see Table A-E) present the policy instruments.

3.1. Land use

Land use and biomass production stages are interrelated for land-based feedstocks. Each policy mechanism included in the landscape provides regulatory or financial support for different issues depending on the individual activities of the respective value chain stage (See Fig. 3). Firstly, *policies for land acquisition* include prohibiting production on certain sensitive land types, as well as incentivising production on abandoned, unused or severely degraded land (also referred to as marginal land). Secondly, policies addressing *soil management* target sustainable land use management, protection of soil quality (including organic carbon), reduction of erosion, and rehabilitation of deteriorated soils.

The **Common Agricultural Policy 2021-2027 (CAP)** [35] aims to support sustainable land management for both agriculture and forest lands, and soil quality and health through greening measures and cross compliance with Good Agricultural and Environmental Conditions (GAEC) [36]. In addition to regulations, it includes financial mechanisms and soft measures to promote bioeconomy through rural development activities. Under the CAP, the **European Agricultural** Fund **for Rural Development (EAFRD)** supports investments to acquire land for biomass production. Similarly, the main aim of the **European Agricultural Guarantee** Fund **(EAGF)** is to support income-generating activities and market measures, which can foster novel biomass production on existing land uses. The **Land use and forestry regulation for 2021-2030 (LULUCF) 2018/841** [37] aims to provide accounting and governance rules for the reduction of GHG from relevant sectors to achieve the long-term climate goals of the **Paris Agreement** [39]. The **Indirect Land Use Change (ILUC) Directive 2015/1513** [39] and **Renewable Energy Directive 2018/2001 (RED II)** [40] aim to prevent unsustainable exploitation of agricultural land used for food production and promote the exploitation of unused and severely degraded land by monitoring land use changes and associated GHG emissions and prohibiting the use of land with high biodiversity value, peatland, and land with high carbon stock. Regulatory tools enforced under these policies include sustainability criteria for biofuels, GHG emission reduction criteria, and certification for low and high risk indirect land use change (iLUC). The EU Forest Strategy and **Reducing emissions from deforestation and forest degradation (REDD +)** [41] objectives are to provide a framework for sustainable forest land management by controlling ecological and socio-economic impacts of forest land use. REDD + also includes financial mechanisms which support monitoring changes in forest carbon stock.

Similarly, policies like the **Soil Thematic Strategy (COM 2012) 46** [42] and CAP aim to regulate soil quality protection by limiting the leaching of toxic substances, preventing soil erosion, and improving land use practices and soil organic content. In addition to the funding mechanisms under the Soil Thematic Strategy, the Cohesion Fund [43] and **European Regional Development** Fund **(ERDF)** [44] aim to reduce soil contamination and rehabilitate contaminated soils. Both of these policies also introduced funding mechanisms to support these aims. **The Farm to Fork Strategy (2020)** supports the transition to a sustainable food system and aims to reduce soil deterioration by implementing targets of reducing fertiliser and pesticide use, nutrient losses, and antimicrobial applications. The **Industrial Emissions Directive (IED) 2010/75/EU** [45] aims to enforce emission limits and best available techniques (BAT) and reduce the impact of industrial installations

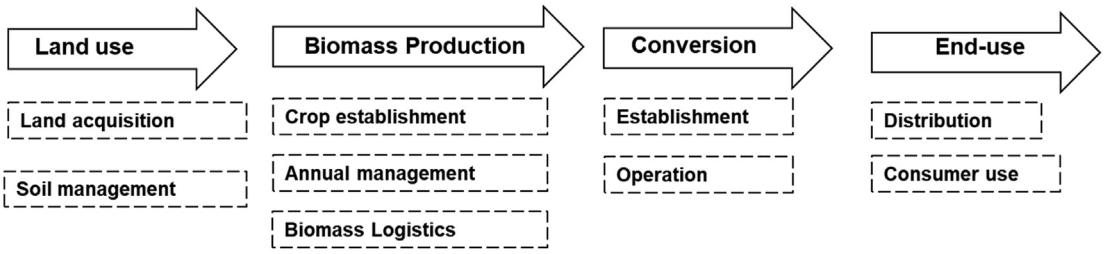


Fig. 2. Value chain stages and activities addressed in the paper.

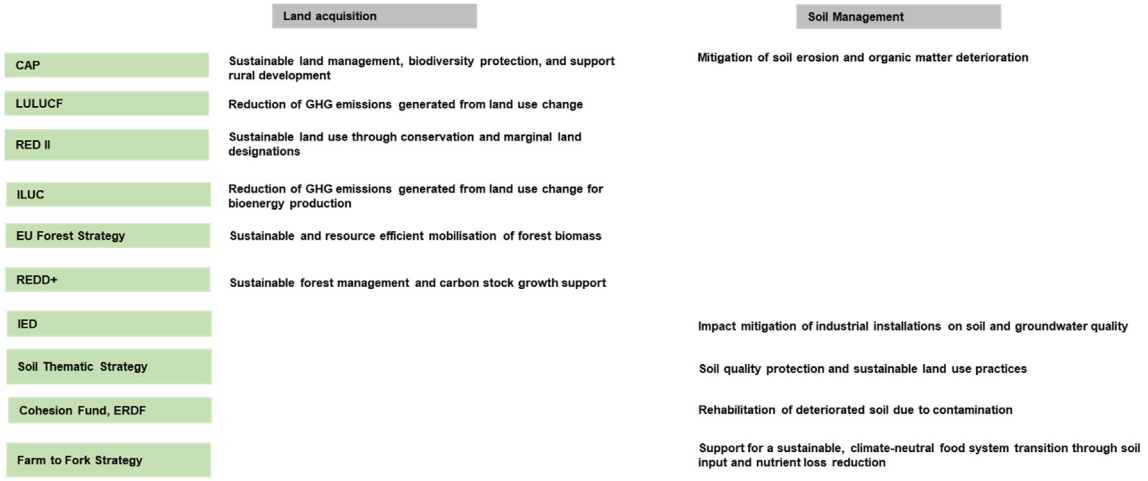


Fig. 3. Land use stage policies and respective objectives per key activity.



Fig. 4. Biomass production stage policies and respective objectives per key activity.

on soil quality. This requires preventative and adaptative soil management which reinforces the polluters pay principle and reduces the risk of soil contamination. Sectoral policies like CAP and IED work in an integrated manner with the Soil Thematic Strategy and the Soil Framework Directive to protect soil quality by monitoring erosion and organic carbon through agro-environmental indicators. This integration puts emphasis on carbon sequestration as a means to offset GHG emissions and reinforce soil protection legislation across all interrelated sectors -agriculture, forestry, waste management, water, climate change, and environment (Panagos and Montanarella, 2018) [46]. At the EU level, GAEC has been an important cross compliance regulatory tool under the greening measures of the CAP promoting soil cover maintenance, sustainable land and soil management practices and limiting the loss of organic matter and erosion in agricultural areas (Panagos et al., 2016) [47]. The **2020 CAP reform (COM (2018 392 final)** [48] proposed new GAEC standards framework for soil organic matter protection, including banning arable stubble burning and ploughing of wetlands and carbon-rich soils.

The **Kyoto Protocol's** [49] objective is to highlight the importance of soil protection and carbon sequestration in agricultural soils for soil management. Soil organic carbon is seen as an important indicator to assess CO_2 offsetting through sequestration (Lugato et al., 2014) [50].

A harmonised soil dataset (Land Use/Cover Area frame statistical Survey Soil, LUCAS) developed by the JRC and European Soil Data Centre (ESDAC) produces EU-level data on physiochemical properties of topsoil including pH, organic carbon, nutrient concentrations and cation exchange capacity (Orgiazzi et al., 2018) [51]. This allows decision makers to develop agricultural policies which are based on the modelling of land use and carbon stocks supported by harmonised datasets.

3.2. *Biomass production*

The key activities involved in biomass production, *crop*

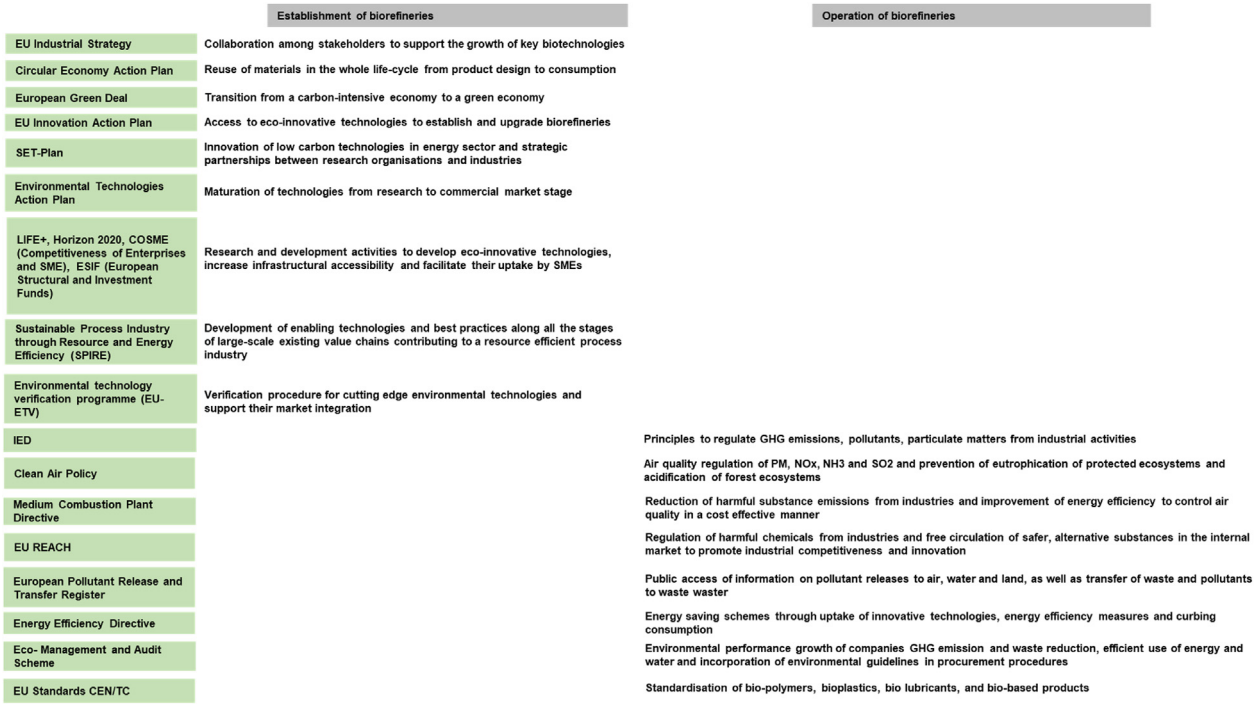


Fig. 5. Conversion stage policies and respective objectives per key activity.

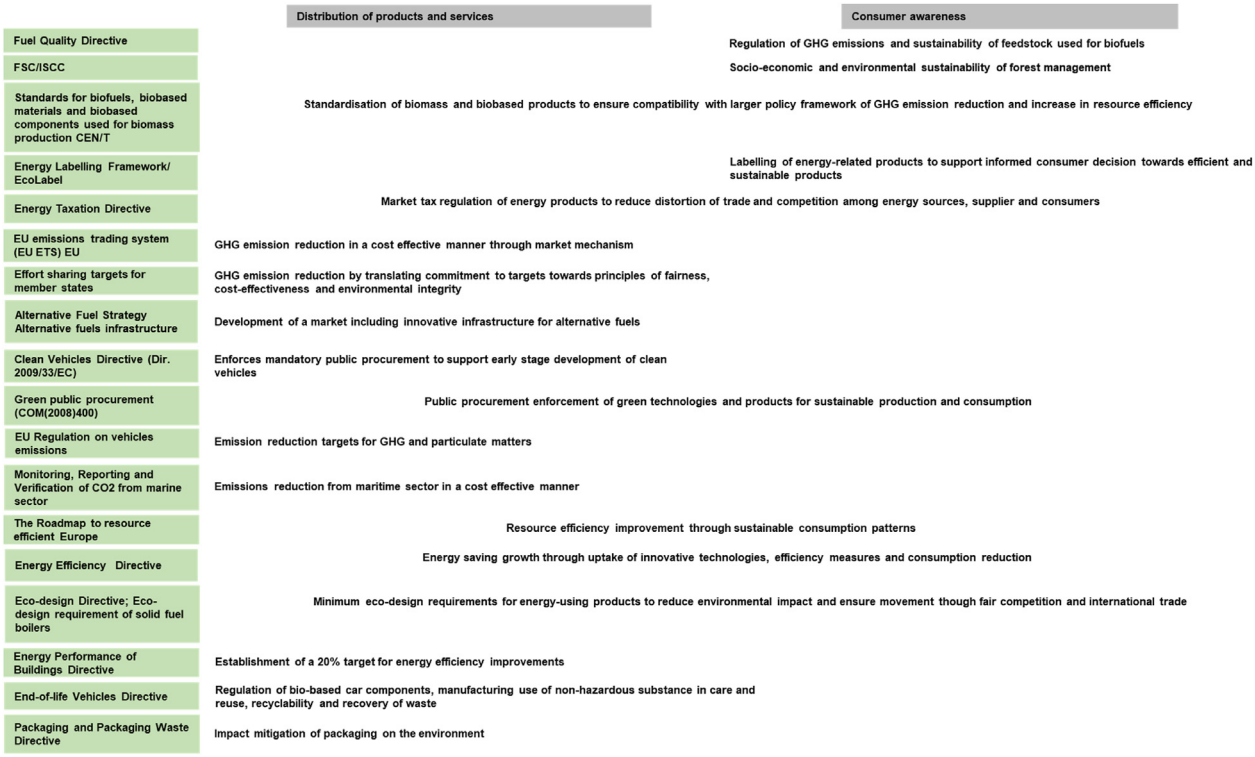


Fig. 6. Policies in the end-use stage and issues they regulate.

establishment and *annual feedstock management,* are regulated by a set of policies (See Fig. 4) which provide rules and financial support through: sustainable natural resource management, mitigation of agricultural and soil management practices, including reducing pollutants and GHG emissions, research and innovation to increase resource efficiency, as well as mobilisation of waste to improve the circularity of biomass. Policies concerning *pre-treatment* also include the promotion of research and innovation for resource efficiency, while policies *relevant to storage* and *transport* target GHG emissions related to biomass logistics.

For the first two activities, both the CAP and RED II support sustainable agricultural practices and biomass production. RED II also implements sustainability criteria for biofuels, bioliquids and biomass fuels emphasising sustainable harvesting practices of

forest biomass. Policies like CAP, LULUCF, RED II all aim to implement GHG reduction criteria in compliance with GAEC, sustainability criteria, and low and high iLUC risk factors for biomass feedstock – with an aim to reduce the competition with land and water resources for food production as they generate lower environmental footprints (Clark et al., 2013; Drews et al., 2020) [52,53]. The Farm to Fork Strategy 2020 promotes sustainable food systems which are environment and climate neutral, therefore non-food biomass crops in rotation with food crops must comply with practices reducing inputs (fertiliser, pesticide and antimicrobial uses) and nutrient losses. Other policies aligned with this effort include the **EU Timber Regulation** [54], EU Forest Strategy, **EU's Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan** [55], LULUCF, and REDD+. These aim to avoid the overexploitation of forest biomass and reduce emissions through sustainable management and harvest accounting mechanisms such as the Forest Reference Level (FRL) [56] which monitors net changes in carbon stocks. Sustainability aims of these forest sector policies are instrumentalised by Forest Management Plans and the Forest-based Sector Technology Platform. REDD + aims to regulate sustainable forest biomass harvesting with carbon market mechanisms funded by the Green Climate Fund.

Other EU policies include the **EU Biodiversity Strategy to 2020 (COM/2011/244)** [57], **Habitat Directive 94/43/EEC** [58], and **Bird Directive 2009/147/EC** [59] whose aim is to regulate the conservation of biodiversity and natural habitat to minimise the ecological costs of land-based biomass production and maintain the productivity of ecosystem services. The **European Sustainable Development Strategy COM (2001)** [60] supports these policy aims by stressing the importance of biodiversity and natural resources to combat climate change and proposes sustainability criteria with an emphasis on biodiversity, GHG emission, energy conversion efficiency and origin of the biomass. The International Union for Conservation of Nature developed guidelines to minimise the ecological invasion risk of biofuel crops for the whole supply chain from crop production to processing. In order to tackle the threats to biodiversity from ecological invasion, the EU adopted **Invasive Alien Species (IAS) Regulation (EU) No 1143/2014** [61] and amended **Regulation (EU) 2019/1262** [62]. The European Union aims to provide cost-reduction incentives for sustainable biomass production and harvesting and biodiversity conservation objectives through financial instruments like **LIFE+** [63], ESIF, Horizon 2020, Natura 2000, **EU Rural Development Policy 2014-2020** and **Cohesion Funding** [168].

In the absence of effective regulation, agricultural practices may lead to harmful impacts on the environment. The **Soil Thematic Strategy (COM 2012)46 final** [65]**, Soil Framework Directive COM (2006)232** [66], **Integrated pollution prevention and control (IPPC) (96/61/EC) Directive, Standards for soil improvers (CEN-TC223)** [67], **Nitrate Directive 91/676/EEC** [69], **EU Water Framework Directive 2000/60/EC** [68], **Clean Air Programme for Europe COM/2013/0918**, and **Directive for sustainable use of pesticides 2009/128/EC** [71] all work towards the common aim to enforce quality standards for chemical inputs to safeguard the quality of land, air and water. Standard for soil improvers (CEN-TC223) aims to regulate mineral fertilisers and the new **EU Fertilising Products Regulation EU 2019/1009** [72] seeks to promote the use of bio- or waste-based fertilisers and recycled materials while reducing dependency on imported fertilisers. The Cohesion fund has allocated 3.1 billion EUR between 2007 and 2013 for soil rehabilitation projects, while the Farm to Fork Strategy 2020 aims to transform 25% of total farmland into organic farming by 2030. By 2022, it will repeal Regulation (EC) No. 2003/2003 which overlooks close to half of fertilisers produced from organic waste streams in the EU market.

The Natura 2000 Network under the EU Biodiversity Strategy not only recognises the important role of soil organic carbon in the protection of European biodiversity but also in climate regulation. Use of fertilisers to improve crop yields can result in dangerous increases of phosphorus in soil and water. The Water Framework Directive is also an important policy which aims to impact biomass production activities as it focuses on land use- and water use-related climate change risks. Therefore, the Natura 2000 Network together with the Water Framework Directive (2000/60/EC) aim to regulate the level of phosphorus by integrating it as a soil quality indicator.

Pre-treatment, storage, and transport logistics are crucial activities following biomass harvest, involving the transfer of biomass from production sites to biorefineries and bio-based industrial plants. The IED and **EU Standards CEN/TC 383 Sustainably produced biomass for energy applications** [73] aim to produce biomass sustainably under specific emission thresholds and adopt BAT to minimise environmental impacts.

The bioeconomy offers a unique opportunity to mobilise biogenic waste as biomass feedstock for minimising resource competition. The amended WFD sets new standards in waste management, integrating ambitious recycling targets in the EU while focusing on energy efficiency. The **Landfill Directive (LD) 1999/31/EC** [74] aims to promote waste hierarchy and energy recovery principles and requires EU Member States to reduce biodegradable waste entering landfills. The **Sewage Sludge Directive (86/278/EEC)** [75] seeks to support the WFD and LD objectives for resource recovery alongside regulating the concentration of heavy metals in soils to prohibit soil quality degradation. Additionally, the **Waste Incineration Directive 2000/76/EC** [76]**, Directive 94/62/EC on packaging and packaging waste** [77] and **Animal by-products and derived products not intended for human consumption Regulation EC No 1069/2009** [78] all equally aim to protect human and environmental health, minimise negative impacts from waste practices and promote the use of waste as biomass feedstock.

3.3. Conversion

The key activities in the conversion stage of the value chain are *establishment of biorefineries* and *smooth operation of biorefineries*. Firstly, the *establishment of biorefineries* is governed by policies (see Fig. 5) which support: the research, development and deployment of innovative low-carbon technologies from pilot and demonstration level to commercial scale, as well as collaborations among research institutions and industries, and public-private partnerships which attract investment and promote a risk-free environment. The conversion stage is the fundamental vehicle for the transition to a bio-based economy through fostering the sustainable conversion of biomass into bioenergy and bioproducts (Kleinschmit et al., 2014; IEA Bioenergy, 2012).

Relevant policies include the **Environmental Technologies Action Plan (ETAP)** [79] adopted in 2004 which aims to support eco-innovative projects for clean products and decarbonise energy-intensive sectors through funding research and development (R&D) activities and infrastructural development. There are several EU funding programmes for eco-innovation [80] such as LIFE+, Horizon 2020, **Competitiveness of Enterprises and SME (COSME)** [81], and ESIF whose five-year cycles end in 2020. Their objective was to support small and medium enterprise (SME) technology scale-up through R&D activities, roll-out of digital technologies and low-carbon economies and sustainable management of natural resources.

Similarly, the **EU Innovation Action Plan** [82] was launched in 2011 to support the overall aim of ETAP to increase access to eco-

innovative technologies and address challenges of resource scarcity and environmental pollution, job growth and sustainable natural resource use. One of its key actions was to put in place European Innovation Partnerships (EIPs) [83] to bring together European SMEs, eco-industry actors and resources by leveraging eco-innovative technologies and lead biorefineries towards global markets. The **Environmental technology verification programme (EU-ETV)** [84] is a voluntary verification procedure for the performance and environmental benefit of innovative technologies, supporting their market integration.

The **SET- Plan** [85] is the technology pillar of the EU's energy and climate policy and aims to maintain EU leadership in low-carbon technologies and reduce EU GHG emissions by 80–95% by 2050. It reinforces partnerships between stakeholders from research and industry to support the establishment of biorefineries and help overcome the high production cost of large scale commercialisation, in part attributed to the lack of secure financing mechanism from the private sector (Schieb et al., 2015) [86]. The **InnovFin** [87], is an example of a funding program under Horizon2020 to provide support for research and innovation projects and industrial demonstration projects. The Innovation Fund [88] aims to support the transition of innovative pilot scale projects to large scale by facilitating their access to markets under low risk conditions by mobilising public-private funds, an effort mirrored by the **Just Transition Mechanisms** [90] under the framework of the **Sustainable Europe Investment Plan** [92] and the **European Green Deal Investment Plan** [92].

Policies for the *operation of biorefineries* target the regulation of emissions and harmful chemicals to protect the environment, energy efficiency to promote industrial competitiveness and standardisation for bio-based products. One of the primary policies to regulate emissions standards at the European level is the IED which targets harmful industrial emissions both for human health and the environment and uses energy efficiency, recovery and recyclability as key conversion technology criteria. The **Clean Air Policy Package** [93] complements the **Medium Combustion Plant Directive (MCPD) 2015/2193** [94] which aims to regulate medium scale combustion plants (with thermal input capacity in the range of 1MWth to 50MWth) while the IED targets large combustion plants (whose capacity exceeds 50MWth). The **European Pollutant Release and Transfer Register (E-PRTR)** [95] was established in 2006 as a publicly accessible register on pollutant releases to air, water and land to create a transparent and accountable system for monitoring emissions. In 2006, **EU REACH Regulation No (1907/2006)** [30] was also adopted to regulate chemicals used in the manufacturing process.

During the last eight years, the European Committee for Standardisation (CEN) has put forth many EU standards for bio-lubricants, bio-polymers, bio-surfactants and bio-solvents which ensure consistent terminology, sampling, bio-based content monitoring, and certification tools, however using different performance indicators. **Standardisation for Bio-polymers and Bioplastics CEN/TC 249** [97] and **Standardisation on Surface Active Agents (Bio-surfactants) CEN TC276** [98] aim to regulate chemicals used in the conversion process of biomass into bio-based products. **Standardisation for Bio-based products (CEN TC411)**, **Standardisation for Bio-lubricants (Liquid petroleum products) CEN/TC 19** and **Standardisation for products made from algae CEN/TC 454** are additional tools to standardise bio-based products. Standardisation can lead to more efficient monitoring of biodegradability, bio-based content, recyclability and sustainability of products, as well as support the compatibility of waste as a source of biomass feedstock. For instance, composting standards for packaging and products such as **EN 13432 (packaging) and plastics (EN 14995)** are put in place to ensure these are recycled and used in aerobic composting. **SusCHEM** [99] (European Technology Platform for Sustainable Chemistry) aims to support sustainable technology for biorefineries through biotechnology research, development and innovation.

Finally, energy and resource efficiency in process industries are regulated by the **EU eco-management and audit scheme (EMAS)** [100] (to be revised with reduced-cost mechanisms for companies), and the **Sustainable Process Industry through Resource and Energy Efficiency (SPIRE)**, a contractual public-private partnership.

3.4. End use

The first key activity of this stage is the *distribution of products and services* for which policies (see Fig. 6) support infrastructural development, tools to promote the market uptake of bio-based products and services, and measures to improve resource and energy efficiency, GHG and pollutant emission standards. The second activity considered concerns raising *consumer awareness* and is aided by policies promoting reuse, recycling, recovery and circularity of bio-based products, as well as regulating their standards through labelling and certification.

The **Sustainable Consumption and Production Action Plan (SCP-AP)** [101] adopted in 2008 was established to enhance the environmental performance of products for increased consumer use. The action plan set ambitious standards to regulate internal markets and improve products through incentives and public procurement, labelling and eco-design of energy- and energy-related products.

The FQD and RED II set sustainability criteria for biofuels to minimise negative impacts starting at the biomass production stage. FQD's sustainability criteria help establish a single, European-wide fuel market for vehicles. Certification initiatives such as **International Sustainability and Carbon Certification (ISCC)** [102] and **Forest Management Certification (FSC)** [103] are implemented at European level to monitor the production of biofuels and are now progressively incorporating other material uses of biomass (Ladu et al., 2017) to broaden market competitivity. ISCC complies with RED II and FQD and covers all sustainable feedstocks (including agricultural and forestry biomass), circular materials and renewables, and includes voluntary certification activities for biodiversity protection, GHG emissions and hazardous chemicals reduction, and water footprint. Market-based mechanisms deployed under **Energy Taxation Directive 2003/96/EC (ETD)** [104] aim to support the uptake of bio-based products by establishing a harmonised tax on energy products to avoid distortions in trade.

End-product distribution requires the coordinated development of alternative fuels infrastructure, both from the supply and demand side (distribution networks, recharging and refuelling points). The **Directive on deployment of Alternative Fuels Infrastructure 2014/94/EU** [105] was adopted for development of alternative fuels infrastructure at national level. Policies also exist to support the use of green technologies or emissions standards at the consumption level. For example, the **Clean Vehicles Directive 2009/33/EC** [106] aims to enforce mandatory public procurement for each member state to support the early stage deployment of vehicles and reduce emissions and pollutants. Similarly, the **Green Public Procurement COM (2008/400)** [107] developed the **EU GPP criteria** [108] which member states can adopt at their own discretion to support sustainable technologies, renewables and products, including a focus on socio-economic impacts.

Regulations such as **Emission Performance for new passenger cars** [109] for road transport take into consideration the weight of vehicles to reduce CO_2 emissions (Pinto, 2009; Marousek et al., 2012, Helms and Krack, 2016). The **EU Regulation 595/2009 on**

Heavy duty vehicles (HDV) standards [110], **EU regulation EU 2017/2400 CO2 emissions and fuel consumption of heavy-duty** [111], **EU Regulation (EU) 2018/956 Monitoring and reporting of CO2 emissions from, and fuel consumption of, new heavy-duty vehicles** [112] and **EU Regulation 692/2008 on light vehicles standards** [113] all work towards the common objective of promoting the adoption of clean and efficient technologies and fuel consumption, by targeting GHG and particulate matters throughout lifecycle performance. Obligation to determine and declare for certification of CO_2 emissions and fuel consumption of new vehicles under the EU Regulations (EU) 2018/956 aims to increase transparency of HDV performance. The **EU Monitoring, Reporting and Verification (EU MRV) 2015/757** is designed to quantify CO_2 emissions for maritime transport and establish reduction targets for ships above 5000 gross tonnage.

Market uptake of innovative products requires consistent and coherent information about their content, sustainability and environmental indicators (Sijtsema et al., 2016; Blind et al., 2017; Bahrami et al., 2019) to build consumer trust. Standardisation, certification schemes and labels support this effort as essential tools to help communicate the availability and benefits of purchasing bio-based products (Ladu et al., 2017). **Energy Labelling (Directive 2010/30/EU and Regulation 2017/1369)** [114] aims to regulate labelling for energy-related products and helps consumers make informed decisions while **EcoLabel** [115] is developed to communicate the benefits of bio-based products and improves their market integration. Similarly, lack of appropriate infrastructure is also an obstacle for the uptake of the products. For example, the apparent lack of refuelling stations to distribute alternative fuels is seen as a major obstacle (ACEA and UITP Press, 2019) [116,117] to meet renewable energy targets in the transport sector. To address issues on alternative infrastructure there are policies like Green Public Procurement, Alternative Fuels Infrastructure, SCP-AP, **EU Energy Union Strategy** [118], European Green Deal, ETIP-Bioenergy, **Research and Innovation Strategies for Smart Specialisation (RIS3)** [119], **Bio-based Industries Joint Undertaking (BBI-JU)** [120], and the new Circular Economy Action Plan, among others. These policies have a common objective to adopt low carbon technologies and products, reduce GHG emissions, and take part in the global climate change mitigation effort.

Standardisation policies [121] provide consistent terminology, standards of bio-solvents, bio-based content, application of LCA, end-of the life options, and sustainability criteria. They include **Standards for solid biofuels (CEN/TC335)**, **Standards for Solid Recovered Fuels (SRF) (CEN-TC343)**, **European Norm Sustainability criteria for biofuels and bioliquids: EN16214, European Norm biodiesel-FAME (Fatty acid methyl esters): EN14214, European Norm Petrol: EN228**, and **prEN16723 - Natural gas and biomethane, CEN/TC 19- Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin**. Each of these is developed to standardise biomass used for biofuels production and support the market integration of bio-based products. RED II aims to incentivise the production of the sustainable aviation fuels (SAFs) at the industrial scale through regulatory targets for the uptake of advanced fuels. In support of RED II there are other certification tools such as ISCC, FSC, FQD which are all implemented at European level with an objective to monitor the production of sustainable biofuels and certification activities.

Concerning market-based instruments improving energy efficiency of bio-based products and consumption patterns, the **Eco-design Directive 2015/125/EC** [122] is a key instrument targeting change in products and consumption patterns. The **Action Plan for the Circular Economy** [123] also highlights this Directive as an important policy instrument addressing resource efficiency. The **Eco-design requirement of solid fuel boilers Regulation (EU) 2015/1189** [124] is a specific example of a regulatory policy enacting energy labelling for woody biomass, with energy use and CO_2 reduction potential as key indicators assessing the performance of conversion technologies (Rietbergen and Blok, 2013).

Long-term renovation strategies covered under **Energy Performance of Buildings Directive (EU)2018/844** [125] objective is to create opportunities for energy savings through both infrastructural renovation for energy efficiency as well as accurate consumer information provision, for instance through installing smart meters.

Waste is addressed through circularity and end-of-life usage of bio-based products, as enacted by the **End-of-life Vehicles Directive 2000/53/EC** [126], which aims to regulate bio-based car components, however its regulations lack specificity (Wurster and Ladu, 2020). To achieve circularity, separate waste collection is a first step towards implementing industrial scale composting. **The Packaging and Packaging Waste Directive 2004/12/EC** [127] provides a framework for member states to set up return, collection and recovery systems. The Directive's main aim is to provide environmental protection and avoid obstacles to trade and distortion of competition. **Standards EN 13432 -A Standard for Compostability** and **EN 14995- Evaluation of Compostability** [128] are also in place to certify the biodegradability of packaging and non-packaging materials to make the process of industrial composting more efficient.

4. Policy gap analysis

This section identifies important challenges, and policy gaps within each value chain stage and activity.

4.1. Land use

A key challenge (see Table 1) in land use for non-food biomass production is **competition and trade-offs** between food and non-food applications (Panoutsou et al., 2020) [129]. This can be overcome with the exploitation of marginal land. While this presents a key opportunity to reduce pressure on agricultural land (Banja et al., 2019) [130], there is still scepticism surrounding crop productivity and its environmental benefits. Similarly, over-exploitation of land for non-food biomass can lead to deforestation or **soil degradation**, compromising land quality and food systems resiliency given growing threats from climate change (Bosch et al., 2015).

Addressing these key challenges aligns with the following bioeconomy objectives: *i) ensuring food and nutrition security; ii) managing natural resource sustainably*, and *iv) mitigating and adapting to climate change.*

4.1.1. Gaps in policies concerning competition and trade-offs of land use and exploitation of marginal land

There are regulatory and financial instruments in place within CAP, LULUCF, ILUC, EU Forest Strategy, etc. to alleviate the challenges, reduce the impact of land use change and prevent the over-exploitation of marginal land. However, most of these policies focus only on biophysical criteria to assess land marginality. Future policies should account for socioeconomic contexts as well and assess the economic potential of land for biomass production (Sallustio et al., 2018) [131]. There is also no common definition of marginality among enforced policy frameworks and this makes implementation of such policies limited. It is important to establish a common understanding of marginal land types for future policy formation and implementation (Gerwin et al., 2018) [132] as inconsistent or widely inapplicable definitions have known to neglect certain marginal land types (Mellor et al., 2020) [133].

Table 1
Land use stage challenges, existing policies which address them and respective policy gaps.

Value Chain Stage	Key Challenges	Bioeconomy Objectives	Do existing policies address challenges to meet the bioeconomy objectives?	If not, what are the policy gaps?
Land Use	Competition for land use Exploitation of marginal land Soil degradation	*Ensuring food and nutrition security* *Managing natural resources sustainably* *Mitigating and adapting to climate change*	Regulatory and financial instruments in place for sustainable use of land and natural resource management Regulation of soil quality, mitigation of erosion, reduction of deterioration due to loss in organic matter and biodiversity, and reduction of contamination to ensure food security as well as to manage natural resources sustainably There are harmonised soil datasets at the EU level which support modelling for land use change and carbon stock to develop climate-smart agricultural policies (Ledo et al., 2019) [136]	Lack of harmonised definition of marginal land across EU and policies which address socioeconomic land marginality No specific regulatory instrument such as targets to monitor the soil quality and to reduce soil threats at the EU level (Panagos and Montanarella, 2018), while sectoral policies regulating soil emission limits lack integration

There are also policies like the 2030 Climate and Energy Framework under which the SET plan aims to support the whole innovation chain from research to market uptake, RED II that supports low-iLUC biomass production for biofuels through cultivation on marginal, degraded and contaminated lands, and the CAP-RDP which has allocated funding for less favoured areas to rehabilitate marginal lands. Moving further, R&D activities can be tailored towards the exploitation of marginal land to reduce pressure on agricultural land and make the best use of available funding resources.

4.1.2. Gaps in policies regarding soil degradation

The Soil Framework Directive is not a legally binding component of the Soil Strategy as it is not adopted by all EU Member States due to administrative burdens and high costs of its implementation (Glaesner et al., 2014 as cited in Ronchi et al., 2019). Hence, varying national policies on soil protection rarely align with other policies regulating soil quality (Frelih-Larsen at al., 2016) [134]. National and sectoral policies that regulate soil quality lack uniformity in standards at the EU level and integration among sectoral policies, the latter being a main focus point of the Soil Thematic Strategy (EC, 2012) [135].

4.2. Biomass production

Biomass production faces challenges as demand for biomass increases (see Table 2). This includes identifying suitable land types (e.g. abandoned land) that do not compete with food production and mobilising biomass production in a sustainable manner. However, these practices can intensify **agriculture further** as well as cause **unsustainable expansion of land** which can **have negative impacts on biodiversity** due to invasive crop species, on **soil and water quality, and GHG emissions** (Drews et al., 2020) [139]. These largely depend on the land use changes induced, biomass crop choices and cropping patterns, harvest level of biomass, soil inputs, land structure, and native ecology (Predroli et al., 2013) [138]. Thus there are key concerns for biomass sustainability, resource efficiency, emission from land use change and water footprints for biomass production (Drews et al., 2020) [139]. As competition for biomass feedstocks increases, waste streams are perceived as a key opportunity to reduce pressure on agricultural and forestry resources. However, this raises the challenge of **maintaining waste biomass feedstock quality**, as heterogeneous waste materials can create complications for biorefineries (Sanchis-Sebastia et al., 2019 [140]; Bona D. et al., 2018) [141]. Finally, biomass production growth means **increasing logistical needs for pretreatment, storage and transport of biomass feedstock.**

These identified challenges of the biomass production stage pose barriers for meeting the bioeconomy objectives of *ii) managing natural resources sustainably, iii) reducing dependence on non-renewable resources, iv) mitigating and adapting to climate change,* and *v) creating jobs and strengthening European competitiveness.*

4.2.1. Gaps in policies regarding biomass feedstock sustainability and resource efficiency

There are regulatory policy instruments which introduce explicit sustainability criteria, including GHG emission reduction levels and, low and high risk land use change issues. The Water Framework Directive provides soft measures, under which Member States developed the **Programme of Measures** for sustainable management of water resources. However, these current sustainability criteria do not incorporate water quality and water consumption aspects specific to the biomass production stage (Ji

Table 2
Biomass production stage challenges, existing policies which address them and respective policy gaps.

Value Chain Stage	Key Challenges	Bioeconomy Objectives	Do existing policies address challenges to meet the bioeconomy objectives?	If not, what are the policy gaps?
Biomass Production	Feedstock sustainability and resource efficiency -sustainable agricultural practices (ensuring biodiversity conservation; avoiding invasive crop species; maintaining soil, water and air quality)	*Managing natural resources sustainably* *Reducing dependence on non-renewable resources* *Mitigating and adapting to climate change* *Creating jobs and strengthening European competitiveness*	Regulatory policy instruments supporting conservation of natural resources (biodiversity, soil, water, land), sustainable management and harvest of agricultural and forest biomass production, sustainable practices to promote soil health, and mobilisation of waste as biomass feedstock	Room for improvements in regulatory measures by including specific sustainability criteria for water quality and water use monitoring. Additional financial measures to support the implementation of policies which regulate standards of soil improvers and emission limits
	Waste biomass feedstock quality		Regulatory requirements and targets for waste separation, recycling and treatment. Various regulatory and financial measures in place which address waste resource mobilisation by implementing waste hierarchy principles	There is a need for additional policy provisions (soft measures like supporting the exchange of information on waste type, content, potential conversion processes and supporting databases) to support waste mobilisation and valorisation. Additional investment support for established and novel technologies which can manage and process the biogenic waste in large volumes meeting the sustainability requirements.
	Biomass logistics (pre-treatment, storage and transport)		Certain policies focus on post-harvest logistics of forest biomass, management of waste feedstock to reduce GHG emission and transport-related carbon emission reduction in the supply chain	There is a need for additional policies to support biomass logistics such as pre-treatment of diverse biomass feedstocks, and storage and transport with low carbon footprint

and Long, 2016) [142]. There is a need for regulatory tools which monitor water quality and water use efficiency strictly for the biomass production stage.

In addition, there are strategies, regulatory tools like certification and financial support to ensure the sustainability of forest-based biomass, however additional policy interventions which ensure the sustainability of the whole value chain including the conversion of forest biomass and forest based products would be beneficial (Karvonen et al., 2017; Holopainen et al., 2015) [143,144].

Finally, there are quality standards, soil quality indicators, harmonised emission limits to regulate the quality of fertilisers, and soil improvers used in biomass production process to reduce impacts on soil and air quality. However, there are not enough dedicated financial mechanisms supporting the implementation of these policies, other than the Cohesion Fund which aims to restore and decontaminate brownfields.

4.2.2. Gaps in policies to address resource competition

Diversification of biomass sources is highly important to meet the growing demand of biomass. As such, mobilisation of waste to reduce competition for finite land and natural resources is supported by the Circular Economy Package, WFD, LD and Sewage Sludge Directive. These policies aim to implement regulatory requirements and targets for waste separation, recycling and treatment. WFD and LD aim to provide financial instruments for implementing the waste hierarchy and discouraging landfilling respectively but do not have sufficient provisions to mobilise underutilised waste feedstock. There are soft provisions such as waste prevention programmes, public consultation for permitting procedures, and harmonised calculation methods (to measure recycling rates) for member states to adopt. However, for a successful valorisation of waste through optimising compatibility of conversion processes, the first step is the characterisation of biomass waste to ensure proper disaggregation based on physiochemical properties such as moisture content, volatile matter, carbon and ash content. Thus, there is a need for additional policy provisions (soft measures like supporting the exchange of information and supporting database development) to support waste mobilisation and valorisation. Additional financial support should also be planned to increase investment already established as well as novel technologies which can manage and process the biogenic waste in large volumes to meet the requirements of sustainability (O'Callaghan, K., 2016) [145].

4.2.3. Gap in policies regarding challenges associated with post-harvest biomass logistics

The CAP 2021-2027 reforms could focus on strengthening the competitiveness of EU biomass producers through cooperation and financial support for the establishment of producer organisations (POs) to support supply chains and improve logistics. The short food supply chain development has been supported for many years by instruments like **LEADER (Local Action Groups engaged through the Rural Development Programme of the CAP)** [146] to reduce transport-related carbon emissions in food production and supply chain. The regulatory tool of EU FLEGT regulates the legal trade of the biomass post-harvest, while the Directive on packaging and packaging waste has provisions for the management of the waste to reduce GHG emissions. However, there is a need for additional policies to support biomass logistics including pre-treatment of diverse biomass feedstocks, and storage and transport options with low carbon footprint.

4.3. Conversion

One of the main challenges for the establishment of biorefineries is to **improve access to technology by reducing gaps**

Table 3
Conversion stage challenges, existing policies which address them and respective policy gaps.

Value Chain Stage	Key Challenges	Bioeconomy Objectives	Do existing policies address challenges to meet the bioeconomy objectives?	If not, what are the policy gaps?
Conversion	Improve access to technology by reducing gaps between R&D and deployment of technologies, and by increasing investments for market uptake	*Reducing dependence on non-renewable, unsustainable resources* *Mitigating and adapting to climate change* *Strengthening European competitiveness and creating jobs*	There are policies which support R&D and innovation activities to promote eco-innovative technologies and provide necessary support to uptake technology from small scale to large commercial scale through access to finance and business support services	Lack of specific funding mechanisms, information provisions and capacity building programmes for SMEs and industries to support complex biomass logistics during the conversion process and valorisation of value added products from waste streams
	Consistent, year-round supply of biomass feedstock to biorefineries through mobilisation of waste resources, optimisation of logistical processes, location of the biorefineries etc.		There are regulatory policy measures which enforce standards to regulate the chemicals used in the production process of bio-based plastic and surface active agents and regulate industrial emissions (GHGs and other pollutants)	Lack of specific regulatory requirements for leveraging potential waste streams as biomass feedstock. Dedicated funding needed to facilitate establishment of biorefineries in close proximity to biomass sources and improve collaboration among suppliers

between research, development and deployment of technologies, and increasing investments and capacity building for the market uptake of SMEs. As a first step, establishment requires a financially risk-free environment to attract investment and facilitate the transition of technology from demonstration to large-scale commercial projects.

Operation of biorefineries requires **consistent year-round feedstock supply**. This is considered a major challenge for their successful establishment (Eksioglu et al., 2009) [171] and cost effectiveness of biorefinery processes will depend on the availability of biomass (Scarlat et al., 2015) [147] and type of biomass available. Biorefinery location and feedstock sourcing can be optimised through geo-spatial and temporal factors which determine both the sustainability and efficiency of supply chains (Murthy, 2019) [148]. The conversion stage thus requires challenging logistical optimisation, including ensuring the value chain link with a year-round supply of biomass and coping with diverse feedstock sources which have varying moisture content, ash content and complex characteristics – a potential barrier for conversion processes with specific requirements. Alternately, mobilisation of waste can complement or replace feedstock supply. Challenges that arise from diversified feedstock streams can be met with innovative and flexible conversion processes. The production of value-added end products from residues (waste and by-products) is possible through well-designed technological valorisation strategies and integrated biorefinery concepts (Luque and Clark, 2013; Pleissner et al., 2016; Negro et al., 2017) [149–151].

Addressing these key challenges in the conversion stage can facilitate meeting the bioeconomy objectives of *iii) reducing dependence on non-renewable and unsustainable resources, iv) mitigating and adapting to climate change,* and *v) strengthening European competitiveness and creating jobs.*

4.3.1. Gaps in policies regarding access to technology through bridging research, development and deployment

Various policies aim to accelerate the establishment of biorefineries (see Table 3) through research, development and innovation promoting eco-innovative technologies and their transition from small to commercial scale through access to finance and business support services. For instance, the European Green Deal seeks to increase public and private investments for biorefineries and technology valorisation practices. However, there is a lack of dedicated policies targeting the optimisation of complex conversion logistics. More support is needed to reduce energy inputs and pre-processing costs of biomass feedstocks, and to improve access to technologies and machinery making conversion processes more flexible and capable of processing biomass with varying moisture, ash and chemical content.

4.3.2. Gaps in policies regarding the consistency of biomass feedstock supply

For the smooth operation of biorefineries, there are standards, permits, mandatory emission limits, reporting requirements, voluntary audit and certification systems which aim to reduce industrial GHGs and pollutant emissions. These regulatory tools support the uptake of energy efficient technologies by maintaining performance standards, thus contributing to a competitive European market that produces high quality bio-based products. However, there are insufficient policies providing support for integrating more diverse biomass streams. In order to diversify biomass streams, additional regulatory tools which are harmonised with the EU chemical policies on recycled materials (REACH Review report, 2018) [152] are needed, where clearly defined labels can help monitor complex compositions of biological

Table 4
End use stage challenges, existing policies which address them and respective policy gaps.

Value Chain Stage	Key Challenges	Bioeconomy Objectives	Do existing policies address challenges to meet the bioeconomy objectives?	If not, what are the policy gaps?
End Use	Compatibility of bio-based products and services with existing processes, standards and distribution channels	*Reducing dependence on non-renewable, unsustainable resources* *Mitigating and adapting to climate change* *Strengthening European competitiveness and creating jobs*	There are policies which support the consumption of alternative (clean) fuels by enforcing emission limits, building alternative infrastructure, promoting green technologies through public procurements and introducing financial mechanisms to promote energy efficiency	Need of additional policy support for the distribution of sustainable aviation fuels (SAF) (or bio jet fuels) and mobilisation of advanced biofuels in general
	Lack of consumer awareness about quality (sustainability) and availability of bio-based products		Existing policies employ standards, labelling, certification mechanisms which provide key information about bio-based products	Existing policies do not cover the wide range of bio-based products and provide limited information on their circularity and sustainability impacts. New standardisation initiatives can extend cradle-to-grave assessments to include end-of-life advantages of bio-based products in comparison to petrochemical based products

materials commonly known as UVCB (Unknown or Variable Composition, Complex reaction products or Biological materials) [153]. These efforts will help improve the circularity and sustainability of bio-based products. Finally, there is also lack of dedicated funding support to facilitate the establishment of biorefineries in close proximity to biomass sources and to improve collaborations among value chain actors.

4.4. End use

Consumption practices and consumers play a central role in the end use stage, while policy makers are instrumental in developing a favourable and conducive regulatory environment (Morone et al., 2020) [172]. **Consumer acceptance** becomes a challenge with underdeveloped standards/certification procedures and unfamiliarity with bio-based products (Sijtsema et al., 2016; Scherer et al., 2017; Morone et al., 2020) [172–174]. Therefore, the first key objective is **to ensure that new products are compatible with existing processes, standards and distribution channels or infrastructures,** and secondly, **to increase consumer awareness about the quality and availability of bio-based products.**

Addressing these key end use stage challenges can support the bioeconomy objectives of *iii) reducing dependence on non-renewable and unsustainable resources, iv mitigating and adapting to climate change* and *v) strengthening European competitiveness and creating jobs.*

4.4.1. Gap in policies concerning the compatibility of bio-based products and services with existing processes, standards and distribution channels

Several policies in place aim to support the distribution of bio-based products and services by enforcing emission limits and sustainability criteria (see Table 4), where suppliers and consumers progressively uptake more efficient green technologies with required standards. There are also policies like Alternative Fuels Infrastructure and Alternative Fuels Strategy which support the building of alternative infrastructures to improve distribution channels. In spite of this, the large scale distribution of low carbon fuels remains a challenge due to the lack of adequate investments to reduce production costs and certification procedures (Chiaramonti, 2019). While carbon market mechanisms and investments funds such as the Innovation Fund and Modernisation Fund under the **EU Emissions Trading System (EU ETS)** [154] aim to support the innovation and investment challenges for a low-carbon transition, in general there is no dedicated funding mechanism targeting the uptake of advanced biofuel technologies and distribution of sustainable aviation fuels (SAFs). In addition to providing dedicated funding, EU regulations must either comply or align with global certification standards (currently the leading one being the American Section of the International Association for Testing Materials) to make SAFs commercially viable in Europe and ensure their sustainability across the whole value chain. A lack of dedicated policy interventions for advanced biofuels correlates with limited investment, thus slowing their uptake and maintaining a significant price gap with fossil fuels. The RED II is the leading EU policy framework aiming to support the uptake of advanced biofuels for 2020-2030 together with carbon neutral targets under the European Green Deal. These can mobilise investment and support needed for the establishment of large scale biorefineries, demonstration plants and fuel certification processes (see Table 5).

4.4.2. Gaps in policies concerning consumer awareness

Certain existing policies imposing standardisation, labelling,

Table 5
Challenges and recommendations per value chain stage { Regulations (R); Financing mechanisms (F); Soft measures (S) }

Value Chain Stages	Key Challenges	Recommendations	Type of policy instruments
Land Use	Competition for land use Exploitation of marginal land Soil degradation	Administer regulatory policies to encourage farmers to adopt agricultural and soil management practices to cultivate biomass on marginal lands and channel financial support to create value and job opportunities in rural areas Develop building capacity and knowledge bases for stakeholders on sustainable land use management practices Produce harmonised regulatory instruments to monitor soil quality across Europe	R, F S R
Biomass Production	Sustainable agricultural practices (biodiversity conservation, soil, water and air quality) to ensure feedstock sustainability and resource efficiency Waste biomass feedstock quality Biomass logistics	Capitalise on European-level datasets and research on GHG implications of water use for biomass production to translate into standardised regulatory tools across policies Introduce novel regulatory, financial policy developments and information provisions to help mobilise underutilised biomass sources Increase investment towards infrastructures and biomass production logistical processes	R, S R, F, S F
Conversion	Improve access to technology and reduce gap between research and deployment of technologies, as well as increase investment for establishment of biorefineries Consistent year-round supply of quality biomass feedstock	Increase funding support, capacity building activities, and information provisions to optimise costs and GHG emissions within conversion processes Provide monitoring tools for regulating the composition of biological materials to improving circularity and sustainability of bio-based products	F, S R
End use	Compatibility of bio-based products and services with existing processes, standards and distribution channels Lack of consumer awareness about the quality as well as availability of bio-based products	Improve investment targeting the infrastructure of distribution channels Improve labelling and certification policies by including more information on the sustainability impacts and life-cycle of relevant products and services	F S, R

certification, monitoring and reporting schemes effectively deliver key information about bio-based products and services, guiding consumers to make informed choices. These officially communicate the benefits of a limited set of bio-based products (biofuels, bio-lubricants, biopolymers, bio-surfactants, bio-solvents) informing on bio-based content, sustainability criteria and end-of-life options. In addition, European-level bio-based product labelling is limited to information on their components and does not provide information on environmental sustainability indicators from the biomass production process (Meeusen et al., 2015; Peuckert and Quitzow, 2017) [175]. Consumers require clear information which allows to benchmark sustainability standards and aid in comparing impacts of bio-based products against petrochemical products. Additionally, additional policy-led tools are needed to cover a wider, diverse range of materials and products and integrate cradle-to-grave, full value chain assessment which includes end-of-life, rather than cradle-to-gate assessment (Ladu and Blind, 2017) [155]. Providing an in-depth understanding of end-of-life options for bio-based products can clearly communicate sustainability and circularity perspectives. According to the OPEN-BIO project, the EcoLabel policy is seen as an important tool to communicate the benefits of bio-based products and services (ibid).

5. Recommendations

The linear, interlinked value chain approach for landscaping and gap analysis of European biomass policies used in this paper facilitated the structured and comprehensive analysis of i) existing policies which address key activities within biobased value chains, ii) challenges for ensuring their sustainability and market competitivity, and iii) respective policy gaps, across all four stages of the value chain.

This section articulates policy recommendations for each value chain stage. These recommendations are rationalised according to their potential to achieve the five core objectives of the European Bioeconomy Strategy, overcome the identified challenges and contribute to a more harmonised set of policy interventions.

5.1. Land use

Future interventions within the Common Agricultural Policy, Farm to Fork and Biodiversity Strategy should **harmonise their policy interventions to promote the use of marginal lands** and **increase** financial support **for existing flagship projects** successfully turning marginal land into productive biomass systems to sustain the bioeconomy. Future policy formations and updates can further align their objectives with that of the Bioeconomy Strategy. For example, both ILUC and LULUCF can be refined to include financial instruments targeting the exploitation of marginal lands to reduce GHG emissions and support the CAP's funding support for marginal lands under the Area of Natural Constraints (ANC) scheme. Harmonising initiatives across different sectoral policies increases the attractiveness of the use of marginal lands for biomass production, attracting investors to make long-term investments (Pulighe et al., 2019) [156]. Novel policies can thus inform and incentivise farmers to adopt agricultural and soil management practices to cultivate biomass on abandoned and marginal lands (Glithero et al., 2015) [157], creating value and providing job opportunities in rural areas (Cervelli et al., 2020) [158]. Providing capacity building and knowledge base development for stakeholders on sustainable land use management practices, new agricultural production systems with low land use change and environmental impacts can deliver feedstocks to address multiple bioeconomy objectives, including mitigation and adaptation to climate change (Smith and Olesen, 2010; Englund et al., 2020) [159,160].

Another key recommendation in the land use stage is to implement harmonised regulatory instruments across Europe **to ensure consistent monitoring of soil quality and prevent soil degradation**. In the past, these tools have been lacking, however they are now available at the European level (e.g. LUCAS [161]). Further development of these tools can help manage soil management efforts and monitor soil deterioration from land use for biomass production. The IED, Soil Thematic Strategy, Cohesion Fund and ERDF are all policies with the potential to introduce harmonised monitoring frameworks of soil quality. These suggestions are linked to *ensuring food security*, *managing natural resources sustainably*, *mitigating and adapting to climate change,* and *strengthening European competitiveness and creating job opportunities,* including in rural areas.

5.2. Biomass production

Concerning biomass production, policy refining is required to integrate **the sustainable expansion of biomass cultivation and natural resource (land, soil, water) use**; **the mobilisation of underutilised waste sources to reduce resource competition** and **the improvement of biomass production logistics through investment in infrastructure and pre-treatment processes.** These efforts can contribute to *managing natural resources sustainably*, *mitigating and adapting to climate change*, and *strengthening European competitiveness and create job opportunities*, especially in rural areas. Existing policies such as the EU Water Framework Directive and IED can better align with these Bioeconomy Strategies by improving sustainability criteria for water use during the biomass production stage. This can be achieved by capitalising on European-level datasets and research on GHG implications of water use for biomass production to translate into standardised regulatory tools across policies. Additionally, the EU Forest Strategy, REDD+, EU Timber Regulation, EU FLEGT should aim to improve energy efficiency performance of post-harvest logistical activities for forest biomass production including storage, transport, and pre-processing of feedstock. According to the Municipal waste statistics (Eurostat, 2020) [162], the amount of recycled municipal solid waste (MSW) is expected to increase to 65% and disposal reduced by 10%. In order to achieve these targets, the Directive on packaging and waste, WFD, and the Waste Incineration Directive can formulate additional support for the mobilisation and circularity of waste to be fully exploited as a bioeconomy resource. The soft policy provisions of supporting the exchange of information and databases on waste characterisation (type, content) and compatible conversion processes are required to support waste mobilisation and valorisation. Exploitation of biogenic waste is considered a key challenge, therefore new policies, governance procedures and cooperation among various sectors are needed in addition to developing novel technologies (Mahjoub and Domscheit, 2020) [163]. The targets set under EU legislation have created opportunities to investigate the end-of-use (EoU) and end-of-life (EoL) alternatives of bio-based waste and turn them into valuable resources (Briassoulis, D., et al., 2019) [164]. Moving forward, novel regulatory and financial policy developments are needed to help mobilise underutilised biomass resources and improve logistics by channelling investment towards infrastructures and pre-treatment, storage and transport activities to support supply links with biorefineries.

5.2.1. Conversion

The main policy needs for the conversion stage are **to increase** support **for the optimisation of complex conversion processes and logistics to attract consistent year-round supply of low-cost,**

high-quality sustainable feedstock and **to monitor the heterogenous composition of biological materials produced during the conversion process of biomass resources from multiple sources (including bio-waste) to bio-based products.** These have the potential to *reduce dependence on non-renewable and unsustainable resources*, help *mitigate and adapt to climate change*, and *strengthen European competitiveness and create job opportunities*. Relevant policies promoting low-carbon technologies such as the SET Plan, ETAP, LIFE+, Horizon 2020, SPIRE, Investment Plan, COSME, and ESIF can better align with these objectives by also focusing on reducing the cost of conversion processes. Well planned localisation biorefineries from the standpoint of biomass sources and improvement in the organisational and technological integration of the different logistical operations is important to ensure the profitable, ecologically sustainable and year-round supply of biomass (Gold and Seuring, 2011) [165]. Further increasing funding support for capacity building activities and establishment of biorefineries in close proximity of biomass sources and information provisions for complex logistical and conversion processes can ensure their cost and GHG efficiency, sustainability, reliability of product quality. Additionally, policies like EU REACH, European Pollutant Release and Transfer Register, and EU Standards CEN TC 383 can formulate regulatory tools to monitor the composition of biological materials in the conversion process as an essential contribution to the smooth operation of biorefineries following the principles of sustainability as well as circularity.

5.2.2. End use

Finally, the key policy developments for the end use stage are **to improve** support **for large-scale distribution** as well as **to create European-level labels, certifications and standards for a wide range of bio-based products and services**. These have the potential to *reduce dependence on non-renewable and unsustainable resources*, help *mitigate and adapt to climate change,* and *strengthen European competitiveness and create job opportunities.* To accomplish these objectives, the Alternative Fuel Strategy, Alternative Fuels Infrastructure, Green Public Procurement, and the Roadmap to Resource Efficient can include investment support for the infrastructural expansion of distribution channels for both bio-based services and products. This can ensure their continuous supply which is key for establishing confidence in consumers. Similarly, Packaging and Packaging Waste Directive, Eco Design Requirement, Energy Efficient Directive can formulate European level harmonised labels and standards and increase transparency of product sustainability and life-cycle impacts. The transparency in life cycle impacts is important not only to inform the regulation and standards but it also gives early adopters (either individual consumers or firms) the opportunity to make informed choice and advocate for the most promising bio-based products and services (Pajula, T., et al., 2017) [166].

6. Conclusion

The paper applied the value chain approach to identify challenges and policy gaps across non-food biomass value chains. In doing so, it has also examined the objectives of the policies to understand how they can be updated to align with the core objectives of the Bieoconomy Strategy. This analysis helps to understand how sectoral policies are interlinked rather than isolated within the umbrella framework of the European bioeconomy. Policy review and landscaping of relevant biomass, bioprocessing and biobased product policies by value chain approach have made it apparent that challenges in one stage impacts another. Therefore, to ensure a successful bioeconomy market transition, these challenges need to be undertaken simultaneouly, where all sectoral policies integrate recommended future developments within a similar time frame (Lewandowski, I., 2015) [167].

Out of almost 90 biomass, bioprocessing and biobased product policies reviewed, many are still not completely coherent with the core bioeconomy objectives and do not act in synergy with each. Therefore, further updating these policies can better align their objectives with that of the Bioeconomy Strategy. Out of all the policies reviewed, only a few policy documents included the term bioeconomy in their content, this means that even if policies do not embed the concept of bioeconomy in their definition, they do reinforce some of the objectives of the Bioeconomy Strategy. Therefore bioeconomy related policies which reinforces the core objectives of the Bioeconomy Strategy therefore could embed the concept of bioeconomy so that there this sets a framework of coherence in working towards the common objectives.

For most of the challenges identified in each stage of the value chain, there are policies in place which directly or indirectly address them. However most gaps identified reveal the need to complement these existing policies with additional instruments to make them more robust. Therefore recommendations are made with an understanding that the mix of policy instruments like financial, regulatory and information provisions will compliment the exisiting policies and potentially help to increase the coherence of these sectoral policies with the core bioeconomy objectives.

This paper concludes that additional support for sustainable exploitation of marginal lands can reduce resource (land, water) competition and soil deterioration, and allow for sustainable expansion of land use for biomass cultivation. Similarly, mobilisation of waste resources would also reduce resource competition and improvement in infrastructures for biomass logistical processes like transportation, pre-treatment, storage and secure the consistent year-round supply of low-cost and high quality biomass necessary for the conversion stage. Next, policies supporting the optimisation of conversion processes with low impact on the environment is necessary, as well as the ability to monitor heterogenous compositions of biological materials which can increase biomass circularity and sustainability. This will also provide clear information to improve European-level labelling and certification of bio-based products and services, therefore improving consumer awareness and trust. To secure the consumption rate, a large scale distribution of the bio-based products and services needs to be ensured by improving distribution channels.

CRediT authorship contribution statement

Asha Singh: Conceptualization, Data curation, Formal analysis, Methodology, Resources, Validation, Writing - original draft, preparation. **Thomas Christensen:** Writing - review & editing. **Calliope Panoutsou:** Conceptualization, Methodology, Resources, Supervision, Validation, Writing - review & editing.

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Annex

Table A
Policies and policy mechanism for land use stage activities

Main activities	Policies	Issues that policies regulate	Regulations	Financial	Soft measures
Land acquisition	CAP 2021-2027	sustainable land management, biodiversity protection, support rural development and promote bioeconomy	Compliance with good agricultural practices (GAECs); Mandatory greening measures	EAFRD and EAGF financed greening measures and bioeconomy activities. Horizon Europe, LIFE Programme	Voluntary mechanisms for rural development activities
	LULUCF	Reduction of GHG emissions generated from land use change	Targets for GHG removal. Accounting and governance rules for forest land management		
	RED II and ILUC	Sustainable land use through conservation and marginal land designations Reduction of GHG emissions generated from land use change for bioenergy production	Sustainability criteria for biofuels, GHG emission reduction criteria, Certification for low risk and high risk ILUC		
	EU Forest Strategy	sustainable and resource efficient mobilisation of forest biomass		LIFE + supports nature conservation, climate change adaptation, information and protection needs. REDD + carbon market mechanisms.	Non-binding forests targets, Forest Management plans, Forest-based Sector Technology Platform, MRV of forest ecosystem
	Reducing emissions from deforestation and forest degradation (REDD+)	sustainable forest management and carbon stocks development		Financial market mechanisms to create value from carbon stock.	National Strategy and Action Plan; MRV (Monitoring, Reporting and Verification) System; Information sharing; Assessment of Forest Reference Level
Soil management	Soil Thematic Strategy and proposal for EU Soil Framework Directive	Soil quality protection and sustainable land use practices	Limits the introduction of toxic substance to soil.	Reduction of soil contamination risk by funding mechanism for remediation. Support research activities in areas of soil erosion, soil sealing, soil carbon and nitrogen cycles	Risk reduction targets. Commission supported awareness raising activities, e.g. Soil Atlas of Europe distribution, European Network for Soil Awareness (ENSA), European Soil Bureau Network (ESBN) are some examples
	CAP 2021-2027	Mitigation of soil erosion and organic matter deterioration	Compliance with good agricultural practices (GAECs); Mandatory greening measures	EAFRD and EAGF financed greening measures and Bioeconomy activities. Horizon Europe, LIFE Programme	Voluntary mechanisms for rural development activities
	Cohesion fund and European Regional Development Fund	rehabilitation of deteriorated soil due to contamination		Funds for rehabilitation of contaminated sites	
	Farm to Fork Strategy	Support for a sustainable, climate-neutral food system transition through soil input and nutrient loss reduction	Develop EU code and monitoring framework for responsible business and marketing conduct in food supply chain (legally binding targets to reduce food waste, use of pesticide and fertiliser, reduce nutrients loss, reduce deteriotation of soil fertility) Achieve organic farming in 25% of total farmland in EU by 2030.	Horizon Europe, InvestEU Fund to support R&I activities and to foster investment in agro-food sector, improve access to finance for SMEs	Improve advisory and extension services (implement AKIS) to enable all food chain actors and enhance cooperation to improve transparency. Achieve 100% internet access for farmers by 2025.
	Industrial Emissions Directive	Impact mitigation of industrial installations on soil and groundwater quality	Zero tolerance for pollutants and Polluters pay principles. Permits, standards, binding rules, emission limit values, best available techniques etc for members states to comply.		Inventory on emissions to be reported regularly
	Kyoto Protocol	Support soil protection and carbon sequestration in agricultural soils for soil management			

Table B
Policies and policy mechanism for biomass production stage activities

Main activities	Policies	Issues that policies regulate	Regulation	Financial	Soft measures
Crop establishment & annual management	CAP 2021-2027	sustainable land management both agriculture and forest lands to promote bioeocnomy	Compliance with good agricultural practices (GAECs); Mandatory greening measures	EAFRD and EAGF financed greening measures and bioeconomy activities. Horizon Europe, LIFE Programme	Voluntary mechanisms for rural development activities
	RED II	sustainable land use and harvesting practices	Sustainability criteria for biofuels, GHG emission reduction criteria		
	EU Forest Strategy	sustainable and resource efficient mobilisation of forest biomass		LIFE + supports nature conservation, climate change adaptation, information and protection needs. REDD + carbon market mechanisms.	Non-binding forests targets, Forest Management plans, Forest-based Sector Techn ology Platform MRV of forest ecosystem
	Reducing emissions from deforestation and forest degradation (REDD+)	sustainable forest management and carbon stocks development		Financial market mechanisms to create value from carbon stock.	National Strategy and Action Plan; MRV (Monitoring, Reporting and Verification) System; Information sharing; Assessment of Forest Reference Level
	EU Timber Regulation	legal harvest and trade of forest biomass	Certification to enforce forest law- FSC (Forest Stewardship Council)		
	EU's FLEGT	legal harvest and trade of forest biomass			Voluntary partnership agreements (VPAs)
	EU Biodiversity Strategy 2020	minimise ecological cost of biomass harvesting	Biodiversity targets		
	Habitat Directive	conservation of natural habitat to minimise the ecological impacts of agricultural activities	Designated special protected areas. Natura 2000 network to protect threated species		
	Bird Directive	conservation of natural habitat to minimise the ecological impacts of agricultural activities			
	Invasive Alien Species (IAS) Regulation	Protection of the ecosystem from biological invasion of species. Provides measures to be taken across the EU to prevent, early detection, rapid eradiation and management of the invasive species.	List of Invasive Alien Species (IAS)	LIFE, Horizon 2020, Rural Development Policy,	Information support system, Information networks to facilitate access to information on alien species; Search and Mapping tool using the citizen science support.
	Soil Thematic Strategy	soil quality protection by implementing sustainable crop management practices	Limits the introduction of toxic substance to soil.	Reduction of soil contamination risk by funding mechanism for remediation	Risk reduction targets. Commission supported awareness raising activities, e.g. Soil Atlas of Europe distribution, European Network for Soil Awareness (ENSA), European Soil Bureau Network (ESBN) are some examples
	IPPC Directive	regulates emission to soil from industrial sites (agricultural activities at industrial scale, use of fertilisers, pesticides, use of machineries)	Emission limit values, quality standards, best available techniques which can be adopted by MSs		
	Standards for soil improvers (CEN TC 223)	protect soil by standardizing materials (soil improvers) used in agricultural soil	Binding targets, voluntary products labels and guidelines		

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Table B (*continued*)

Main activities	Policies	Issues that policies regulate	Regulation	Financial	Soft measures
	Directive for sustainable use of pesticides	sustainable use of pesticides in EU for cropping practices	Integrated Pest Management (IPM) principles for MSs to adopt		
	EU Fertilising Products Regulation	promote the use of recycled nutrients (organic) to increase nutrient efficiency under the principles of circular economy	regulation of fertilising products		
	Nitrate Directive	Protection of ground and water surfaces by promoting good farming practices	National monitoring and reporting system. Nitrate Vulnerable Zones (NVZs)		
	Clean Air Programme	Regulation of emissions of NH3 and PM2.5 from agriculture activities	targets and emission limit values, MRV system		
	EU Water Framework Directive	sustainable use of water resource	Common Implementation Strategy (CIS) and established a list of priority substances for chemical analysis and monitoring of water.		Improvement of information exchange between MSs under Information Exchange Platform (CIRCABC)
Waste Mobilisation (Annual Management)	Circular Economy Package	Circularity of materials, food, water and nutrients, and reduction of waste	Communication		
	Waste Framework Directive	Reduction of negative impacts of incineration and co-incineration of waste in environment	Compliance for waste separation. Targets for diversion of biodegradable waste. Penalties for non-compliance.		
	Landfill Directive	Reuse and recycling of resources through innovative, circular waste management	Legislative -sets targets for reduction of waste.	Economic instrument to discourage landfilling.	Harmonised calculation methods for improved calculation of recycling rates
	Sewage Sludge Directive	use of treated sewage sludge in agriculture and reduce chemical fertiliser use	Requirements to keep record of sludges and soil samples. Limit of acceptable level of heavy metal in treated sludge.		
	Waste Incineration Directive	prevent and reduce negative impacts of incineration and co-incineration of waste in environment	Emission limits on gases as well as waste water from incineration plants.		Access to information for permitting procedure.
	Directive on packaging and packaging waste	Innovation in waste management practices and GHG emissions reduction	Recycling targets and list of items which fits under the criteria of packaging to increase the recovery and recycling of packaging waste		
	Animal by-products and derived products not intended for human consumption	Use of animal waste as feedstock for biogas	Regulatory measures for - approval for establishment of plants, the implementation of parameters for transformation into biogas or compost, hazard analysis and critical control points (HACCP) principles.		
Biomass Logistics- Pre-treatment, storage, transport	Industrial Emissions Directive	industrial installations deterioration in the quality of soil (and groundwater).	Zero tolerance for pollutants and Polluters pay principles. Permits, standards, binding rules, emission limit values, best available techniques etc for members states to comply.		Inventory on emissions to be reported regularly
		creates standard in terminology, conformity	Standards		

	European Standards CEN/TC 383 Sustainably produced biomass for energy applications	assessment, biodiversity and environmental aspects and calculation methods of GHG emissions from sustainably produced biomass for energy applications.			
	Directive on packaging and packaging waste	Innovation in waste management practices and GHG emissions reduction	Recycling targets and list of items which fits under the criteria of packaging to increase the recovery and recycling of packaging waste		
	EU Timber Regulation	legal harvest and trade of forest biomass	Certification to enforce forest law- FSC (Forest Stewardship Council)		

Table C
Policies and policy mechanisms for conversion stage activities

Main activities	Policies	Issues that policies regulate	Type of instrument: Regulatory	Type of instrument: Financial	Type of instrument: Soft measures
Establishment of biorefineries	Environmental Technologies Action Plan (ETAP)	Maturation of technologies from research stage to reach market stage.		Cohesion Funds, LIFE, Structural Funds, Competitiveness and Innovation Programme (CIP), Market based instruments	Environmental technology verification programme (EU-ETV)- Voluntary verification tool to increase consumers' confidence in new environmental technologies targets. Awareness and Training programmes; Green Public Procurement
	LIFE+, Horizon 2020, Investment Plan, COSME (Competitiveness of Enterprises and SME), ESIF (European Structural and Investment Funds)	Research and development activities to promote eco-innovative technologies, SMEs to adopt eco-innovative technologies and to build infrastructure		Funding instruments- grants, public procurement contracts	Capacity building, Sharing information and dissemination of best practices; Pre commercial procurement; Public procurement innovation;
	EU Innovation Action Plan (Eco-AP)	Access to eco-innovative technologies to establish biorefineries which can address challenges of resource scarcity and environmental pollution, job growth and sustainable natural resource use.		European Business Awards for the Environment (EBAE) to encourage SMEs. Horizon 2020, LIFE Programme, Competitiveness of Enterprises and Small and Medium-sized Enterprises (COSME) funding.	Reinforces initiatives such as EMAS, EU Ecolabel, Environmental technology verification programme (EU-ETV)- Voluntary verification tool. Green Action Plans for SMEs.

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Table C (*continued*)

Main activities	Policies	Issues that policies regulate	Type of instrument: Regulatory	Type of instrument: Financial	Type of instrument: Soft measures
	Competitiveness and Innovation Framework Programme (CIP)	Eco-innovation activities in SMEs for commercialisation of production processes and products by providing access to finance and business support services.		Access to finances and grants; support schemes	Business and policy support services; training on new technologies; ICT support for adoption of low-carbon technologies;
	SET Plan	Innovation of Low Carbon Technologies in energy sector and contribute in worldwide transition to a low carbon economy by 2050 by building strategic partnerships among research organisations and industries.		Funding for research and knowledge development and technology transfer activities.	Training, education and outreach activities for new researchers and professionals in strategic energy sectors.
	Innovation Fund	Support large-scale innovative projects to support clean products and decarbonise energy intensive sectors, create jobs, provide technical assistance and investment in renewable energy sources		Financial incentives -to invest in low carbon technologies, supporting technologies to reach markets. Funds cross-cutting projects and small-scale projects	
	European Green Deal (Just Transition Mechanisms)	Transition from carbon-intensive economy to green economy and are exposed to more risks or disadvantageous points for energy transition.		Financial support -The just Transition Fund, InvestEU Scheme and European Investment Bank Loans	Technical assistance, Risk sharing conditions for public and private investors
	new Circular Economy Action Plan	Reuse of materials in the whole life-cycle from product design to consumption			
	EU industrial strategy	Collaboration among stakeholders to boost the growth of key biotechnologies			
	Sustainable Process Industry through Resource and Energy Efficiency (SPIRE)	Development of enabling technologies and best practices along all the stages of large scale existing value chain productions that will contribute to a resource efficient process industry.			Contractual Public private partnership
Operation of biorefineries	Industrial Emissions Directive (IED)2010/75/EU	Principles to regulate GHG emissions, pollutants, particulate matters from industrial activities .	Zero tolerance for pollutants and Polluters pay principles. Permits, standards, binding rules, emission limit values, best available techniques etc for members states to comply.		Inventory on emissions to be reported regularly
	Clean Air Policy	Air quality regulation of PM, NOx, NH3 and SO2 and prevent eutrophication of protected ecosystems, acidification of forest ecosystems	Targets to regulate the air quality limit values limit values for PM, NO2, SO2. Reporting and monitoring of national emission inventories. Air pollution control programmes to be adopted and implemented by all MSs		Strategy (Communication)
	Medium Combustion Plant Directive (MCPD) EU 2015/2193	Regulation of emission from combustion plants which has thermal input size of >1 MWth	Emissions limits value (ELVs) depending on the size of the plants and fuel uses. It applies		Provides information and encourages exchange among stakeholders on the advanced

	and <50MWth. To reduce the harmful substances emissions from industries, improve their energy efficiency to control air quality in cost effective manner.	to all operators and owners of combustion plant rated between 1 MW and 50 MW thermal input. ELVs are different for plants <5 MW and >5 MW. Reporting requirements with minimum administrative burden		techniques available to lower emissions.
European Pollutant Release and Transfer Register (E-PRTR)	Public access of information on pollutants releases to air, water and land and transfer of water and pollutants to waste water.	Kieve Protocol is first legally binding international instrument on pollutant release and transfer registers.		
EU REACH 317/2014	Regulation of harmful chemicals used in the industry and promotes the free circulation of substances in the internal market to promote industrial competitiveness and innovation.	Registration, Evaluation, Restrictions and Authorisations and information requirements for substance that flow in the supply chain. Compliance: registration of chemicals in central database, evaluation of hazardous chemicals		
Standardisation for Bio-polymers and Bioplastics CEN/TC 249; Standardisation on surface active agents (CEN-TC276); Standardisation committee Standards for Biobased products (CEN TC411); Standardisation for Bio-lubricants (Liquid petroleum products) CEN/TC 19; Standardisation for products made from algae CEN/TC 454	Standardisation of bio-polymers, bioplastics, bio lubricants, bio-based products.			
Energy Efficiency Directive	Energy saving schemes through uptake of innovative technologies, energy efficiency measures and curbing consumption	Target for energy efficiency. Energy Labelling. Rules on metering, transparent allocation of cost of heating. Monitoring energy efficiency.	Incentives for producers and manufacturers to use low carbon and innovative technologies. Investment support.	Guidance notes for member states to transpose the Directive into national law.
The EU Eco-Management and Audit Scheme (EMAS)	Environmental performance growth of companies GHG emission and waste reduction, efficient use of energy and water and incorporation of environmental guidelines in procurement procedures			Voluntary audit and certification system

Table D
Policies and policy mechanism for end use stage activities

Main activities	Policies	Issues that policies regulate	Type of instrument: Regulatory	Type of instrument: Financial	Type of instrument: Soft measures
Distribution of products and Consumer awareness	Fuel Quality Directive	Regulation of the GHG emission from biofuel and sustainability of the feedstock used for biofuels.	requirements of sustainability Criteria and targets for GHG reduction; uniform GHG emission reduction calculation and reporting methods		
	Forest Management Certification (FSC)	Socio-economic and environmental sustainability of forest management	FSC Certification		
	ISCC (International Sustainability and Carbon Certification)				ISCC is voluntary sustainability certification based on activities like increase in biodiversity, reducing GHG emissions, phasing out of hazardous chemicals and reducing consumption of water
	Standards for solid biofuels (CEN/TC335); Standards for Solid Recovered Fuels (SRF) (CEN-TC343); European Norm Sustainability criteria for biofuels and bioliquids: EN16214; European Norm biodiesel-FAME (Fatty acid methyl esters): EN14214; European Norm Petrol: EN228; prEN16723 - Natural gas and biomethane	Standardisation of the biomass used, and biofuels produced to ensure that they are compatible with larger policy framework of GHG emission reduction and increase in resource efficiency	Binding Standards		
	CEN/TC 19- Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin, CEN/TC 249- Plastics, CEN/TC 276 Surface active agents, CEN/TC 454- Algae and algae products	Standardisation of the biomass used, and bio-based products produced to ensure that they are compatible with larger policy framework of GHG emission reduction and increase in resource efficiency	Binding Standards		
	Energy Labelling Framework Regulation (EU) 2017/136; The Ecolabel	Labelling of the energy-related products and this helps consumer make informed decision about their choices and choose efficient and sustainable products	Requirement of eco labelling, energy labelling on energy related products		
	Energy Taxation Directive (ETD) Dir. 2003/96/EC	Market regulation (through tax) of the energy products to avoid distortion of trade and competition between energy sources, supplier and consumers		Energy tax are imposed based on energy used	
	EU emissions trading system (EU ETS) EU 2018/410	GHG emission reduction in cost effective manner through market mechanism	Caps; Monitoring and reporting regulation (MRR); Accreditation and Verification Regulation (AVR)	Carbon market mechanisms- receive or buy emission allowances. Investment funds-Innovation fund and Modernisation fund	
	Alternative Fuel Strategy COM (2013) 17; Alternative fuels infrastructure (Dir. 2014/94/EU)	Development of market for alternative fuels and development of infrastructure	Requires MSs to develop national policy frameworks for the market development of alternative fuels and their infrastructure		
		Mandatory public procurement to			

Table D (*continued*)

Main activities	Policies	Issues that policies regulate	Type of instrument: Regulatory	Type of instrument: Financial	Type of instrument: Soft measures
	Clean Vehicles Directive (Dir. 2009/33/EC)	support early stage development of clean vehicles			
	Green public procurement (COM(2008)400)	Public procurement of green technologies and products for sustainable production and consumption of renewables			Voluntary EU GPP criteria
	Emission performance standards for new passenger cars (Reg 443/2009)	Regulation of emissions for new passenger cars	Emission limits		
	EU Regulation 595/2009 on Heavy duty vehicles standards; EU regulation EU 2017/2400 CO2 emissions and fuel consumption of heavy-duty; EU Regulation (EU) 2018/956 monitoring and reporting of CO2 emissions from and fuel consumption of new heavy-duty vehicles	Emission reduction targets for GHG and particulate matters; Obligation to determine and declare for certification of CO2 emission and fuel consumption of new vehicles;	Emission limits, Targets, Monitoring and reporting requirements of emissions		
	EU Regulation 692/2008 on light vehicles standards	Emission reduction targets for GHG and particulates matters	Emission limits		
	Monitoring, reporting and verification (MRV) of CO2 from maritime transport -EU Regulation 2015/757	Emissions reduction from maritime sector in a cost effective manner	Data collection and reporting (amount and emission factor of fuel consumed), verification		
	The Roadmap to resource efficient Europe	Resource efficiency improvement by changing the sustainable consumption and production pattern.		financial support mechanism	Framework of resource efficiency for MSs to adopt
	Eco-design Directive 2009/125/EC; Eco-design Requirement of solid fuel boilers Regulation (EU) 2015/1189	Regulate the minimum eco-design requirements for energy-using products, such as boilers, water heaters, computers, televisions or industrial fans to reduce their environmental impact and ensure movement of these products though fair competition and international trade	Compulsory eco-design requirements for energy-using products		
	Energy Efficiency Directive EU 2018/2002	To promote energy saving by encouraging uptake of innovative technologies, by improving energy efficiency measures, by reducing consumption.	Target for energy efficiency. Energy Labelling. Rules on metering, transparent allocation of cost of heating. Monitoring energy efficiency.	Target for energy efficiency. Energy Labelling. Rules on metering, transparent allocation of cost of heating. Monitoring energy efficiency.	Guidance notes for member states to transpose the Directive into national law.
	Energy Performance of Buildings Directive (EU) 2018/844	Establishment of 20% target for energy efficiency improvements	Energy performance certificate to be included in sale/rental of buildings; inspection schemes for heating and air-conditioning systems, minimum energy performance requirements for new buildings and for renovation of buildings and retrofit of building elements,	Financial measures to improve energy efficiency of buildings	
	End-of-life Vehicles Directive 2000/53/EC	Regulation of bio-based car components, manufacturers to use non-hazardous substance in care and promotes reuse, recyclability and	Targets to reuse, recovery and recycling		

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Table D (*continued*)

Main activities	Policies	Issues that policies regulate	Type of instrument: Regulatory	Type of instrument: Financial	Type of instrument: Soft measures
		recovery of waste vehicles			
	Packaging and Packaging Waste Directive (EU) 2015/720	Impact mitigation of packaging on environment	Targets for recovery and recycling of packaging waste. Provides framework to set up return, collection and recovery systems.		

Table E
Cross cutting policies in the land use, biomass production, conversion and end-use stages

Value chain stage	Policies	Issues that policies regulate	Type of instrument: Regulatory, financial and soft measures
Land use and Biomass production	2030 Climate and Energy Framework	Sustainable use of land and forest ILUC impacts from biomass use for various bio-based industries	EU 2030 sets targets for GHG emission reduction, share of renewable energy and energy efficiency. SET plan for investments in research and development.
	New Industrial Strategy for Europe 2020**1**	European industry's global competitiveness, climate-neutrality by 2050 and shape its digital future	Strategy promotes biotechnology and biopharmaceutical industry.
	Research and Innovation Strategies for Smart Specialisation	Smart growth, competitive advantage and knowledge-based economy through innovation and emerging technologies	Framework for building national strategies and synergies with other funding programmes such as ESIF, Horizon Europe 2021-2027, ERDF.
	Horizon Europe	Research and innovation in agriculture, rural development and the bioeconomy Competitive and sustainable farming and forestry	Financial support for research and innovation activities
	SCAR Network	European Agricultural and Bioeconomy research and innovation activities	Supports public and private partnership in research and innovation activities
Conversion and End use	Clean Energy for All European Package	Transition from fossil fuels towards cleaner energy	Legislative acts providing a framework for MSs to transpose the new Directives into national law (including the Renewable Energy Directive, Energy Performance of Buildings, Energy Efficiency Directive … etc.). Measures to monitor energy poverty, and coal regions in transition are few of the non-legislative initiatives.
	European Green Deal**2**	Transition from fossil fuels and EU climate neutrality by 2050 European industries as global leaders in adopting clean products and technologies	Provides roadmap with actions to boost the efficient use of resources by moving to a clean, circular economy and to restore biodiversity and cut pollution.
	New EU Industrial Policy Strategy 2020	Collaboration among industries and companies, academic and research institutions, service providers and suppliers and alliances supporting the growth of key biotechnologies	Provides framework to MSs, industry, SMEs to collaborate and create strategies and action plan to achieve a collective vision of EU's climate neutral and digital leadership by 2030. Innovation hubs, access to funding for SME through Public Offering Fund and ESCALAR Initiative to boost the capital funds and public and private investments.
	New Circular Economy Action Plan**3**	Sustainable products and manufacturing processes, informed consumers and buyers, support for sectors	Adopts legislative and non-legislative measures targeting design, promoting circular economy processes, fostering

Table E (*continued*)

Value chain stage	Policies	Issues that policies regulate	Type of instrument: Regulatory, financial and soft measures
		where circularity potential is high, and reduction of waste	sustainable consumption, and aiming to ensure that the resources used are kept within the EU economy for as long as possible.
	Energy Efficiency Directive 2018/20 02**4**	Energy systems decarbonisation with 40% GHG emissions reduction target by 2030 compared to 1990 level and 32.5% energy efficiency target	Provides financial incentives for producers and manufacturers to use low carbon and innovative technologies for conversion processes. MSs publish a 3-year national energy efficiency action plans (NEEAPs) to reduce primary and final energy consumption. Indicators include energy consumption in million tonnes of oil equivalent or energy used per unit of product (Pakere and Blumberga, 2017)
	European Technology and Innovation Platform on Bioenergy	Development of cost-competitive, innovative world-class bioenergy and biofuels value chains through a process of guidance, prioritisation and promotion of research, technology development and demonstration	Contributes to development of research and innovation strategy, knowledge-sharing mechanisms for dissemination and barriers identification to deliver innovation to energy market.
	Research and Innovation Strategies for Smart Specialisation	Integrated agenda creating alliances in research and innovation and adopting an entrepreneurial approach to identify market opportunities, optimise access to and use of resources	Provides framework for national research and innovation strategy for smart specialisation.
	Bio-Based Industries Joint Undertaking	Public private partnership between the EU and bio-based industries consortia, driven by the Strategic Innovation and Research Agenda (SIRA)	Investment for bio-based innovation with focus on biomass feedstock, biorefineries and market products and policies.
	EU 2050 Long-term Strategy COM (2018)773	Climate neutrality by 2050 and reinforcement of the European Green Deal Objective	The Strategy provides framework and urges EU MSs to develop national-long term strategies to meet the commitments made by EU under Paris Agreement.
	European Structural and Investment Fund	Job creation, sustainable and healthy EU economy and environment	Provides funding for **5 core areas-** research and innovation, digital technologies, low carbon supporting low-carbon economy, sustainable management of natural resources and small businesses Total budget for a 7-year period (2014–2020) is EUR 454 billion
	Effort sharing targets for member states 2021-2030	Reduction of GHG emissions by translating commitment to targets on principles of fairness, cost-effectiveness and environmental integrity	Sets national targets for sectors -transport, building, agriculture, waste and non ETS industries.
Cross-value chain	The Roadmap to resource efficient Europe COM 211/5715	Change towards resource efficiency and outlines how the EU economy can transform by 2050 through structural and technological change	
	EU Emission Trading System (EU ETS)6	flagship initiative aiming to deliver 21% of GHG reduction by 2020 by supporting innovation and adoption of low-carbon technologies. There have been	Impact indicators used are low-carbon technology innovation and adoption and patents (Teixido et al., 2019); different trading periods7 since its inception and Phase IV (2021-2030)8 imposes strict carbon allowances and dedicated funds targeting 40% total emissions

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Table E (*continued*)

Value chain stage	Policies	Issues that policies regulate	Type of instrument: Regulatory, financial and soft measures
			reduction by 2030. More than 11,000 energy intensive plants from power generation and manufacturing industries are covered by the EU ETS (Babonneau et al., 2018) as well as LULUCF, international maritime shipping, and aviation.
	Effort Sharing Decision (ESD)9	Non-ETS sectors such as road transport, buildings, agriculture, waste, small industry jointly have a 10% CO2 reduction target by 2020 through the legislation	Supports the Europe Climate and Energy Policy Framework for 2020
	BRIDGE 2020, SET Action Plan 8 Renewable fuels and Bioenergy, Horizon 2020, European Fund of Strategic Investment (EFSI), The Innovation Fund 10 and the NER300 Programme11	new financing opportunities for bioeconomy projects, promoting research and innovation, digital technologies, low-carbon economies, sustainable management of natural resources and novel businesses	Low carbon technology research and development activities, adoption rates at the firm level (Lofgren et al., 2014; Schmift et al., 2012; Calel and Dechezleprêtre, 2016 as cited in Teixido et al., 2019) and low carbon patents at county level (Bel and Joseph,2018) are some of the indicators which are used to assess the impacts of these regulatory caps, emission allowance policies and financial measures like taxations and incentives to assess the impact of these policies whose main objectives are emission reduction by supporting innovation and adoption of low-carbon technologies.

1 https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf.
2 https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf.
3 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN.
4 https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ%3AL%3A2018%3A328%3ATOC&uri=uriserv%3AOJ.L_.2018.328.01.0210.01.ENG.
5 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0571.
6 European Commission, Directive (EU) 2018/410 of the European Parliament and of the Council of March 14, 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814.
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0410&from=EN.
7 Phase I (2005-2007); Phase II (2008-2012); Phase III (2013-2020); Phase IV (2021-2030).
8 European Parliament and Council, Directive 2018/410 of the European Parliament and of the Council Amending Directive 2003/87/EC to Enhance Cost-effective Emission Reductions and Low-carbon Investments, and Decision 2015/1814.
9European Commission, Regulation (EU) 2018/842 of the European Parliament and of the Council of May 30, 2018 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 amending Regulation (EU) No 525/2013.
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0026.01.ENG.
10 European Commission Delegated Regulation (EU) 2019/856 of February 26, 2019 supplementing Directive 2003/87/EC of the European Parliament and of the Council with regard to the operation of the Innovation Fund.
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0856&from=EN.
11 European Commission Decision (EU) 2017/2172 of November 20, 2017 amending Decision 2010/670/EU as regards the deployment of non-disbursed revenues from the first round of calls for proposals.
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