DECARBONISATION OF ENERGY IN THE EUROPEAN UNION BY 2050: CHALLENGES AND POTENTIALS

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Abstract

The economic shock of the coronavirus pandemic highlighted the human impacts of pollution and climate change, thus advancing the decarbonization agenda. The emergence of a low-carbon, circular bioeconomy is now possible and many governments have enacted policies that establish a circular economy. Decarbonisation of the EU economy is one of the main strategic goals of energy transition making thus the EU the first carbon neutral region in the world. Although decarbonisation is an important goal of the EU, however, views on the social, economic, and security implications of decarbonisation are conflicting. Decarbonising the energy system requires a fundamental transformation in the way societies provide, transport and consume energy. Disagreement exists over how this system should look by 2050. The large-scale expansion of low-carbon electricity, phase-out of unabated fossil fuels, and widespread direct electrification are uncontroversial. In more controversial areas, like the deployment of hydrogen and synthetic methane, policy should explore options. This study discusses policy options for the decarbonisation process in the EU. Further research must include the social, economic and security aspects of decarbonisation.

1. Overview

The EU aims to become climate-neutral by 2050. Decarbonising the energy sector is crucial because the production and use of energy accounts for more than 75% of the EU's GHG emissions and three-quarters of the EU energy system relies on fossil fuels. Decarbonisation of the energy system will require a massive transformation in the way energy is provided, transported and used. The European Green Deal can only be successful when the unabated combustion of oil, natural gas and coal is phased out. For energy-based services, a number of climate-friendly technology options and energy carriers are possible, ranging from electrification to synthetic methane gas and other synthetic hydrocarbons to hydrogen. In the medium- and long-term, only a limited number of fuel types will continue to require carbon (long-distance shipping and trucks, aviation fuels). Where solar and wind power is often produced in surplus, it is possible to produce green hydrogen, that can be used for energy as well.

The circular bioeconomy is a major lever for decarbonizing the economy and sequestering the carbon captured by agriculture. The success of the EU Bioeconomy Strategy has already encouraged 10 Member States to develop their own national bioeconomy strategies and more Member States are in the process of developing their respective strategies. But the new Member States have not yet developed a bioeconomy strategy and lag behind the decarbonisation process of the energy sector. The EU target for renewable energy sources (20%) was met by 2020; however, the target set for most of the new Member States was lower than the average target of the EU, therefore massive decarbonisation plans should be put in place to be able to reach the GHG emission targets by 2050.

Several options for decarbonising the use of natural gas exist. Biogas/methane are already used today, but have a limited potential. Rather, green hydrogen is likely to replace natural gas in several end uses. Fugitive methane emissions from imported natural gas mostly arise outside the European Union. Comprehensive methane emission monitoring, and reporting requirements for natural gas imports are an important step. Alongside its chemical uses, hydrogen can also be combusted in a turbine to generate heat, or passed through a fuel cell to produce electricity to replace fossil fuel consumption in sectors such as steel production, large road vehicles, or aviation and maritime. The driving cost component of production is the fuel input required for transformation (water electrolysis).

There are already many measures in place that reduce oil consumption e.g. by taxing the consumption of energy products and promoting renewable energy, electrification and energy efficiency. The transport sector is the biggest driver of oil demand at the EU level – two-thirds of the final demand for oil comes from transport. Transport is the largest source of greenhouse gas (GHG) emissions in the EU after energy generation. Europe still needs to find a way to phase out fossil oil, pushing forward both electric vehicles and sustainable advanced biofuels. Today, biofuels, biogas and biomethane account for only 3.5% of all gases and fuels consumption and are largely based on food and feed crops. The integration of the mobility and the energy (electrical power distribution) sector into the energy and mobility system is crucial. Electromobility is key in road and rail transport, while new mobility services will increase the efficiency of transport. Other transport modes will have to rely more on advanced biofuels and e-fuels.

Renewable electricity is expected to decarbonize a large proportion of the energy system by 2050, and hydrogen is seen as a way to decarbonize parts of the energy system electricity cannot reach (including industrial processes such as steel and cement production, and transport sectors such as trucking, shipping, and aviation). Electrification of transport and heating, and also any production of hydrogen or synthetic fuels in Europe, will require a massive build-out of renewable electricity generation. But according to the proposal of the European Commission at the beginning of 2022, gas and nuclear has a role to facilitate the transition towards a predominantly renewable-based future and could be classified as "sustainable investments" under certain conditions (temporary green label to certain gas and nuclear projects). As fossil fuel resources gradually phase out, crops cultivated for bioenergy (including biofuels) and for the production of biobased materials could affect food security (taking away land and calories from human nutrition), with the risk of increasing food prices.

A sufficiently tight EU Emissions Trading System (ETS) cap could lead to a phase out of coal by 2030 because it makes coal power plants unprofitable. Since the 2018 EU ETS reform, the European CO_2 allowance price has risen substantially: from well below €10/t CO_2 until early 2018, to a price around €25/t CO_2 in 2019 and even above €80/t CO_2 in March 2022. The proposal to tighten the EU ETS, extend it to shipping and introduce a second EU ETS for transport and buildings will help to strengthen the central role of carbon pricing. The EU imports significantly more carbon than it exports, and the issue of carbon leakage cannot be ignored. The challenge for the EU is to design a carbon border tax to prevent carbon leakage by incentivizing other countries across the world to decarbonize.

The paper is organised as follows: the overview section gives a brief overview of the topic analyzed; the introduction and literature review section discusses the results and conclusions of previously published studies closely related to to the present study; the method section provides the metdodological details about the comprehensive literature review; in section four we describe the results and in the final section conclusions are derived.

2. Introduction and litetature review

The economic shock of the coronavirus pandemic highlighted the human impacts of pollution and climate change, thus advancing the decarbonization agenda. The emergence of a low-carbon, circular bioeconomy is now possible and many governments have enacted policies that spur climate action and establish a circular bioeconomy. The global energy mix is shifting from fossil fuels to renewables. As "Green Deal" gains momentum, new ecosystems are forming and new technologies are emerging. China has also announced ambitious carbon-reduction goals. Energy transformation is helping to grow renewables, develop new energy carriers, improve energy efficiency, reduce emissions and create new markets for carbon and other products as part of an increasingly circular economy. On the other hand the development of decarbonisation including inceasing electrification, wide-scale use of renewable energy and intensifying energy efficiency measures present unique challenges. The main question is how governments and companies in different sectors can accelerate the decarbonization process over the next decades and achieve climate neutrality by 2050 (Deloitte, 2020).

The top drivers of decarbonization include policy and government targets, customer and community demands, investor pressure, technology and operational cost reduction. Support for climate action has increased worldwide putting pressure on governments and businesses to address sustainability issues and the need of biobased economies (Popp et al., 2021). The coronavirus pandemic in 2020 and 2021 has further highlighted the environmental damage and pollution caused by the use of fossil energy coupled with the change in consumer attitudes and the positive impact of reduced mobility and shut down plants on the environment. More and more businesses recognised that they have no other choice but to embrace a low-carbon future to improve customer loyalty and assure their long-term viability (Oláh et al., 2021). From sustainable bioplastics to green cosmetics demand is also increasing for other carbon-neutral products beyond energy. Policymakers follow the demanding action on climate change of the public and many governments have set carbon-reduction targets and enacted green legislation (Deloitte, 2020)

Beyond setting reduction targets, dozens of governments are using carbon pricing schemes to accelerate progress toward their goals either through direct taxes on fossil fuels or through cap-and-trade programs. These programs have so far produced mixed results including successful and ineffective results. With increasing energy prices some governments tax carbon indirectly through renewable portfolio standards, energy efficiency mandates, emissions regulations, and carbon-offset pricing. In response to policy shifts and customer needs, investors are taking decarbonization seriously as well. Reduction in technology costs is contributing to the success of decarbonization strategies. Energy storage is key to large-scale adoption of renewable energy. Battery-pack prices are projected to fall even further driving electrification across the global economy. Annual battery pack prices dropped some 6 % from 2020 to 2021. In 2010, lithium-ion battery pack prices averaged $1,200 per kWh, in 2021 they decreased by 89 %, to an average of just $132 per kWh (Loveday, 2021). In addition, advancements in digital technology, such as the Internet of Things (IoT), blockchain, digital twins, and AI-enabled energy-management and trading platforms, also promise to boost efficiency and drive costs down across both conventional and renewable energy value chains.

While some energy companies are mainly responding to government mandates, others see the energy transition as an opportunity to transform themselves via long-term scenario planning over the next decades. Thus far, the transition to a low-carbon economy has largely been led by the power and utilities (including renewables) sector. Energy-related CO_2 emissions have fallen in 2020 due to Covid-19 pandemic, however, emissions from the world's power plants reached their highest ever level (36.3 Gt) in line with the jump in global economic output of 5.9% in 2021. A rapid economic recovery was driven by unprecedented fiscal and monetary stimulus and a fast roll-out of vaccines with far-reaching impacts on energy demand in 2021.The rebound in 2021 more than reversed the pandemic-induced decline in emissions in 2020 On the other hand, renewables-based generation reached an all-time high in 2021. Without increasing output from renewables and nuclear power, the rise in global CO_2 emissions in 2021 would have been higher (IEA, 2022). The world must now ensure that sustainable investments combined with the accelerated deployment of clean energy technologies will reduce CO_2 emissions even in 2022 to achieve net zero CO_2 emissions by 2050.

Due to a combination of green policies, such as carbon pricing schemes and renewable portfolio standards are driving power generators away from coal-fired thermal generation. Cleaner-burning natural gas is being used as a bridge fuel in transitioning away from coal. But in 2021 the costs of operating existing coal plants in the United States and EU power systems were considerably cheaper than the operating costs for gas-fired power plants. Spiking natural gas prices resulted in gas-to-coal switching, increasing emissions worldwide (IEA, 2022).

Mining and metals organizations are already working toward electrifying their operations and are collaborating with industry associations and other groups to develop innovative solutions for decarbonizing energy-intensive processes, such as smelting and calcining. Companies in the oil, gas and chemicals sectors based on producing and processing hydrocarbons, have generally been slower to change. Nonetheless, several companies are now seizing upon the transition to a low-carbon economy as a means to transform not only how they operate, but also what they offer. Plans include investing in renewable energy sources, such as solar, wind, hydrogen, biofuels and carbon capture (Murray, 2020; bp, 2020). Similarly, several multinational chemical companies have committed to integrate circular economy principles into their business models, such as sustainable product design, use of renewable electricity (DuPont, 2019). Other companies plan to become carbon-neutral by using carbon capture, utilisation and storage (Occidental, 2019).

The contraction in global demand caused by the coronavirus pandemic and excess supply have hit upstream and downstream operations hard. Cutting carbon emissions may be a priority for some companies in the short-term, but the market conditions have changed (high natural gas and food prices) and are likely to encourage them to examine different business models. Oil and gas companies are feeling pressure from all sides to reduce emissions. However, investor pressure has been particularly intense to understand the long term investment strategies of oil and gas companies. Common mitigation strategies focus on lowering the carbon intensity of the value chain by enhancing energy efficiency and reducing energy intensity, electrifying operations and incorporating renewables to fulfill power needs, adopting hydrogen, efuels/synthetic fuels, biofuels and ammonia and improving logistics to reduce fuel consumption. To satisfy investors and remain viable during the transition, oil and gas companies essentially have two primary avenues for transforming their business models, namely diversifying into other forms of energy and enabling technologies. Some companies have decided to build up competencies in renewables, such as wind and solar power, smart technologies to help balance the electrical grid as more intermittent renewables come online, or energy-efficient methods for producing green hydrogen.

Many companies are shifting their business models so that more value is created through downstream customers, rather than upstream assets. For instance, an oil and gas company might purchase a retail power provider to offer biofuels bundled with renewable electricity. Another option is to find business opportunities for emissions. CO_2 can be turned into a valuable raw material, as a feedstock for a variety of building materials, chemicals and fuels. Carbon capture technologies have been rapidly evolving to remove CO_2 from from the high levels of concentration in power-plant emissions to the relatively low ones in open air (Boghdadi, 2020; Carey, 2021). Commercially viable ttechnologies will generate a race to capture carbon emissions and sell them as a valuable commodity. As companies transform their business models, many of them are simultaneously considering decarbonization pathways for their existing upstream and downstream businesses, often proactively working with ecosystem partners to accelerate that process. Nevertheless, differences in finance models are a barrier. There are many questions as how these shifting risk and financial factors could affect traditional oil and gas investors since they will probably need to adjust to having a portfolio of different businesses within the same corporation.

Transition risks include depressed asset values, stranded assets and changing market demand. For example, companies that own gas pipelines may someday encounter decreased utilization or disuse, the odds of which increase with time. Big coal mining and coal-fired power plants end production raising the question of who ends up owning high-emissions assets, potentially creating new risks. Another question is at what stage do asset valuations start to take into account the eventual phase out of fossil fuels. Physical risks include direct and indirect impacts of severe weather on infrastructure, worker safety and productivity. Vertical integration and cross-sector consolidation may be part of how to manage the decarbonization challenges, for example, with bilateral partnerships or acquisitions throughout the value chain (Deloitte, 2020).

In 2019 in the final energy consumption of petroleum products (such as heating oil, petrol, diesel fuel), dominated the EU energy mix (41%), followed by natural gas (22%) and eletricity (21%) and direct use of renewables (10 %), derived heat (4 %) and solid fossil fuels (2%). The real consumption of renewable energy is higher than 10%, because several renewable sources are included in electricity (Eurostat, 2022). The energy available in the EU comes from energy produced in the EU and from energy imported from third countries. In 2019, the EU produced around 39% of its own energy, while 61% was imported. The increasing energy prices and high volatility gave incentives to reduce the EU dependence on energy imports. Russia's invasion of Ukraine has prompted strategic EU policy changes. In 2021, the EU imported more than 40% of its total gas consumption, 27% of oil imports and 46% of coal imports from Russia, and energy represented 62% of EU total imports from Russia, and cost €99 billion (European Commission, 2022a).

In March, 2022, the Commission outlined measures in the REPowerEU plan to reduce Russian gas imports and reach complete independence from Russian fossil fuels well before the end of the decade. The key elements in this plan include diversifying supplies, reducing demand and boosting the production of green energy in the EU (European Commission, 2022b). The main priority to reduce dependence on imports of fossil fuels under the RePower EU concept is the rapid enlargement of the share of renewables in the energy mix, in addititon to increasing energy efficiency.Targets set for renewables and energy efficiency by 2030 will deliver a 55% reduction in GHG emissions by 2030. The RePower EU plan underlines the potential for the acceleration of wind and solar power production. Biomethane and renewable hydrogen is seen as a major new alternative supply source. Power purchase agreements can ensure the most efficient development. Citizens can also play a key role to reduce the EU's overall energy consumption and make energy savings (European Commission, 2022b).

Energy is the commodity that fuels the economy. The EU's prosperity and security depend on a stable and affordable energy supply. EU energy policy has driven significant change in recent years, with a considerable drop in the most polluting fuels, as consumption has moved more towards natural gas and renewables. While EU production of renewables has grown substantially in recent years, gas production has declined, leading to a greater reliance on gas imports. Decision makers increasingly recognise the importance of lifestyle changes in reaching low emission targets. How the mitigation potential of changes in mobility, dietary, housing or consumption behaviour compare to those of ambitious technological changes in terms of decarbonisation remains a key question. The trade-offs between energy and food may be substantially alleviated when deploying technological and behavioural changes simultaneously (Costa et al., 2021)

The EU met its 2020 target (20%), with renewable energy consumption increasing to 21.3% in 2020. Electricity generation from renewable energy sources increased to 37.3% in 2020. The share of renewable energy in transport and buildings (heating and cooling) also increased in the same period, albeit at a lower rate. The revised Renewables Energy Directive (RED II) has set a target of having a 14% share of renewables in transport. Conventional biofuels, such as bioethanol or biodiesel, were capped at 7% by 2030, while 3.5% should be reserved for so-called advanced biofuels (European Commission, 2022c). The transport sector is indeed characterised by high dependency on oil today, and is a difficult sector to decarbonise. While some fuels, such as oil, are directly consumed, the use of electricity first requires the transformation of a separate energy input, for example, solar, wind or natural gas.

Global energy demand in the transport sector is on the rise due to the growing population and increased movement of people and goods. Shifting towards electric mobility has recently emerged as a global strategy for decarbonizing the transport sector and is receiving growing support from local governments across the world. EV and solar technologies are reaching market matureness. However, the EU is struggling with the development of charging infrastructure, its organisation and financing. The efficiency of direct electrification in transport and heating implies that wherever it is not prevented by excessive infrastructure costs, electric solutions are always preferable.

EU policies include ambitious aims of electrification of transport, emission standards of cars, a mandate for advanced biofuels and a cap on conventional biofuels. Without decarbonising transport, the EU will not be able to reach its climate neutrality target by 2050. Transport is the largest source of greenhouse gas (GHG) emissions in the EU after energy generation. It accounts for almost a quarter of GHG emissions and is the only sector in the EU that has seen emissions increasing since 1990. Cars and trucks are responsible for about two-thirds of transport emissions, and decarbonising them is hard without fundamental changes to behaviour, technology and infrastructure. Policy-makers need to invest in infrastructure and create strong incentives to change behaviour and to innovate, while keeping mobility affordable. The EU might also import more electricity directly from its neighbours. Furthermore, through the shift in transport from internal combustion engines to electric vehicles and hydrogen, the demand for biofuels is set to decrease.

There is consensus that electricity will play a major role in many energy service applications. But for a substantial fraction of the energy market, methane and hydrogen might be suitable alternatives. Electricity might be imported, produced from nuclear or different types of renewables, from centralised or decentralised sources. Despite their increasing potential and further cost reductions, biogas and biomethane are likely to continue to play a rather small role in replacing natural gas. Decarbonization can also create new energy security risks, mainly from the imports of products and raw materials that serve as inputs for clean energy and clean technologies (for example, rare-earth elements). In the EU there is no clearly defined model for monitoring the success of decarbonisation. The current method of monitoring is based exclusively on environmentally related indicators while decarbonisation is associated with social, economic and security aspects, which need to be developed and included in the further monitoring process (Radovanović et al., 2022).

A certification scheme will be needed to quickly encourage the right investments in the EU and its suppliers. Most of the investment in decarbonisation will have to come from end-users changing their appliances. At the same time, parts of natural gas infrastructure may be converted to hydrogen infrastructure, while some other natural gas assets may become unused ("stranded"). Industrial sectors will have to replace emissions-intensive production processes with low-carbon alternatives. A similar challenge exists for household investments such as heat pumps, hydrogen boilers or electric vehicles (McWilliams and Zachmann, 2021). Finally, making consumer-end public infrastructure (electric charging, clean fuels pipelines and sufficient electricity connection capacity) available is crucial for enabling consumers to switch to low-carbon energy appliances. Strategic policies can be implemented on the ground through collaboration between the energy and transport sectors.

The BIOEAST region (new Member States oft he EU excluding Malta and Ciprus) has a wide innovation and deployment gap between research knowledge and biobased products compared to the old Member States. Invention needs to move up the scale of technology readiness levels. Education in the circular bioeconomy must be transdisciplinary with complex systems thinking. Moreover, this region is extremely dependant on crude oil and natural gas imports from the Russian Federation. A massive transition to the circular bioeconomy can boost the production of renewable energy in these countries and decouple their economy from the use of fossil fuels ((Košir et al., 2021).

3. Methods

This paper takes a systematic approach to review the challenges and potentials of the decarbonization outlook of energy in the European Union by 2050 and describes the required transformation of the energy system with regard to the provision, transport and consumption of energy. In the literature review, authors followed Stechemesser et al. (2012) approach. The first step was to identify research questions, database and keywords. After screening criteria relevant literature was identified as the second step. In the third step we investigated the content of the selected literature in accordance with the research question. In the last step, selected scientific publications were reviewed and analyzed.

The subject of decarbonization of energy in the EU has been studied from many different perspectives, therefore, authors have carried out multi-disciplinary research from multiple perspectives. The aim of interdisciplinary research is to explore a particular topic with multiple disciplines with joint knowledge production (Tress et al., 2004). For the purpose to get comprehensive views of the outlook of transforming the energy system in the EU a broad research question was selected: "What are the challenges and potentials of the decarbonization process in the EU?" Authors put an emphasis on Member States of the EU with national bioecomy strategies.

The search was based on the terms: "green deal", "fossil energy", "renewable energy", "decarbonization of the energy system", "bioeconomy strategy", "low-carbon electricity", "hydrogen" and "synthetic methane". Authors conducted a literature review on the decarbonization challenges of energy in the EU and associated potential risks. A review of publications from Google Scholar, Scopus and Web of Science was carried out to determine relevant publications to be included into the analysis of the research topic. The steps of literature selection based on screening criteria are shown in Figure 1.

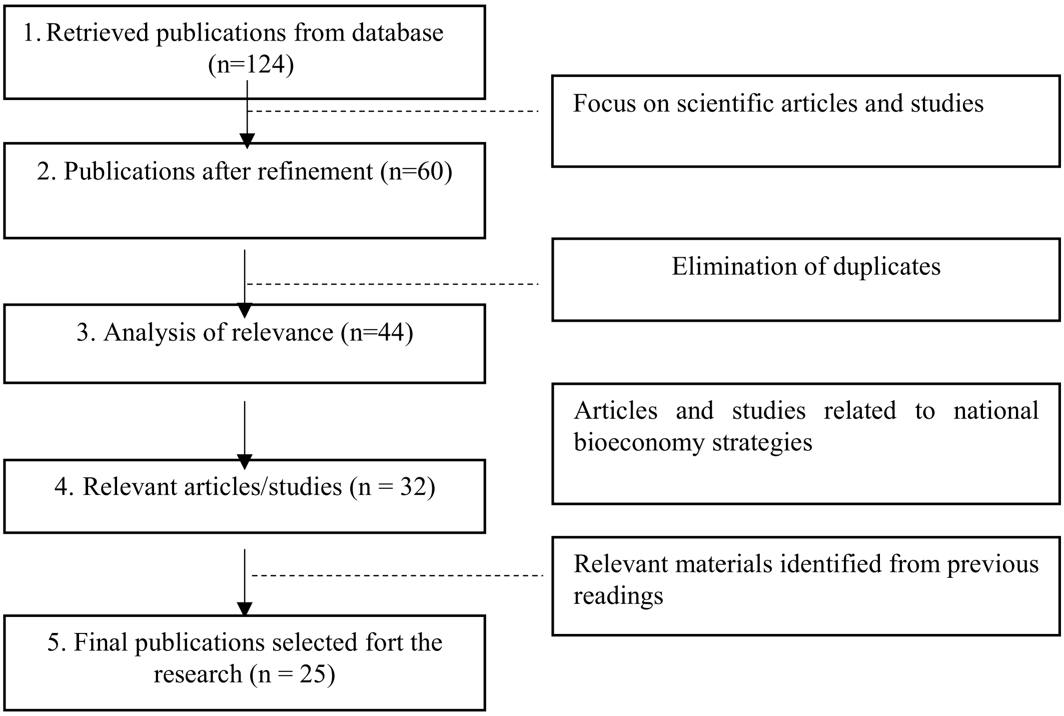

Figure 1: Methods of literature selection
Source: Pfau et al., 2014

4. Results

To date, 49 countries have developed bioeconomy strategies or action plans to replace fossil carbon with renewable carbon, but most of the listed countries have no dedicated bioeconomy strategy at national level (Table 1). What is the bioeconomy? Decoupling energy, materials and products from fossil energy resources and replacing fossil carbon with renewable carbon, namely carbon from biomass (biosphere), carbon from recycling (technosphere) and carbon from CO_2 (atmosphere) or exhaust gases (technoshere).

Table 1: Countries with bioeconomy strategies in 2022

Africa	**America**	**Asia**	**Australia & Oceania**	**Europe**
Kenya	Argentina	China		Austria
Mali	Brazil	India	Australia	Belgium
Mauritania	Canada	Indonesia	New Zealand	Denmark
Mozambique	Colombia	Japan		Estonia
Namibia	Mexico	Malaysia		Finland
Nigeria	Paraguay	South Korea		France
Senegal	Uruguay	Sri Lanka		Germany
South Africa	USA	Thailand		Iceland
Tanzania		Vietnam		Ireland
Uganda				Italy
				Latvia
				Lithuania
				Norway
				Poland
				Portugal
				Russia
				Spain
				Sweden
				The Netherlands

				The United Kingdom

Source: Bioökonomie.de (2022)

The success of the EU Bioeconomy Strategy has already encouraged ten Member States to develop their own national bioeconomy strategies and seven more Member States are in the process of developing their respective strategies.

Table 2. Member States with dedicated bioeconomy strategy and bioeconomy strategy under development

Member States with dedicated bioeconomy strategy at national level	**Dedicated bioeconomy strategy at national level under development**
Austria	Czechia
Finland	Croatia
France	Denmark
Germany	Lithuania
Ireland	Poland
Italy	Slovakia
Latvia	Sweden
Netherlands	
Portugal	
Spain	

Source: European Commission (2022d): Knowledge Centre for Bioeconomy, Countries, https://knowledge4policy.ec.europa.eu/bioeconomy_en

10 Member States of the EU, mainly the new Member States (excluding Latvia) BIOEAST countries – lack bioeconomy strategy and action plans. The linear economy plays an important role in these countries, therefore stakeholders need to develop and invest in new business models where the bioeconomy is based on higher value-added bio-based solutions that replace fossil equivalents. The transition to renewable energy sources will lead to significant changes especially in the new Member States highly dependant on energy imports (natural gas and crude oil) from the Russian Federation coupled with significant implications for the development of their economy. The transition to a circular and sustainable bioeconomy in the BIOEAST countries must be a political priority to enable biobased sectors to create biobased products and services with higher added value (Košir et al., 2021).

In addititon, these countries need a specific education system for the bioeconomy and bridge the innovation gap by strengthening civil society, good governance and the development of national bioeconomy strategies and research agendas. The leading European universities in the field of bioeconomy must intensify their cooperation and join forces in research, teaching, education, and innovation. They have laid the cornerstone for a "European Bioeconomy University" consortium (Košir et al., 2021). Europe's six leading universities in the field of bioeconomy are intensifying their cooperation and joining forces in research, teaching, education, and innovation. They have laid the cornerstone for the "European Bioeconomy University" consortium: University of Bologna (Italy), University of Eastern Finland (Finland), University of Hohenheim (Germany), AgroParisTech, Paris Institute of Technology for Life, Food and Environmental Sciences (France), University of Natural Resources and Life Sciences, Vienna (BOKU, Austria), Wageningen University and Research (Netherlands). Universities in the BIOEAST countries have no time to waste in getting ready to cooperate with the consortium.

Furthermore, attracting private investors and entrepreneurs and fostering cooperation within countries and across the macro-region are key. Substantial investments under the EU Bioeconomy Strategy have further helped to strengthen and scale-up the bio-based sectors, especially through the Bio-based Industries Joint Undertaking and its successor partnership, Circular Biobased Europe. Additional emphasis on the potential of the bioeconomy to enable the transition towards environmental, economic, and social sustainability is needed (European Commission, 2022e).

Large amounts of the knowledge required to facilitate this transition are still lacking in the EU. The results suggest that without behavioural change, the dependency of Europe on carbon removal technologies for its net-zero ambitions increases. Structural changes will be necessary to achieve full decarbonisation by 2050, yet changes in lifestyles are crucial, contributing to achieving climate targets sooner. The EU has no appropriate knowledge infrastructure that collects, structures and ensures the quality of the available energy sector data and makes it publicly accessible. The EU Member States National Energy and Climate Plans (NECPs) should be made more useful by reviewing the data that Member States provide, and encouraging them to use a harmonised reporting system. The European Green Deal proposal addresses crucial elements but could be strengthened. Carbon pricing should cover all sectors and GHGs and provide more long-term price guidance. The revisions of the EU ETS have to be in line with the long-term goal of climate neutrality. The climate balance of energy imports should be certified according to strict criteria that encourage suppliers to ensure low carbon/carbon-neutral value chains.

The EU will require an energy network infrastructure for a fundamental transition including a substantial increase in electricity generation from renewables. Market principles must be introduced for new network-based energy industries such as hydrogen. Another challenge is how to carry abundantly available renewable energy (especially in summer) over to periods when energy is less available (especially in winter). The question arises how different energy markets are co-designed (sector coupling). Furthermore, investors need clarity on how the energy market in the EU will ensure the profitability of investments to achieve the target of the Green Deal. Policy can facilitate commercialisation contracts for industry and households to guarantee that clean energy is competitive with fossil energy even when carbon prices are not yet high enough. Strengthening the EU governance of the renewables target will incentivise further investment into corresponding assets. Most EU Member States already have national phase-out policies, usually with a phase-out schedule for coal-fired power plants and a terminal date. The digitalisation of the future energy system is able to integrate higher shares of renewables and promotes energy efficiency, enhance demand flexibility and the integration of variable renewables.

5. Conclusions

What conclusions can be drawn from the literature review? For companies that emit and/or produce hydrocarbons, the pressure to change is building on all sides. The emergence of a low-carbon, circular economy is now possible with the support of many governments in the EU. The human impacts of pollution and climate change contribute to the decarbonization agenda in the long run. New technologies make it possible to use CO_2 as a feedstock for chemicals and plastics. Waste-to-hydrogen plants are being built. Renewable electricity is rapidly descending the cost curve. Many companies may by 2030 view everything they produce, including emissions, by-products and end-products, as a resource that can be traded to create economic value. A new, cleaner, more circular bioeconomy can emerge. New partnerships and markets are likely to form.

While we cannot provide a comprehensive assessment of the massive European Green Deal proposal, we think this analysis addresses crucial elements. Greenhouse gas pricing should cover all sectors and greenhouse gases. Upcoming revisions of the EU ETS have to ensure the alignment with the long-term goal of climate neutrality.The climate balance of energy imports should be certified to encourage suppliers to ensure carbon-neutral value chains. The EU will require an energy network infrastructure that enables a substantial increase in electricity generation from renewables. Key challenge is how to carry abundantly available renewable energy over to periods when energy is less available.

By pursuing decarbonization, the EU could become effectively energy independent by 2050. Although the EU would no longer depend on fossil fuel imports, it might develop new dependencies on imports of technologies vital to a zero-emissions economy (solar panels, cobalt for batteries or iridium for electrolyzers). Without decarbonising transport, the EU will not be able to reach its climate neutrality target by 2050. Transport is the largest source of GHG emissions in the EU after energy generation. Without decarbonising transport, the EU will not be able to reach its climate neutrality target by 2050. Transport is the largest source of GHG emissions in the EU after energy generation.

Decarbonisation of the energy system will require a massive transformation in the way energy is provided, transported and used. Views on what the system should or would look like in 2050 still strongly diverge. Electrification of transport and heating will require a massive build-up of renewable electricity generation. Current national energy and climate plans are insufficient to achieve an EU-wide climate neutrality by 2050. A strong commitment is needed to ensure that Member States' policies are aligned with the European targets. The results suggest that without behavioural change, the dependency of Europe on carbon removal technologies for its net-zero ambitions increases. Structural changes will be necessary to achieve full decarbonisation by 2050, yet changes in lifestyles are crucial, contributing to achieving climate targets sooner.

Further research must include the social, economic and security aspects of decarbonisation. The transition to climate neutrality will create significant implications for the economic, social and ecological development in the Central and Eastern European Member States that are highly dependant on energy imports from the Russian Federation.

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