

## Climate change mitigation with CCUS

Maria Dos-Santos, Associate Professor, Escola Superior de Comunicação Social – IPL and DINÂMIA´CET - ISCTE - University Institute of Lisbon (corresponding author)

[msantos@escs.ipl.pt](mailto:msantos@escs.ipl.pt)

ORCID iD 0000-0002-1992-0419

Estrada de Benfica, 1649-026 Lisboa Portugal.

### Abstract

Carbon Capture Utilization and Storage (CCUS) is a technology highlighted as one of the tools in climate change mitigation and one of the ways to reach the goal of 1.5 set by the Paris Agreement. The European Commission (EC) developed this goal by creating and implementing the European Green Deal (EGD) – the European Union's (EU) environmental policy. This paper provides an analysis of environmental policies and an overview of crucial CCUS projects of selected member states based on a benchmarking analysis of 27+ UK member states. An overall review of a total of 28 countries was undertaken based on economic and environmental factors. Afterward, a benchmarking analysis was performed ranking the countries according to the TOP10 for the selected five categories: total net emissions with international transport, percentage share of the energy sector, percentage share of fossil fuels, percentage share of fossil fuels in the Gross Electricity Production (GEP), and numbers of CCUS projects. Subsequently, a detailed and comprehensive overview of 3 selected Member States was done, with a special focus on the national energy policy towards net-zero emission goals, the role of CCUS in domestic environmental policy, with current projects and facilities development. Finally, this paper outlines how the EGD has reformed the national energy policies of selected member states, and what is the part of CCUS technology in the national efforts towards climate neutrality.

### 1. Introduction

Since the early 1970s, the European Union (EU) has been a pivotal actor in global environmental protection, implementing extensive legislative measures to mitigate environmental impacts.

The European Union has long been a leader in environmental protection, spearheading legislative actions aimed at reducing environmental degradation. This proactive stance has become increasingly significant in the context of rising global electricity demand and associated GHG emissions. The EU's efforts culminate in the European Green Deal, a visionary framework to transform the EU into the first climate-neutral economic bloc by 2050.

Since the onset of the industrial era, the demand for electricity has surged globally, contributing significantly to GHG emissions. According to the Intergovernmental Panel on Climate Change (IPCC), these emissions could rise by 25–90% by 2030 compared to 1990 levels, contingent on global economic trends (IPCC, 2000). This projection underscores the urgent need for effective emission reduction strategies.

From 2000 to 2020, the EU successfully reduced its total GHG emissions. However, the proportion of emissions contributed by each member state's economy has remained relatively constant. This suggests that while national efforts are yielding results, they are not yet sufficient to alter the overall emissions landscape significantly. The EU continues

to set ambitious climate goals, reflecting its commitment to reducing GHG emissions through coordinated policy efforts.

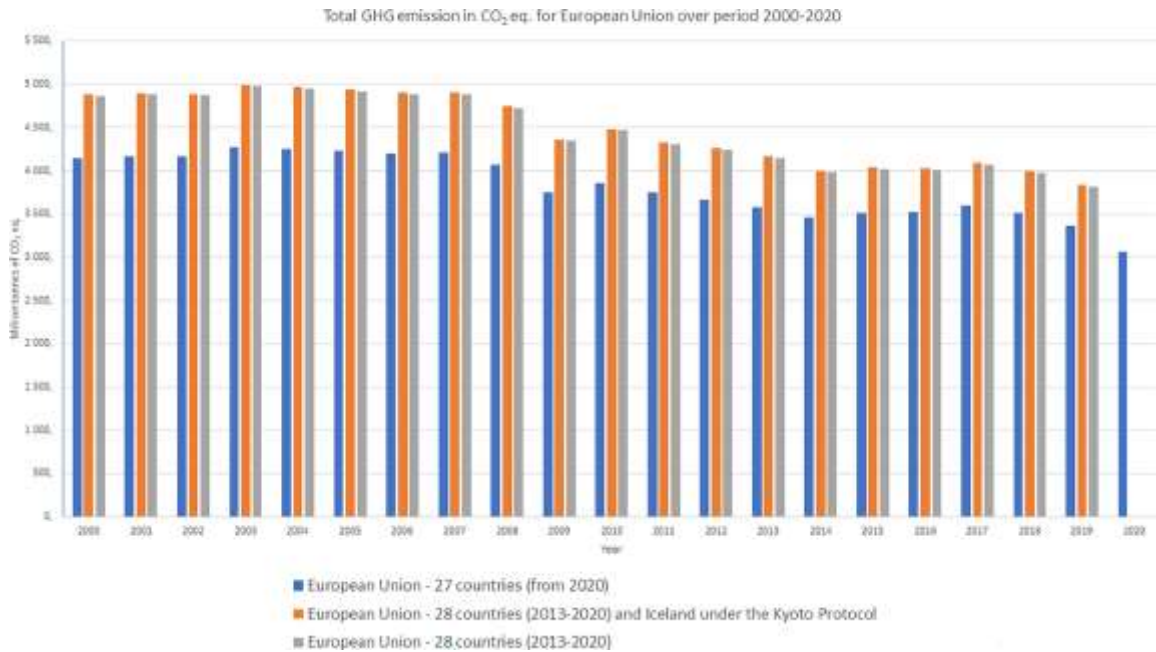


Fig.1. Total GHG emissions in Europe from 2000 to 2020 (Eurostat database, 2024).

This paper analyses the EU's role in reducing greenhouse gas (GHG) emissions and the CCUS contribution, the trends in energy demand, and the introduction of the European Green Deal (EGD) as a comprehensive strategy to achieve climate neutrality by 2050. It highlights the key objectives and actions under the EGD, including the promotion of carbon capture, utilization, and storage (CCUS) technologies.

## 2. Methods

The methodology includes a scoping review as well as an examination of key CCUS projects in European countries with the highest number of such projects, specifically the United Kingdom, the Netherlands, and Germany.

## 3. Results and discussion

The main results presented include descriptions of major European CCUS decarbonization projects across European countries, along with their current status regarding greenhouse gas emissions.

### 3.2 The United Kingdom

The Trade and Cooperation Agreement (TCA), effective from May 1, 2021, outlines the post-Brexit relationship between the United Kingdom (UK) and the European Union (EU) (Fella et al., 2020). Despite the UK's departure from the EU on February 1, 2020, the country remains engaged with the EU on climate change mitigation efforts (Wachowiak, 2021). Under the EU Withdrawal Agreement, the UK continues to adhere to shared climate

targets established under the Kyoto Protocol, which also extend to the Crown Dependencies and Overseas Territories.

Before Brexit and the TCA, the UK's Climate Change Act 2008, effective from November 26, 2008, set a pioneering framework for addressing climate change (UK Government, 2008). This legislation mandated an 80% reduction in greenhouse gas (GHG) emissions from 1990 levels by 2050, with interim goals structured through five-year carbon budgets. The act also established the Committee on Climate Change (CCC) to guide the government on emission reduction strategies and monitor progress.

In 2017, the UK introduced the Clean Growth Strategy to promote low-carbon innovation, followed by the Industrial Strategy, later refined by the 2020 Ten-Point Plan for a Green Industrial Revolution (UKBEIS, 2017; UK Government, 2017). These policies aim to align economic competitiveness with climate change mitigation.

In June 2019, the UK set a legal mandate to achieve net-zero GHG emissions by 2050, becoming the first major economy to do so (UK Government, 2019).

### **3.2.1 UK GHG Emissions**

Since 1990, the UK has reduced its total net GHG emissions by 44%. The International Energy Agency (IEA) reported a significant decline in coal usage in power and heat production by 83.9% between 2007 and 2011, as renewable energy sources (RES) gained prominence (IEA, 2019). In 2018, the Automated and Electric Vehicles Act facilitated the expansion of electric vehicle infrastructure, supporting the UK's goals for net-zero transport emissions by 2050 (Automated and Electric Vehicles Act 2018). The Road to Zero strategy further outlines plans for at least 50-70% of new car sales to be ultra-low emission by 2030, with a complete transition to zero-emission vehicles by 2050 (UKBEIS, 2018).

The energy sector's GHG emissions primarily stem from fossil fuel combustion, with natural gas accounting for the largest share (40.37% of generated electricity). Efforts to reduce emissions include phasing out coal-fired plants, converting them to biomass or waste fuels, and developing combined cycle gas turbines (CCGT) and renewable energy sources.

In 2019, the UK's industrial processes contributed significantly to GHG emissions, with the mineral industry responsible for 6.84% of domestic emissions. Notably, cement production accounted for 70.28% of emissions within the mineral industry (Brown et al., 2021). Despite these figures, industrial sector emissions have decreased by over 80% since 1990, reflecting substantial progress in emission reduction (Brown et al., 2021; Waite, 2019).

### **3.2.2 CCUS Possibilities in UK**

The UK is a leader in carbon capture, utilization, and storage (CCUS) projects, supported by the Industrial Decarbonization Strategy launched in March 2021 (UK Government, 2021a). The country has substantial underground CO<sub>2</sub> storage capacity, primarily in offshore saline aquifers and depleted oil and gas fields. The UK Storage Appraisal Project (UKSAP) has identified over 500 potential storage sites, with an estimated capacity of around 78 Gt (CO<sub>2</sub> Stored Project Homepage, 2023; Bentham et al., 2014).

The UK government aims to capture 20–30 MtCO<sub>2</sub> annually by 2030, including 6 MtCO<sub>2</sub>

from industrial sources, as part of its net-zero strategy (UK Government, 2022). The Ten-Point Plan for a Green Industrial Revolution emphasizes the role of CCUS in achieving these targets, highlighting ongoing projects like the Humber and Teesside Clusters and the Acorn Project (Calvillo et al., 2022; Griffin et al., 2016; Griffin et al., 2018).

The UK Hydrogen Strategy, launched in 2021, underscores the importance of low-carbon hydrogen, targeting 5 GW of production capacity by 2030 (UK Government, 2021).

### **3.2.3 UK's CCUS Projects**

#### **Humber: The Heart of UK Decarbonization**

The Humber region is a key industrial hub, responsible for 37% of the UK's CO<sub>2</sub> emissions. The Zero Carbon Humber initiative includes projects such as H2H Saltend and Drax BECCS, aiming to reduce the region's emissions through CCUS and hydrogen production (Drax Group PLC, 2022a).

#### **Humber Zero**

Humber Zero, a collaboration with Phillips 66 Ltd and VPI Immingham, aims to capture up to 8 Mtpa of CO<sub>2</sub> by 2026, with plans to store the captured CO<sub>2</sub> offshore (Wood PLC, 2022).

#### **Storegga and the Acorn Project**

Storegga, a leading CCUS developer, is advancing the Acorn Project, focusing on creating CCUS infrastructure in North East Scotland. The project, supported by the UK government and the EU, is crucial for decarbonizing the region's industrial activities (Alcalde et al., 2019; Allen et al., 2020; Acorn, 2022).

#### **Drax Power Station with BECCS**

Drax Power Station has converted four of its six units to biomass, aiming to implement BECCS technology to capture CO<sub>2</sub> emissions. Pilot projects are underway to test various capture technologies, including a trial with metal-organic frameworks (University of Nottingham, 2022).

#### **Keadby 3 CCS Project**

The Keadby 3 project, developed by SSE and Equinor, plans to capture at least 1.5 million tons of CO<sub>2</sub> per year, contributing to the decarbonization of the East Coast Cluster (SSE Thermal PLC, 2022a).

#### **Keadby Hydrogen Power Station**

Keadby Hydrogen Power Station, another joint project by SSE and Equinor, aims to produce hydrogen-powered electricity, supporting the UK's target for 5 GW of low-carbon hydrogen production by 2030 (SSE Thermal PLC, 2022c).

#### **Peterhead CCS Project**

The Peterhead CCS Project, a collaboration between SSE and Shell, plans to capture 1 million tons of CO<sub>2</sub> per year, utilizing Shell's Cansolv® technology for carbon capture (SSE Thermal and Equinor, 2022).

#### **Teesside**

The Net Zero Teesside project, in partnership with the Northern Endurance Partnership and Zero Carbon Humber, aims to begin CO<sub>2</sub> injection by 2026, furthering the UK's

decarbonization efforts (UK Government, 2021b).

#### Blue Hydrogen Projects

Several ongoing projects focus on producing blue hydrogen through methane reforming and CCUS, contributing to the UK's comprehensive approach to reducing GHG emissions and achieving its climate goals.

### 3.3 The Netherlands

The Netherlands is a key player in international climate policy, being an original member of the European Union, OECD, and International Energy Agency. The country has committed to significant climate action, including a 14% share of renewable energy sources (RES) in total energy consumption and a 16% reduction in non-ETS emissions from 2005 levels by 2020 (IEA, 2020a).

In 2019, the Dutch government enacted the Climate Act, setting goals to cut greenhouse gas (GHG) emissions by 49% by 2030 and 95% by 2050 relative to 1990 levels. This framework includes the Climate Plan, National Energy and Climate Plan (NECP), and National Climate Agreement, which outline comprehensive measures across various sectors (Ministerie van Economische Zaken en Klimaat, 2019). The government also plans to modernize energy laws to support these initiatives.

The Netherlands aims to scale up green hydrogen production to 500 MW by 2025 and 3-4 GW by 2030, supported by an annual Climate Budget allocation of €35 million (Ministerie van Economische Zaken en Klimaat, 2020).

#### 3.4 Germany

Following the Kyoto Protocol in 1998, Germany's Energiewende policy, introduced in 2010, has been the cornerstone of its energy transition. It focuses on expanding renewable energy, enhancing energy efficiency, and phasing out nuclear power. The Energiewende has significantly influenced Germany's climate policy, shaping the Climate Action Programme 2020 and the Climate Action Plan 2050, which aim for substantial GHG reductions (IEA, 2020; Ministry for the Environment, 2014; 2016).

In November 2016, Germany's strategy was further defined in the Climate Action Plan 2050, setting long-term targets for sector-specific GHG reductions: 40% by 2020, 55% by 2030 (later upgraded to 65%), 70% by 2040, and 80–95% by 2050 (Ministry for the Environment, 2016). For the energy sector, the plan targets an 80% share of renewable energy sources (RES) by 2030 and a gradual phase-out of fossil fuels and nuclear energy. Due to the 2022 energy crisis, there have been plans to extend nuclear power plant operations (Partridge, 2020; Deutsche Welle, 2022; BBC News, 2022). The plan also targets a 50% reduction in industrial emissions by 2030, utilizing CCUS solutions for sectors like steel, chemicals, and cement (Ministry for the Environment, 2016).

Germany's National Hydrogen Strategy, introduced in 2020, aims to further decarbonize by promoting hydrogen as a key energy source (Ministry for the Environment, 2020).

#### 3.4.2 GHG Emissions

In 2019, Germany led the EU in total net GHG emissions, with fossil fuels comprising 28.32% of total energy supply (TES) and RES accounting for 40.68% of gross energy

production (GEP) (Eurostat, 2023). The energy sector contributed 31.48% of total emissions, followed by industry (22.40%) and domestic transport (20.20%) (Federal Environment Agency, 2021). From 1990 to 2019, Germany reduced its total GHG emissions by 35.1%, reflecting its high level of industrialization (Federal Environment Agency, 2021).

In 2019, the mineral industry was responsible for 7.31% of Germany's total domestic GHG emissions. Within this category, cement production accounted for 68.44%, with the chemical and metal industries contributing 10.79% and 30.43%, respectively (Federal Environment Agency, 2021).

### **3.4.4 Germany's CCUS Possibilities**

Germany's estimated CO<sub>2</sub> storage capacity is approximately 5 Gt, with potential ranges varying from 3 to 44 Gt, depending on the source (Höller and Viebahn, 2011; Esken et al., 2010). Despite public opposition to CO<sub>2</sub> sequestration, political debates continue, focusing on CCUS as a necessary technology for industries like steel, chemicals, and cement, where other decarbonization methods are economically infeasible (Cameron, 2020; Wettengel, 2019; Vögele et al., 2018; Dütschke and Duscha, 2022).

### **3.4.5 CCUS Projects**

#### **H2morrow**

H2morrow, a CCOS project led by Equinor and Open Grid Europe, aims to import natural gas from Norway, reform it in Germany for blue hydrogen production, and store the captured CO<sub>2</sub> in the North Sea. The project aims to supply 8.6 TWh of hydrogen annually, avoiding up to 1.9 Mtpa of CO<sub>2</sub> emissions (Equinor ASA, 2019).

#### **H2ercules**

H2ercules, a project by OGE and RWE, involves installing 1 GW electrolyzers for green hydrogen production, connected to a 1500 km pipeline infrastructure. This project, costing an estimated €3.5 billion, aims to connect industrial customers in Germany and internationally, contributing to the European hydrogen market (Open Grid Europe GmbH, 2023; RWE Aktiengesellschaft, 2022).

#### **Westküste 100**

The Westküste 100 project, initiated by Raffinerie Heide in 2019, involves installing a 30 MW electrolyser for green hydrogen production, powered by offshore wind. The project includes using captured CO<sub>2</sub> for biofuel production and supplying green fuel for aviation. It received €6.5 million in funding from the Federal Ministry of Economic Affairs and Energy in 2021 (Westküste, 2022; Gray et al., 2021).

Germany's green transition involves a temporary shift to blue hydrogen before fully transitioning to green hydrogen, essential for meeting the 2030 climate targets. The development of a clear framework for CO<sub>2</sub> sequestration is crucial for energy-intensive industries and for transitioning from blue to green hydrogen (Dickel, 2020; Schmid and Hahn, 2021).

## **Conclusion**

The European Union's leadership in environmental protection and climate policy is evident through its comprehensive legislative actions and the ambitious goals set under the European Green Deal.

The EU's commitment to achieving climate neutrality by 2050, supported by technologies like CCUS, underscores its role as a global pioneer in climate action. Continued efforts and innovations will be essential to meet these goals and maintain the EU's position at the forefront of environmental sustainability. Reevaluating the role of Carbon Capture, Utilization, and Storage (CCUS) is crucial for achieving climate goals by 2050, with significant investment in development funds needed to support both small- and large-scale projects. Implementing a top-down EU initiative on CCUS could enhance knowledge exchange and facilitate international projects, particularly benefiting high-emission countries and those facing CO<sub>2</sub> storage challenges. Integrating the concept of industrial clusters with smart city initiatives is recommended, with collaboration among local authorities, academia, and industry to maximize the effectiveness of these clusters and consider potential carbon transport and hub opportunities. National and EU hydrogen strategies should incorporate Renewable Energy Sources (RES) and CCUS to transition from blue to green hydrogen. The European Green Deal should be updated into a global climate agreement that aligns with Paris Agreement goals, fostering new green industries and advancing sustainability efforts.

## References

Cameron, K. (2020). The future of CCS in Germany. *The Guardian*. Retrieved from <https://www.theguardian.com/environment/2020/oct/01/future-ccs-germany>

Deutsche Welle. (2022). Germany's energy crisis and nuclear energy. Retrieved from <https://www.dw.com/en/germany-energy-crisis-nuclear-power/a-58295423>

Dickel, S. (2020). Germany's green transition and blue hydrogen. *Energy Policy*, 139, 111347. <https://doi.org/10.1016/j.enpol.2020.111347>

Dütschke, E., & Duscha, V. (2022). CCUS as a decarbonization strategy for industry. *Environmental Innovation and Societal Transitions*, 42, 192-202.

<https://doi.org/10.1016/j.eist.2021.10.001> European Commission. (2020). *National Energy and Climate Plan of the Netherlands*. Retrieved from [https://ec.europa.eu/energy/sites/ener/files/documents/national\\_energy\\_and\\_climate\\_plan\\_2021-2030\\_netherlands.pdf](https://ec.europa.eu/energy/sites/ener/files/documents/national_energy_and_climate_plan_2021-2030_netherlands.pdf)

Federal Environment Agency. (2021). *Greenhouse Gas Emissions in Germany*. Retrieved from <https://www.umweltbundesamt.de/en/topics/climate-energy/greenhouse-gas-emissions>

Höller, S., & Viebahn, P. (2011). *CCS Potential in Germany*. *Energy Procedia*, 4, 3904-3911. <https://doi.org/10.1016/j.egypro.2011.02.268>

Ministerie van Economische Zaken en Klimaat. (2019). *National Climate Agreement*. Retrieved from <https://www.government.nl/topics/climate-policy>

Desde o início da década de 1970, a UE tem desempenhado um papel de liderança no cenário político global em proteção ambiental, estabelecendo várias diretrizes para proteger o meio ambiente ao longo das décadas por meio de inúmeras ações legislativas (Bourguignon et al., 2019; Siddi, 2020).

Desde a era industrial, a demanda global por eletricidade aumentou significativamente, o que está diretamente relacionado às emissões de gases de efeito estufa (GEE), que podem aumentar até 2030 entre 25% e 90% em comparação com 1990, dependendo do cenário da economia global (IPCC 2000).

Em contrapartida, no período de 2000 a 2020, as emissões totais de GEE da UE foram reduzidas, conforme mostrado na Fig. 1. No entanto, a porcentagem de participação de cada estado-membro na comunidade econômica em termos de emissões manteve-se em níveis semelhantes aos dos anos anteriores, como mostrado na Fig. 2. Embora, como resultado da ação legislativa, cada estado-membro esteja reduzindo suas emissões nacionais de GEE ano após ano, a participação geral permanece em um nível semelhante. É essencial fazer progressos, definir metas climáticas e trabalhar progressivamente para alcançá-las.

4o

#### **Dito por si:**

traduz sff Each carbon dioxide utilization technology not only has its requirements in terms of the quality and parameters of the CO<sub>2</sub> stream but also the potential and efficiency ( Fig. 3 ) with which the captured CO<sub>2</sub> can be converted into a new product.

#### **Dito pelo ChatGPT:**

ChatGPT

Cada tecnologia de utilização de dióxido de carbono não só tem seus requisitos em termos de qualidade e parâmetros do fluxo de CO<sub>2</sub>, mas também o potencial e a eficiência (Fig. 3) com que o CO<sub>2</sub> capturado pode ser convertido em um novo produto.

4o

#### **Dito por si:**

traduz UK GHG emission Since 1990 the UK's total net emission decreased by 44 % ( Fig. 6 ). According to the IEA report about the UK's Energy Policy coal usage in the power & heat sector fell by 83.9 % over the period 2007–2011 thus to strong increase share of RES in TES and strengthened the UK carbon price floor ( IEA 2019 ).

#### **Dito pelo ChatGPT:**

ChatGPT

## Emissões de GEE no Reino Unido

Desde 1990, a emissão líquida total do Reino Unido diminuiu em 44% (Fig. 6). De acordo com o relatório da AIE sobre a Política Energética do Reino Unido, o uso de carvão no setor de energia e aquecimento caiu 83,9% no período de 2007–2011, devido ao forte aumento da participação das energias renováveis no TES e ao fortalecimento do piso de preço do carbono no Reino Unido (AIE 2019).

40

## 5. Conclusões

Com base nas observações e conclusões da revisão dos estados-membros selecionados da UE, cujo caminho para a neutralidade climática poderia ser dificultado, várias conclusões podem ser tiradas.

Em primeiro lugar, o papel do CCUS tanto nos programas europeus quanto nacionais de descarbonização e/ou transição energética deve ser reavaliado para alcançar as metas climáticas até 2050. Além disso, uma ênfase especial deve ser dada aos fundos europeus e nacionais de desenvolvimento de CCUS, que podem ser um incentivo para o início de projetos de CCUS em pequena e grande escala. Como mostrado em vários exemplos (como o Projeto Acorn no Reino Unido), esses fundos e a competitividade de custos têm importância especial.

Além disso, a implementação de uma iniciativa da UE de cima para baixo na implantação do CCUS pode ajudar a fortalecer a troca de experiências e a implementação de projetos internacionais. Os países com uma alta participação nas emissões de GEE da Europa (por exemplo, Alemanha, Polônia, Países Baixos, Itália), assim como aqueles com uma alta participação de combustíveis fósseis na matriz energética (como Polônia, Países Baixos, Alemanha e Itália) e aqueles que enfrentam dificuldades no uso de armazenamento de CO<sub>2</sub> devido a condições geológicas (por exemplo, Itália, Malta, Chipre), podem se beneficiar particularmente dessa solução.

Adicionalmente, a ideia de clusters industriais, reformulada paralelamente à ideia de cidades inteligentes, deve ser aplicada o máximo possível pelos formuladores de políticas (Países Baixos e Reino Unido como exemplos de excelência). A cooperação conjunta entre autoridades locais, academia e indústria pode se beneficiar da troca de experiências. Projetos de clusters para regiões intensivas em indústrias (como a Alta Silésia na Polônia ou a região do Ruhr e a Área Industrial do Reno na Alemanha) devem sempre considerar potenciais rotas internacionais de transporte e hubs de carbono.

Por fim, as estratégias de hidrogênio nacionais e europeias devem sempre ser consideradas em conjunto com as tecnologias de energias renováveis (RES) e/ou CCUS, para transformar o hidrogênio azul em hidrogênio azul de baixo carbono ou hidrogênio verde (como no Reino Unido, Alemanha e Países Baixos).

Por último, a União Europeia deveria reformular o Acordo Verde Europeu (European Green Deal) em um novo acordo climático global de economias unidas pelo clima, para alcançar metas atualizadas com base nos objetivos do Acordo de Paris. O EGD não deve apenas pressionar os estados-membros a realizar uma transformação econômica significativa, mas também abrir caminho para várias possibilidades de novas indústrias

verdes e para o fortalecimento da utilização dos Objetivos de Desenvolvimento Sustentável das Nações Unidas.