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Driving climate action: brokers as catalysts in EU policy networks

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Abstract
Innovative, data-driven strategies for research and improved global mitigation action are essential to tackle climate change. This research employs network science methods to understand the transitive network structures of diverse climate action measures or initiatives and reveal patterns that highlight policy pathways and cooperation for these initiatives. Our framing of climate action as a multi-layered network allows us to more explicitly illustrate the interdependencies between government mandates, business sustainability efforts, and social action partnerships. We identify normalized network metrics, such as centrality and structural balance, to reveal proxies for policy pathways that improve coordination while supporting the EU-level focus on influential agents and influential path trajectories for support. This study enhances the field of collaborative sustainability by introducing network science theory into climate action planning. Our results demonstrate that climate action networks leverage the potential of influential nodes that can facilitate larger systemic shifts. This study expands our analytical scope to examine the temporal evolution of climate action within networks, assessing how influencing policy agendas and social mandates affect the trajectory of climate action sustainability implementation. We use case studies of climate action initiatives to demonstrate the utility of the framework in informing decisions. We identify the brokers and present the sectors that should be engaged for effective climate action networks to maximize collaboration and resourceful engagement and learning through climate action policies or programs. The research findings provide actionable recommendations for policymakers, institutions, and advocacy groups in the climate action area.

Keywords Climate change, Network science, Brokers, Systemic change, Evidence-based policymaking

Introduction

The European Union (EU) has committed to ambitious climate and energy targets (Lanterna 2024), requiring coordinated efforts across multiple environmental governance levels. The implementation of these policies is shaped by the complex interactions between national governments, EU institutions, and non-state actors. Brokers are actors who facilitate communication and coordination within policy networks and play a vital role in this landscape. Nevertheless, their influence on the climate policy outcomes and implementation remains largely underexplored. This study examines brokerage positions in EU climate policy networks, focusing on their evolution over time and their impact on policy coherence. The paradigm shift in European countries toward sustainability, driven by a changing climate and energy policy landscape, is well known (Lesch et al. 2023). The change has been prompted by the imperative of responding to climate change, providing energy security, and promoting economic resilience (Hossain 2025). Due to the complexity of such problems, it is essential to study interactions between states, sectors, and actors to understand thoroughly how policies are generated and deployed effectively (Nita and Rozylowicz 2022). The interconnectedness of climate control within the EU requires a network vision, where actors cooperate, negotiate, and occasionally compete to establish common sustainability goals.

One of the pillars of policy implementation is the ability of different actors to work together through coordination and cooperative structures (Gavrilidis et al. 2022; Niță et al. 2023). In the dynamic system, brokers emerge as central actors who manage information exchange, bridge policy gaps, and facilitate cooperation. In climate policy, they play a critical role because negotiating national interests in relation to EU-wide goals requires mediation, strategic planning, and policy alignment (Hossu et al. 2022). Knowing how these brokers operate in the EU's policy network can provide insights into the processes that facilitate or hinder effective policy implementation.

Network analysis has increasingly been applied in policy studies to illustrate the impact of actor relationships on policy adoption and governance (Sandstrom et al. 2015). Brokerage theory suggests that brokers operate as an intermediaries, facilitating cooperation and information exchange among otherwise disconnected actors. Social Network Analysis (SNA) offers a robust methodological instrument to examine these interactions systematically (Becker and Bodin 2022). By mapping the connections between actors engaged in climate and energy policy, SNA enables us to trace important brokers and assess their power in the policy settings. Furthermore, through network visualization and quantitative analysis, SNA allows us to determine collaboration patterns, network structures, centrality degrees, and brokerage positions characterizing the effectiveness of policy diffusion across the EU. This approach goes beyond traditional institutional analyses by uncovering subtle network structures that influence decision-making processes.

The purpose of this research is to examine climate action networks operating in the EU using a network science approach. The goal is to identify critical structures and actors that might enhance the effective delivery of climate action policy. Also, with brokering roles at the forefront of enabling coordination and knowledge sharing, the focus would be on how brokers support exchange across the multilevel governance landscape. This is critical given the different actors involved in facilitating collaborative management across governmental levels, the institutions of the EU, the private sector, and civil society. The primary research objective is to map climate action networks, identifying linkages between governments, EU institutions, business and corporate actors, and social movements. By observing these linkages, this research will identify levels of collaboration and key connections that advance policy implementation. Engaging with a network perspective enhances our interactions with various actors' connections toward effective climate policy. Another primary purpose is to identify the key actors and brokers within a climate action network. Network measures, such as measures of centrality and structure, will be employed in the analysis to identify nodes capable of coordinating and facilitating cross-sectoral collaboration. Understanding the form and function of power hubs operating on behalf of the climate will enhance our understanding of the climate action ecosystem as a whole.

Data and methodology

Data collection

The analysis is based on European Environment Agency (EEA) data and national climate action plans, specifically the Integrated National Climate and Energy Policies and Measures (PaM) dataset (EEA 2024). The dataset published on October 21, 2024, gathers 3,326 national policies and measures and is available in the EEA Data Hub, which serves as a comprehensive source for regulatory and strategic measures implemented by EU member countries to achieve climate neutrality. For this analysis, we only retained those national policies or measures that are explicitly linked to a EU-level policy, which reduced the number of policies to 2,164. The policies cover numerous areas relevant to EU climate governance, providing structured data on important characteristics such as: Policy dimensions (thematic categories such as decarbonization, energy efficiency, and renewable energy), Countries (EU member states in which policy implementation occurs), Geographical coverage (geographical extent of the impact of each policy), Quantified objectives (objectives and expected outcomes defined in the policies), Status of implementation (implementation stage, e.g., planned, ongoing, completed), Implementation period (starting and expected completion dates for each policy), General comments (policy justification and implementation qualitative information), Targeted sectors (industrial and economic sectors affected by the policy, e.g., transport, agriculture, energy, industry). They span from legislative directives and funding programs to voluntary measures, agreements, and regulatory frameworks, testifying to the multi-faceted nature of EU climate policy. The investigated EEA dataset is a sound foundation for analysis of policy implementation patterns and the identification of key actors in the policy network.

EU energy policy network analysis

The EU has established a comprehensive framework of energy policies in order to respond to the challenges of climate change, energy security, and sustainable development. This section provides a systematic summary of the key directives, regulations, and other measures in place to guide the EU countries to their ambitious energy and climate goals. Table 1 presents significant EU energy-related policies and regulations about energy efficiency, renewable energy development, emissions reductions, and energy security. Parts of these directives encourage sustainability, promote the uptake of clean technologies, and foster resiliency in the EU energy market. The policies we discuss in more detail were selected due to their centrality in the network and frequency in the dataset, demonstrating a higher level of relevance in the EU climate and energy policy landscape.

Clean Vehicles Directive

The Clean Vehicles Directive (Directive (EU) 2019/1161) supports the Alternative Fuels Infrastructure Directive (AFID) initiatives through the promotion of the purchase of clean vehicles in public procurement. The Directive requires public authorities to, at

Table 1 Directives / Regulations / Policies considered in the network analysis

Directive/Regulation/Policy	Description (source ((EEA) EEA))
Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU	Facilitates the creation of infrastructure for alternative fuels (e.g., hydrogen) to help move to more sustainable modes of transport.
Carbon capture (and storage) (CCS) directive	Supports the advancement of Carbon Capture (and Storage) (CCS) technologies to support reducing CO_2 emissions from industrial activities (Shogenova et al. 2013).
Clean vehicles directive	Requires public authorities to obtain low-emission and energy vehicles, creating demand for clean vehicles.
Commission recommendation on permit-granting procedures for power purchase agreements (PPAs)	Encouraging the simplification of permitting processes for PPAs will facilitate more renewable energy investment.
ommon agricultural policy	Contains provisions encouraging sustainable agricultural practices, which will help support energy-efficient practices and renewable energy use
Directive on European critical infrastructures	Provides security for critical energy-related infrastructures such as electricity and gas networks.
Directive on safety of offshore oil and gas operations	Creates safety standards for the offshore oil and gas exploration and production to help reduce environmental risk.
Emission trading system (ETS) directive	Establishes the Emission Trading System a carbon pricing mechanism to reduce greenhouse gas emissions.
Eco-design framework directive	Mandates energy-efficient product designs that will lower energy use when applied within appliances and industrial products.
Effort sharing decision	Sets binding national greenhouse gas (GHG) emission reduction targets for non-ETS sector, including transport, agriculture, and buildings.
Effort sharing regulation	Building on the Effort Sharing Decision with stricter national targets by 2030 for reducing GHG.
Electricity market directive	Intends to create a competitive, consumer-focused electricity market and delivers a higher level of renewable energy.
Electricity market regulation	It supports electricity market efficiency and the increased uptake of clean energy in combination with efficient electricity market operation.
Energy efficiency directive	Sets binding targets for reducing energy consumption in buildings, industries, and transport, contributing to overall energy savings.
Energy performance of buildings directive	Prioritizes improving energy efficiency in buildings through retrofitting and integrating renewable energy.
Energy taxation directive	Creates the tax framework for energy products and electricity with an eye towards incentivizing energy efficiency and reducing CO_2 emissions.
Euro 5/6 regulation	Creates stricter emission limits for automobiles to combat air pollution from transportation.
Euro VI regulation	Sets up a successor to Euro 5/6, which has an emphasis on heavy-duty vehicles and requires strict emission limits to reduce their pollution.
European climate law	Establishes the EU's goal to achieve Climate neutrality by 2050 in legislation and creates a framework upon which we can achieve net-zero emissions.
European structural and investment funds	Allocates funding towards projects focused on energy efficiency and renewable energy in service of the EU's energy transition.
Euro vignette directive	Creates tolling regimes for heavy-duty vehicles, stimulating lower-emission transportation.
F-gas regulation	Regulates fluorinated greenhouse gas (GHG) emissions, which have a relatively high potential for global warming.
Fuel quality directive	Regulates fuel quality standards to reduce air pollutants and promote cleaner fuels.
Gas storage regulation	Ensures the security of gas supplies through appropriate storage levels to mitigate shortages in emergencies.
Governance regulation	Creates a monitoring framework for the implementation of the EU's energy and climate policies through National Energy and Climate Plans (NECPs).

Table 1 (continued)

Directive/Regulation/Policy	Description (source ((EEA) EEA))
Industrial emissions directive	Establish limits on industrial emissions to reduce air and water pollution from large industrial facilities.
Just transition fund regulation	Provides financial assistance for their economies to move away from fossil fuels to low-carbon economies.
Land-use change and forestry (LULUCF) decision	Functioning with respect to GHG emissions and removals from land use, land-use change, and forestry activities to satisfy climate targets.
LULUCF regulation	In the wake of the LULUCF Decision, this is aimed at increasing carbon sinks based on land and forestry management approaches (Ellison et al. 2014).
Labelling regulation	Sets energy labelling requirements for products to help consumers make informed decisions about energy efficiency.
Landfill directive	Aims to minimize the waste sent to landfills, enhance recycling and energy recovery, and generally minimize harm to the environment (Wang et al. 2020).
Medium combustion plant directive	Provides measures to limit emissions from medium-sized combustion plants for air pollution management.
Mobile air-conditioning systems directive	Regulates emissions from air conditioning units installed in vehicles with the goal of reducing the use of high-GWP refrigerants
National emission ceilings (NEC) directive	Provides national emission ceilings for pollutants leading to acidification, eutrophication, and ground-level ozone.
Network and information systems (NIS) directive	Ensures network and information systems security protection for energy sector systems.
Network code on electricity emergency and restoration	Provides for measures ensuring stability of the electricity grid in situations of emergency or disruption.
Nitrate directive	Regulates farming practices for reducing water pollution from nitrates from fertilizers.
Oil stocks directive	Requires Member States to hold minimum oil stocks for security of energy supply.
Recovery and resilience facility regulation	Provides funding for green and digital transition projects, such as renewable energy projects, projects to improve energy efficiency, and green technology.
Regulation on CO_2standards for cars and vans	Set targets for reducing CO_2 emissions from new cars and vans, which will lead to greater use of cleaner vehicles technology.
Regulation on CO_2standards for heavy-duty vehicles	Set emissions limits for heavy-duty vehicles to reduce their carbon footprint.
Regulation on coordinated demand-reduction measures for gas	Aim to reduce demand for gas at times of supply crisis, with the priority of energy security.
Regulation on risk-preparedness in the electricity sector	Improve our preparedness to cope with electricity supply crisis, while improving the reliability and resilience of our energy system.
Renewable Energy directive	Set targets for renewable energy production and consumption, where wind, solar, and other renewable sources can be included.
Security of Gas Supply regulation	Support measures to ensure we have secure gas supplies in times of crisis through greater storage, diversification, and solidarity between Member States.
EU renewable energy financing mechanism	Support measures to enable the financing of renewable energy projects across borders to fast-track the energy transition.
Urban waste water directive	Support measures in the management of urban wastewater to avoid pollution of the water environment and ensure overall water quality
Waste management framework directive	Provide measures for a system of waste management that supports the use of energy recovery and recycling of organic materials rather than sending waste to landfills.
Water framework directive	Aim to protect resources of water and encourage sustainable use of water for energy, particularly hydropower and other energy sectors.

a minimum, purchase, lease, or rent vehicles that meet certain environmental performance indicators, such as low CO_2 and air pollutants emissions. The Directive applies to the public transport market, which includes buses and taxis, as well as any other fleets procured and/or operated on behalf of public authorities, aiming at promoting a more rapid adoption of electric mobility and other low-emission technologies. In particular, the Directive generates market demand for clean technologies, which encourages manufacturers to build more sustainable vehicles and promote investment in cleaner energy. In this way, it promotes improvements in infrastructure and fuels as a third-party benefit, ultimately creating synergies with other policies (i.e., AFID goals) and contributing positively to the overall energy transition.

Renewable Energy Directive (RED II)

The Renewable Energy Directive (Directive (EU) 2018/2001) constitutes a vital component of EU energy policymaking. It introduces legally binding targets that require Member States to focus on renewable energy development while providing a framework to promote renewable energy, in line with climate change ambitions, in the areas of electricity, heating, cooling, and transport. This means that by 2030, at least 32% of the EU's energy consumption should originate from renewable sources. The implications of RED II for the energy sector are considerable: it mobilizes investment in renewable energy projects, such as wind, solar, and biomass, and builds cross-border cooperation to achieve renewable energy targets. It supports the integration of renewable energy into the electricity grid and the capacity of the grid to host variable sources of renewable electricity, such as wind and solar. This legislation is critical to achieving the EU's climate neutrality agenda by decarbonizing energy consumption and production.

Energy Efficiency Directive

The Energy Efficiency Directive (Directive (EU) 2023/1791) plays a significant role in efforts to cut energy consumption in the EU. It establishes legally binding targets for energy efficiency and places an obligation on Member States to introduce measures that will increase energy efficiency in buildings, industrial, and other sectors. The purpose of the directive is to contribute to the overall target of reducing energy consumption by at least 32.5% by 2030, compared to projected consumption. It promotes important actions, including renovations of buildings to improve energy efficiency, promoting the uptake of energy-efficient technologies in industry, and the reduction of waste and optimal use of energy. The directive also requires large companies to undertake energy audits and management systems to identify potential savings. The directive is an important part of reducing the EU's overall energy consumption, costs, and GHG emissions, and links with other pieces of legislation, including the Energy Performance of Buildings Directive and the Eco-design Directive.

Energy Performance of Buildings Directive

The Energy Performance of Buildings Directive (Directive (EU) 2024/1275) specifically targets enhancing energy efficiency in buildings, which account for roughly 40% of the total energy consumption in the EU. It mandates that Member States develop long-term renovation strategies to decarbonize buildings by 2050. These strategies include establishing minimum energy performance standards for both new and existing buildings, promoting the use of smart technologies and energy management systems, and outlining measures to boost renewable energy sources such as solar panels, heat pumps, and other clean energy alternatives. The directive is vital to the EU's climate neutrality aim and is synergistic with the Energy Efficiency Directive—enhancing performance in buildings is a significant proposal for overall energy use reduction.

Carbon emissions reduction: Emissions Trading System and Effort Sharing Regulation

The Emissions Trading System (ETS) and the Effort Sharing Regulation (ESR) are two key policies aimed at limiting greenhouse gas emissions. The ETS was established by Directive 2003/87/EC and encompasses sectors such as power generation, industry, and aviation. It creates a market for Member States to trade carbon allowances, thereby incentivizing companies to reduce emissions. The total cap decreases over time to ensure that total emissions are reduced. The Effort Sharing Regulation (Regulation (EU) 2018/842) covers sectors not included in the ETS, such as transport, buildings, and agriculture, and sets legally binding targets for Member States to achieve a 30% reduction in emissions below 2005 levels by 2030. Together, these two mechanisms underpin the overall EU decarbonization strategy by enacting a mix of market-based and regulatory requirements to reduce emissions from both concentrated and diffuse emissions sectors.

Governance of the energy union and climate action

The Governance Regulation (Regulation (EU) 2018/1999) sets out a framework for monitoring and ensuring proper implementation of the EU's energy and climate policies. It mandates that Member States develop integrated National Energy and Climate Plans (NECPs) outlining how they will achieve their energy and climate objectives. The governance system serves as the mechanism that holds Member States accountable for fulfilling their respective renewable energy, energy efficiency, and reductions in GHG commitments. The EU's energy policy framework is a complex and interdependent system of directives, regulations, and strategies that add transparency to the efforts to promote sustainable energy and carbon reductions while also improving energy efficiency. Policies such as the Alternative Fuels Infrastructure Directive, Clean Vehicles Directive, Renewable Energy Directive, and Energy Efficiency Directive have become the cornerstones for advancing the adoption of renewable energy, enhancing energy efficiency, and minimizing the environmental impact of energy consumption. Such approaches are essential to meet the EU's goal of climate neutrality by 2050 (Mikropoulos et al. 2025) and to provide a secure and competitive energy future. Through these coordinated activities, the EU continues to lead the world towards a low-carbon economy (Soto et al. 2025).

Network construction and analysis

First, we constructed a one-mode EU policy-related network to determine the evolution of EU countries interest in energy-related policies. This was done with a temporal analysis to track the transformation of policy perspectives during the implementation period (i.e., adopted/implemented versus planned). Unlike the policy-country two-mode network, the one-mode network enables an understanding of connectivity and cooperation among countries for implementing EU energy policies. In contrast, the sectoral two-mode network allows for mapping various elements, particularly the most regulated sectors and which countries are most engaged across these sectors.

After this step, we used a two-mode network (Borgatti and Everett 1997) to analyse the interaction between EU member states, policy dimensions, and sectors. The two-mode network allowed us to identify key actors who serve as central brokers in facilitating cross-sectoral coordination and policy diffusion (Jasny and Lubell 2015). Network cohesion density, connectivity, and fragmentation were measured graph-theoretically to gauge network structure and integration of climate policy networks (Marti et al. 2017). The network was characterized by using betweenness centrality (Abbasi et al. 2012) to determine key brokers in the policy space. The two-mode network structure of the countries' interaction with EU policies is structured as a bipartite graph in the form of a group of nodes representing countries and another group of nodes representing EU policies, with edges indicating interactions or connections between the two.

In the two-mode country-policy network, the edges indicate when a country has either enacted or referenced an EU policy in national documents. In the one-mode country network, edges are drawn whenever countries have implemented the same policies. In the two-mode sector network, edges are drawn to denote links between a country and the sectors included in the enacted policy, with the country implementing that policy.

To understand the structural integrity and dynamics of this two-mode graph, some key measures were calculated, including density, average distance, radius, diameter, fragmentation, transitivity, and normalized distance (Hanneman and Riddle 2005). Density reflects the ratio of real ties in the graph to the maximum number of ties in a bipartite network. It is calculated as the ratio of the number of edges (ties) that exist to the maximum number of possible edges between the countries and the EU policies. Average Distance (Avg Dist) denotes the average geodesic path length between the nodes in the graph, calculated for all connected nodes. It indicates the average degree of separation between EU policies and countries in the network. The radius of a graph is the minimum eccentricity (the maximum distance from a node to any other node) in the graph. It measures the "closeness" of the network, with smaller radius values signifying more tightly connected networks. The diameter of the graph represents the length of the longest geodesic in the network or the greatest distance between two nodes. This offers insight into the "spread" of the network, highlighting the most distant points in terms of connectivity. Fragmentation refers to the extent to which the network is divided. When fragmentation is greater than 0, the graph contains disconnected subgraphs. Fragmentation indicates whether the network is one unit or divided into disconnected clusters. Transitivity is defined as the probability that if two nodes are both connected to a third node, they are also connected to each other. Transitivity in bipartite graphs is determined by the ratio of quadruples (groups of four nodes) with four steps (links) to triples or higher-order groups. Normalized distance is calculated by dividing the average distance by the theoretical minimum average distance in a graph of the same node set sizes. This measurement allows for a comparison of the network's efficiency of connectivity with the theoretical minimum potential distance in the graph. These metrics are all computed in terms of geodesic lengths between parts of the bipartite graph, ensuring the results are based on connected subgraphs in the event that fragmentation is greater than 0 (Hanneman and Riddle 2005).

To analyze the interactions among stakeholders, we constructed a second two-mode network linking EU member states with policy dimensions and affected sectors. This approach enables us to map and quantify the relationships within the policy implementation ecosystem, providing insights into the structural position of various actors. Betweenness centrality was used to identify key brokers who serve as intermediaries in policy implementation (Everett and Valente 2016). The network structure enables identification of central entities that influence the diffusion and coordination of climate-related policies across Europe.

In this analysis, we utilize Social Network Analysis (SNA) techniques to identify patterns of structural influence and policy linkages. Using computational software packages such as UCINET 6.806 (Borgatti et al. 2002), Netdraw (Borgatti 2002), we compared the exclusivity of brokerage positions across different groups of policies. Additionally, centrality metrics were used to analyze how brokerage activity relates to policy diffusion across EU countries and to examine whether high-brokerage countries contribute to a faster and more successful spread of policy instruments. This methodology helps clarify how governance arrangements promote climate action by revealing the efficacy of policy coordination and cooperation among EU members. Research shows that network-based approaches and multi-layer perspective theory (Geels 2011) can reveal the structure of biocultural and policy systems, as well as provide information on how actors and ecological variables co-evolve (Nita et al. 2024). In this study, we draw from similar methodologies in network science to analyze the brokerage roles present within EU climate policy networks, with the anticipation that they may facilitate coordinated sustainability.

By leveraging these methodological tools, we aim to provide empirical results on climate policy network dynamics that have significant implications for scholars and policymakers looking to optimize the implementation of sustainability policies across the EU. In addition, we employed visualization techniques from VOSviewer 1.6.20 (Van Eck and Waltman 2010) to show the thematic clustering of climate policies and their dependencies. This approach enabled us to identify the core actors that constitute EU sustainability governance and the extent to which brokers influence policy implementation routes.

Results and discussion

Policy dimensions

Figure 1 provides a graphical representation of EU climate and energy policies that have been implemented or adopted. A blue (older) to yellow (newer) color gradient depicts the timeline for energy-related policies that have been adopted or implemented, while a white to purple gradient represents those planned for implementation by 2040. Key policies, such as the Renewable Energy Directive, Energy Efficiency Directive, and Governance Regulation, are highlighted as central to the EU's decarbonization efforts. A cluster of policies addressing energy, emissions, and building performance signals a strong emphasis on carbon reduction. In contrast, policies like the Medium Combustion Plant Directive and F-Gas Regulation are more peripheral, with a less direct connection to the core framework for energy transition.

Figure 2 illustrates the evolution of Planned Policies and indicates future EU policies set to be implemented between 2025 and 2040. In the network representation, blue reflects earlier deadlines (around the year 2025), while red denotes later deadlines (nearer the year 2040). The Governance Regulation, Energy Efficiency Directive, and

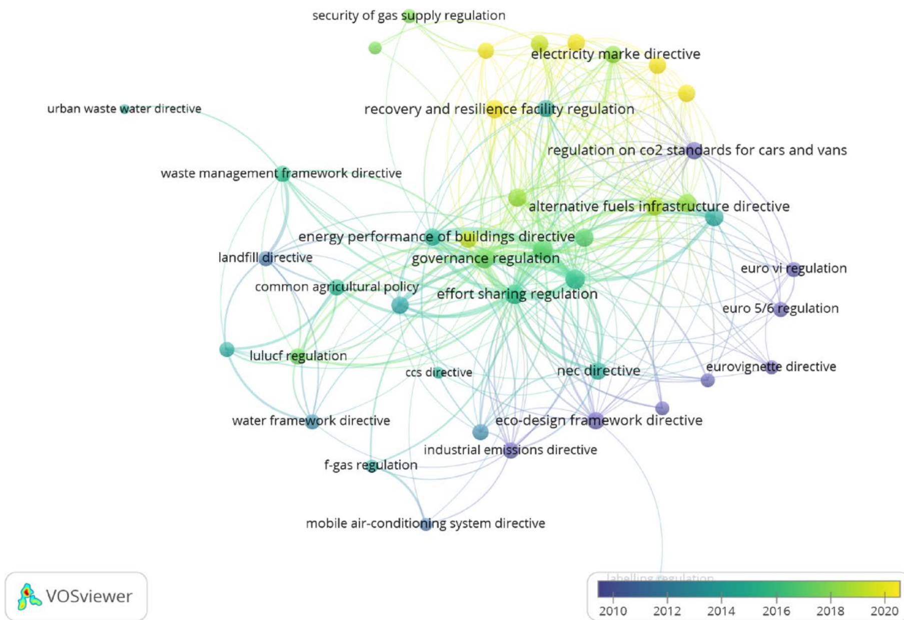

Fig. 1 Evolution of the most significant energy-related policies in the EU based on year of enactment (status of implementation: adopted or implemented)

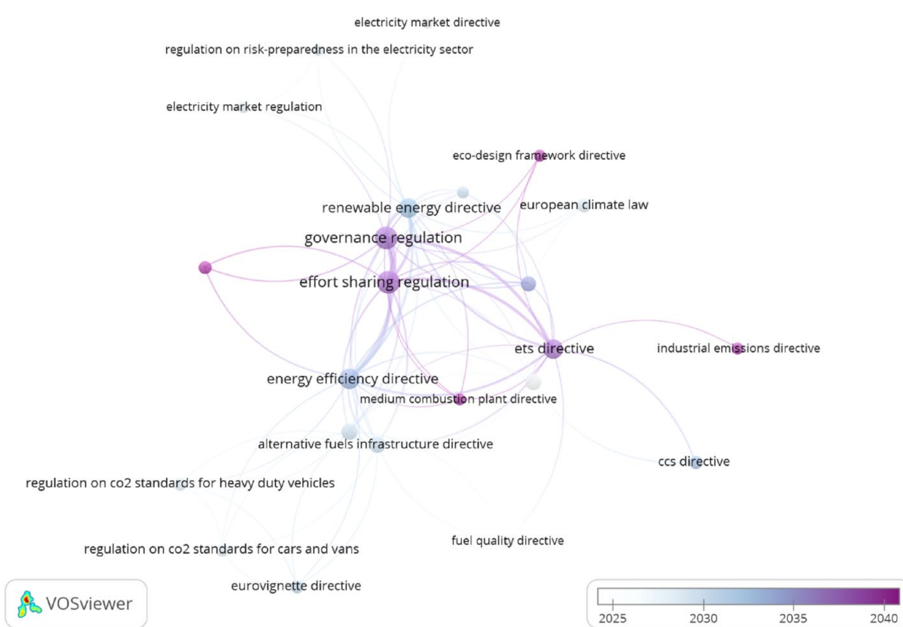

Fig. 2 Evolution of the most significant energy-related policies in the EU based on their enactment (status of implementation: planned)

Renewable Energy Directive remain in the middle, reflecting their continued dominance of the EU's climate agenda. Key future policies such as the European Climate Law, Electricity Market Regulation, and Euro 5/6 Regulations enter the scene as key players. Unlike the earlier network dominated by legacy directives, the planned policy network suggests a progressively integrated framework aimed at enhancing systemic policy alignment. One significant trend characterizing EU networks is the evolution of policies over time. The regulations implemented from 2010 to 2020 were gradually phased out or revised for newer, higher-level policies on the agenda for 2025–2040. The EU has shifted its focus from fundamental energy-saving and emissions-reducing policies to a comprehensive system encompassing clean mobility (through Euro 5/6 Regulations), market regulation, and overall climate law. This shift reflects a more cohesive and ambitious approach to climate action (Khalique et al. 2025).

The second significant trend is the increasing interconnectivity of policies over the years. The first network representation illustrates a well-developed network of interconnected rules, particularly in energy, emissions, and building performance. In the second network representation, upcoming regulations appear more streamlined, indicating the possibility of closer integration and coordination among sectors. This increasing interconnectivity suggests that future EU policies will operate within a more integrated regulatory system aimed at achieving greater synergy among energy, transport, and market regulation. There is also a noticeable sectoral change in these visualizations. Traditionally, the EU concentrated on energy efficiency, renewable energy, and emissions reduction (Kwilinski et al. 2024). In the future, however, the focus areas broaden to encompass market regulation, electrification, transportation standards (Euro 5/6), and the integration of climate law. This is because the EU recognizes the need for a multi-sectoral transition, where energy transition (Shadrina 2025) is linked with market factors, transportation, and law. The continued dominance of policies such as the Governance Regulation, Energy Efficiency Directive, and Renewable Energy Directive is another significant observation. Despite the introduction of new frameworks, these anchor policies remain central to the EU's climate and energy policy. Overall, these developments reflect a progressive shift in EU climate and energy policy. The EU is increasingly embracing comprehensive, integrated policies targeting energy and emissions as well as general market and mobility standards. With clear deadlines extending as far ahead as 2040, the EU's policy direction signals a long-term commitment to achieving climate neutrality through sector-wide cooperation and effective regulatory systems (Kılkış et al. 2024).

Key brokerage actors and policy dimensions

Based on the observation of the two-mode network (Fig. 3), the network cohesion measures shed light on the structural nature of the EU policies-countries network. Figure 3 does not show temporal evolution for countries but rather outlines the current structural roles of countries across all implemented policies. The results of the cohesion analysis are shown in Table 2 below:

The density value indicates a moderate density of links within the network. Since the value is relatively low, it suggests that while some countries and EU policies are relatively well connected, many potential relationships between countries and policies remain unrealized, making the network relatively sparse.

The average distance value describes the average length of the geodesic connections within the bipartite network. It indicates that more than two steps, on average, are required to connect any two nodes within the network. This represents an intermediate level of separation, suggesting that while the network is somewhat connected, there is room for improvement. The radius of 2 indicates that the most centrally located countries or EU policies have an eccentricity of 2, meaning they are relatively close to other nodes in the network. This implies that the network is relatively efficient in terms of connectivity, with nodes being close to one another in terms of path length. A diameter of

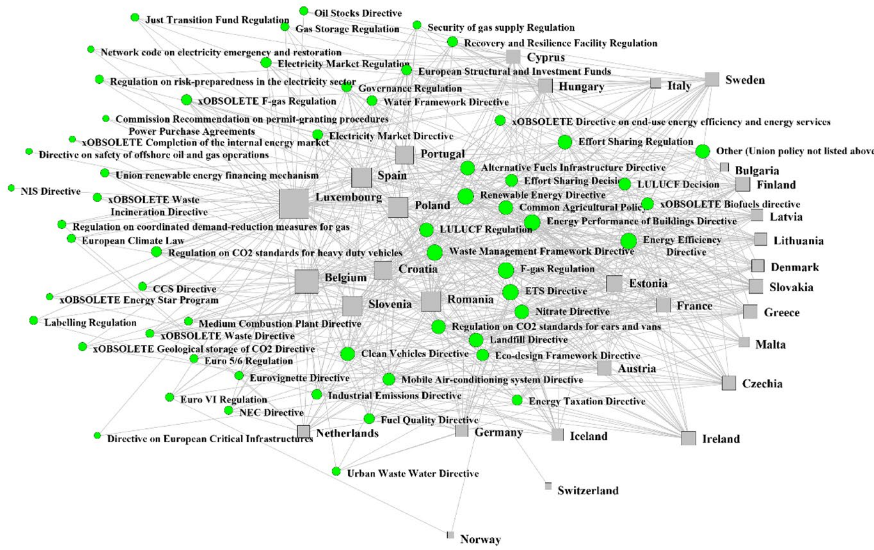

Fig. 3 Two-mode network of related EU policies (green circles) and countries (grey squares)—the size of nodes is given by betweenness centrality scores showing the most central positions in the network

Table 2 Two-mode cohesion measures of the EU policies and countries' bipartite network

Measure	Value
Density	0.373
Avg Dist	2.123
Radius	2.000
Diameter	4.000
Fragmentation	0.000
Transitivity	0.628
Norm Dist	0.728

4 signifies that the longest possible route between any two nodes in the network takes four steps. Although the diameter is not very high, this indicates some level of spread within the network, with certain countries or EU policies being relatively further apart. Moreover, a fragmentation score of 0 indicates that the network is fully connected, with no disconnected subgraphs in the bipartite network. This is a desirable outcome, demonstrating that all EU policies and nations are interconnected, forming a coherent network. Additionally, the transitivity score of 0.628 reflects a moderate level of clustering in the network. This suggests that, despite not every possible connection being present, there is a good likelihood that nations and policies sharing similar links will also be directly connected to one another. A transitivity score like this implies that the network reflects some degree of social closure, where the connections between objects are prone to forming clusters. The normalized distance measure, which provides the ratio of the actual average distance to the theoretical minimum, suggests that the network is quite efficient as far as connectivity is concerned. A value close to 1 indicates that the network is more efficient compared to the theoretical minimum distance achievable for the given node set sizes. A value of 0.728 indicates that the network is very close to the optimal level of connectivity.

The results indicate that the EU policy network and member countries are moderately interconnected, showing no network fragmentation. The analysis reveals that while the network is not dense, it is cohesive enough to demonstrate strong connections among various policies and countries, which are crucial for understanding the dynamics of EU policy implementation. Luxembourg, Germany, France, and Spain emerged as key brokers, mediating between policy areas such as decarbonization and energy efficiency. These nations promoted cross-sectoral coordination, particularly between energy and transportation policies. When comparing the centrality of actual and planned policy networks, we noted that some countries enhanced their brokerage activities. For example, newer EU members like Poland and Romania have taken on more prominent brokerage roles in energy transition policies.

The network presented in Fig. 4 shows the relationships among countries that have developed energy-related policies within the EU. The blue squares denote states with a significant brokerage role, as determined by betweenness centrality. These states act as brokers among various actors, facilitating the exchange of best practices and the implementation of policy actions within the network. States shown as gray squares play a lesser role in the policy implementation process due to fewer strong connections in the network. This figure emphasizes the broker states that coordinate energy measures and provides evidence that some countries are tasked with ensuring coherence and optimal implementation of energy-based policies at the European level.

Sectoral interdependencies

As shown in Fig. 5, the sectoral network analysis identifies that the transport and energy consumption sectors are central policies within the policy interplay network. These sectors have been highly active in brokerage, indicating their embeddedness with other policy areas and significant exposure to regulation. Government agencies and ministries responsible for these sectors serve as key bridging actors between EU-level and national policies. The Transport, Energy Consumption, Energy Supply, and Agriculture sectors have been identified as the most central in the policy network under study, indicating their sensitivity to climate policies and their ability to trigger systemic changes across the EU. In particular, the transport sector, which has the highest centrality score, has a high level of exposure to climate regulation, with significant implications for sustainable

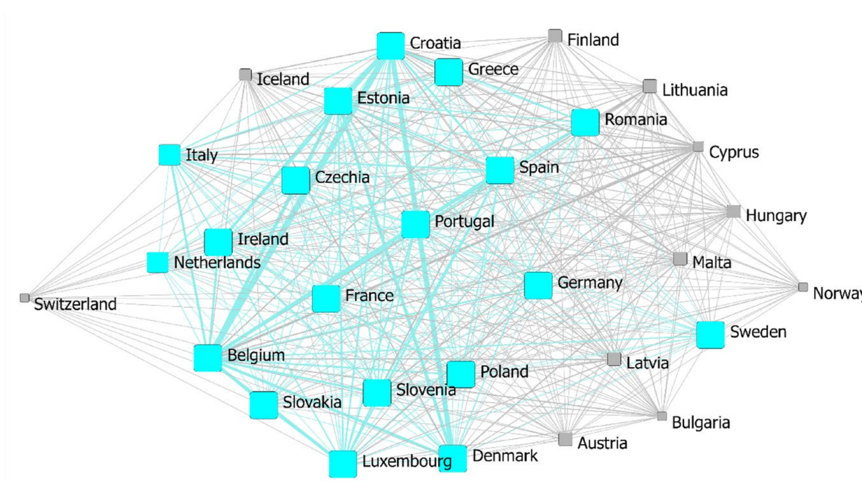

Fig. 4 One-mode network visualization of countries implementing EU energy-related policies. The size of the nodes is determined by betweenness centrality scores, highlighting broker countries within the network structure (blue squares)

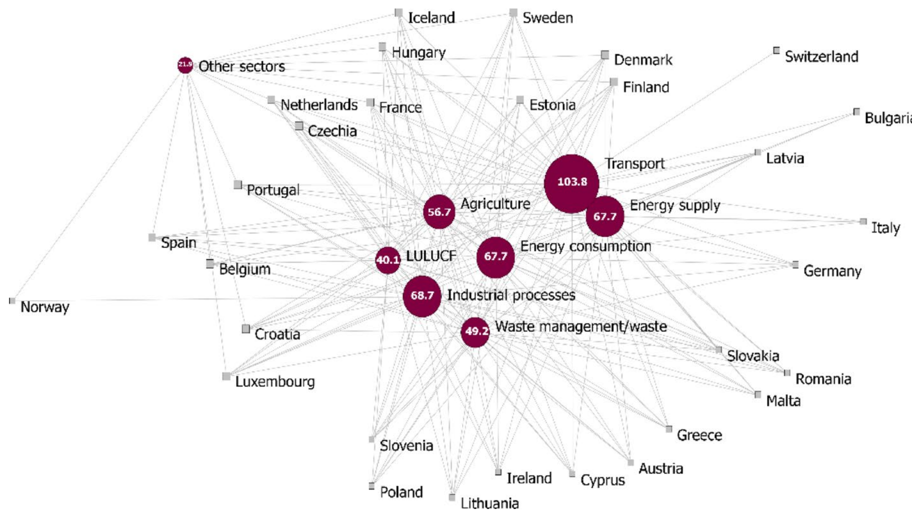

Fig. 5 Two-mode network illustrating the connections between countries (grey squares) and the various sectors affected by the policies they have implemented (colored circles), with node sizes determined by betweenness centrality scores

development and the green transition. Institutional actors involved in policy implementation exhibited intense brokerage activity, facilitating connections across various policy areas such as energy, waste, and land use. The leading nations most active in these areas include Belgium, Croatia, Denmark, Estonia, Finland, France, Hungary, Iceland, Luxembourg, the Netherlands, and Portugal, all of which have played an essential role in adopting and implementing EU legislation at the domestic level. Additionally, the LULUCF (Land Use, Land-Use Change and Forestry) sector and industrial processes are characterized by a high level of brokerage activity, underscoring the importance of land use and industrial greenhouse gas emissions within the environmental policy context. The waste management industry and other sectors of the economy were impacted by such policies, which further validates the importance of an integrated approach to designing climate policies at the European level (Fejzic and Usher 2025).

Limitations of the study

While this research provides valuable insights for the EU climate and energy policy network, it has limitations. First, the analysis relies on existing policy data and recorded network linkages, which may not capture all relevant policies or actors, particularly those that have emerged or have had less documented influence on the EU climate agenda. Second, the two-mode network analysis employed in this research primarily focuses on the relationship between EU policies and states, potentially overlooking important considerations regarding the roles of sub-national actors, NGOs, or private sector entities on policy outcomes. Third, the use of betweenness centrality as a key measure for identifying broker countries may obscure the more nuanced roles that countries play, including their political or economic influence beyond their connections in the network. Finally, the limitation of not addressing exogenous events, that is, international climate agreements or technological breakthroughs—that could significantly change the future trajectory of EU climate policy is an additional limitation of the analysis. Together, these limitations highlight the need for ongoing studies to expand and deepen our understanding of the EU climate policies network.

Policy implications

The study of the EU climate and energy policy network provides a revealing snapshot of EU policy evolution over time, illustrating how policies evolve and respond in relation to others under increasing pressure to decarbonize and transition energy. The phasing out of older policies and the introduction of new ones, as reflected in the representation of adopted and planned policies, signifies a shift towards more comprehensive and multidimensional frameworks. Our findings contribute to the growing body of policy network literature by providing empirical evidence on the functions of brokers in advancing EU climate and sustainability goals (Bellantuono et al. 2022). Additionally, this study provides policymakers with valuable insights on enhancing inter-organizational cooperation and streamlining climate action measures. Understanding these networks is essential to ensure that EU climate policies not only achieve their intended impacts but also foster a more collaborative and resilient policy climate in the future. Future policy frameworks must focus on cross-sector coordination, unified action at both the national and EU levels, and adaptability to emerging challenges and opportunities in addressing climate change (Holme and Rocha 2023). The results of this study also demonstrate the growing integration of EU climate and energy policy. Although core policies like the Renewable Energy Directive, Energy Efficiency Directive, and Governance Regulation are still at the center of policy-making, the development of new frameworks - such as market rules, clean mobility rules, and climate law -indicates a shift toward an increasingly integrated, sector-comprehensive policy regime. This evolution illustrates a more integrated, system-wide vision for sustainability, ensuring that multiple policy areas collaborate to drive EU-wide transformation toward climate neutrality. Future policy will clearly need to evolve from existing foundations, incorporating new areas such as transport and market forces to ensure a holistic approach to climate action (Grajales Noreña et al. 2024).

Another key finding of the research is the increasing prominence of brokers in the EU's climate policy network. Core states, such as Luxembourg, Germany, France, and Spain, have taken on the role of primary brokers that coordinate across sectors and balance national interests with EU-wide ambitions. These states play a crucial role in mediating between different policy domains, especially in the intersection of transport and energy policies. The emergence of newer EU members, like Poland and Romania, as broker states signifies policy leadership and exemplifies the shifting dynamics within the EU. Effective policy implementation will rely on the ongoing involvement of broker states in guiding and orchestrating the efforts of other member states, ensuring that no country is left behind in the transition to a sustainable future (Sovacool et al. 2020).

The sectoral interdependencies in this analysis highlight the central role of agriculture and transport within the EU's climate policy framework. These sectors are pivotal to the EU's decarbonization ambitions, often acting as intermediaries between energy policies, land use policies, and overall climate targets. Given their sensitivity to climate policy, the agriculture and transport sectors must be prioritized in future policy development to ensure they are effectively oriented toward emissions reduction. Because of their importance, these sectors should be supported with targeted policies that empower them to lead efforts in helping the EU achieve its climate objectives (Kök et al. 2025). The frequent brokerage roles in these domains also highlight the need for ongoing cross-sectoral interaction and cooperation to align interests across policy domains and ensure effective policy implementation (Pindaru et al. 2023).

From a policy perspective, the findings suggest that EU energy and climate policies should continue to strengthen interlinkages between various sectors. Decision-makers must prioritize creating synergies between energy, transport, and agriculture policies to achieve a more coordinated approach to climate action (Nita et al. 2022). For instance, improving coordination between energy and transport policies could promote a faster transition to clean mobility, while incorporating agricultural policies into broader climate strategies would enable the sector to contribute to emissions reduction. The emergence of Poland and Romania as key brokers indicates that regional considerations in policy development are necessary to allow all member states—regardless of size and political influence—a seat at the EU's climate table. Finally, our empirical analysis does not address the effectiveness of these policy instruments, which we will explore in future studies, in order to gain a more accurate understanding of the brokers that actually implement climate policies and promote effective sustainability transitions (Agan 2024).

Lastly, the EU is heading towards an ever more integrated and coordinated climate and energy policy regime (Blind 2024). By fostering stronger linkages among policies, maintaining the engagement of key broker states, and addressing interdependencies at the sectoral level, the EU can achieve a more cohesive and effective climate policy. The emerging trend towards unified, multi-dimensional policy is the crucial next step toward the EU's long-term climate goals (Wang et al. 2024).

Conclusion

The research indicates a trend toward more integrated and comprehensive policies, reflecting an increasing recognition of the interconnected nature of climate action, energy efficiency, mobility, and market regulation. These findings contribute to the existing literature on policy networks and highlight the role of brokers as intermediaries in implementing EU climate policies. Brokers are essential for any EU climate policy implementation, bridging the gap in knowledge and effort between actors to facilitate effective sharing of information and resources. Our findings have significant implications for providing advice to policymakers advancing EU climate governance by advocating for the strengthening of brokerage networks through institutional support and stakeholder involvement. These dynamics should be documented to ensure that EU climate policies not only achieve their intended outcomes but also build consistency and longevity in future policies. Future research should continue to observe the evolving policy landscape concerning key players, sectors, and contemporary governance efforts. More specifically, consolidating knowledge around brokerage networks and leveraging contemporary technologies to enable these networks would represent a meaningful advancement to enhance EU climate and energy policy.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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