frontiers | Frontiers in Climate

TYPE Original Research
PUBLISHED 09 May 2024
DOI 10.3389/fclim.2024.1386061

OPEN ACCESS

EDITED BY
Eric Biber,
University of California, Berkeley,
United States

REVIEWED BY
Sebastian Sewerin,
National University of Singapore, Singapore
James Jackson,
The University of Manchester,
United Kingdom

*CORRESPONDENCE
Valeria Zambianchi
valeria.zambianchi@kuleuven.be

RECEIVED 14 February 2024
ACCEPTED 17 April 2024
PUBLISHED 09 May 2024

CITATION
Zambianchi V and Biedenkopf K (2024) Interactions within climate policyscapes: a network analysis of the electricity generation space in the United Kingdom, 1956–2022. *Front. Clim.* 6:1386061.
doi: 10.3389/fclim.2024.1386061

Interactions within climate policyscapes: a network analysis of the electricity generation space in the United Kingdom, 1956–2022

Valeria Zambianchi[1,2]* and Katja Biedenkopf[1]

[1]Leuven International and European Studies, Faculty of Social Sciences, KU Leuven, Leuven, Belgium, [2]Copernicus Institute of Sustainable Development, Faculty of Geosciences, Utrecht University, Utrecht, Netherlands

The systems of policies impacting climate change mitigation are complex. Yet, to date, we have limited conceptual and empirical knowledge on the dynamics within these. We address this gap by employing a systems lens to untangle the interactions between the policies affecting climate change mitigation in the electricity generation space. We conceptualise climate policyscapesfor electricity generation as systems populated with policies whose means impact decarbonisation in the electricity generation space. The impacts under analysis include both support and obstruction of climate change mitigation. We analyse the evolution of the UK climate policyscape from 1956 to 2022. Methodologically, we combine qualitative content analysis and network analysis. We populate the policyscapes with pieces of legislation in the electricity generation space and employ qualitative content analysis to identify the policy means affecting climate change mitigation. Our network analysis of the 2022 climate policyscape reveals that policies hindering climate mitigation remain largely present, which renders the climate policyscape incoherent. We show that policies supporting mitigation are more likely to behave as a group than policies hindering climate mitigation. Climate policies tend to be adopted as packages, whilst fossil policies remain a steady process throughout the history of the UK climate policyscape.

KEYWORDS

climate change mitigation, network analysis, climate policy, institutional complexity, climate change governance, United Kingdom, electricity generation

1 Introduction

Mitigating the climate crisis requires profound societal transformations (Schellnhuber, 1999; Feola, 2015; Biermann et al., 2016; IPCC, 2018; Moore et al., 2021). These range from the phase out of fossil fuels to the uptake of ready-to-deploy renewable energy technologies. Policies, such as legislative and executive instruments, have an undisputed role in advancing these transformations (Eskander and Fankhauser, 2020; Peñasco et al., 2021). A significant proportion of the polices that impact the climate mitigation process is not specifically intended as climate policies by policymakers (Green, 2021a). Climate change mitigation is affected by a wide range of decisions, e.g., policies aiming to maintain the fossil fuel industry, phase fossil fuels out, limit CO_2 emissions, and uptake ready-to-deploy renewables[1], amongst others. This can be problematic for the analysis of climate change mitigation. Considering solely those climate policies which are explicitly intended as such can lead to the exclusion of relevant instruments with severe positive or negative impacts on the overall mitigation process. This paper takes this observation as a starting point by painting the broad picture of policies affecting mitigation, both supporting and limiting CO_2 emission reduction, as well as the extent to which they interact with each other.

Complexity theory contends that a system is greater than the sum of its parts. Applying this theory, Earth system governance[2] scholars argue for the importance of painting the macro-picture of institutions impacting climate action. This step is crucial to understand how the components of a socio-institutional system (such as policy systems) co-exist together (Young, 2010; Macintosh and Wilkinson, 2016; Pattberg and Widerberg, 2019; Biermann and Kim, 2020; Hickmann et al., 2020; Leach, 2021). Focusing solely on policies explicitly intended as "climate policies" by policymakers offers a skewed picture, limiting our knowledge of how jurisdictions comprehensively address climate change mitigation with a broader set of policies (Capano and Howlett, 2020). Additionally, we know little about how these policies interplay with each other (Kosow et al., 2022; Maor and Howlett, 2022). This paper contributes to the concepts of climate policyscapes and policy interactions in the form of overlap-interactions between policy means, i.e., how a policy defines the way to achieve a goal (Sewerin et al., 2022). We apply network theory to the study of the electricity generation space in the United Kingdom (UK) from 1956 to 2022. This paper untangles the system of policies affecting climate change mitigation, either supporting or hindering it. To this end, we address the following research question: *How has the UK climate policyscape for electricity generation evolved between 1956 and 2022, and how do its individual components interact?*

By exploring the electricity generation space in the United Kingdom, this study moves beyond the explicit intent by policymakers in defining climate policies and analyses the broad climate policyscape affecting mitigation. The analysed policies are laws which regulate fossil fuels expansion, uptake of ready-to-deploy renewable energy technologies, and overall CO_2 emission reduction in the space of electricity generation. In doing so, legislative documents are the unit of analysis for a historical large-N analysis. Our sample begins in 1956 when the UK's first environmental law (the Clean Air Act) was enacted (Mosley, 2017), and includes legislation both supporting and hindering mitigation. This approach differs from previous studies on policy mixes as we populate the system of policies with both those for and those against mitigation (Ossenbrink et al., 2019). We specifically consider policies addressing the expansion or phase out of fossil fuels (i.e., coal, gas, and oil), the phase out of fossil fuels, the uptake of ready-to-deploy renewables (i.e., solar photovoltaics, offshore and onshore wind), and the decrease of CO_2 emissions. Overall, we place climate change mitigation in the electricity generation space at the centre of the study rather than explicit intent of policymakers in defining which ones are "climate policies"(Cashore and Bernstein, 2022). Methodologically, we employ a combination of qualitative content analysis of legislative texts and network analysis. In doing so, we trace the history of climate policyscapes in the electricity generation space from 1956 to 2022 and explore the interactions within them by analysing the content of 231 legislative documents. The results of the content analysis offer the basis to determine nodes and links for the network analysis, which unveils the extent to which legislation (mis)aligns within the 2022 climate policyscape. We identify bilateral overlap-interactions based on the degree of alignment between policy means, such as designations of actors receiving subsidies to deploy solar PVs or paying a carbon price. This allows us to categorise the overlap-interactions as *climate-symbiotic* and *fossil-symbiotic*, according to how the overlap-interaction addresses decarbonisation. The findings of this study show an important level of incoherence in the climate policyscape. Yet, *climate-symbiotic* overlap-interactions tend to be more clustered with than *fossil-symbiotic* ones. It suggests that climate policies are designed to operate together. This finding is echoed by the fact that climate policies tend to be adopted collectively at once, whilst fossil policies are steadily adopted over time.

The contribution of this study to the literature is threefold. Theoretically, we expand the literature applying concepts from systems science on interdisciplinary environmental social sciences. Contending that institutional systems are complex entities (Kim, 2013); it is fundamental to study the relationships between the components of such systems (Pattberg and Widerberg, 2019). We draw from network theory to explore the maze of overlap-interactions between policies affecting climate change mitigation. This contribution is mirrored methodologically. Applying network analysis to climate change governance is a promising avenue to explore the policy architecture at multiple governance scales. A growing number of studies employ this method (Kim, 2013; Pattberg and Widerberg, 2015; Milhorance et al., 2020a; Leach, 2021). There are calls to pursue such research also at other governance scales (Pattberg and Widerberg, 2019). Drawing from complexity theory, we ought to unravel the range of dynamics connecting policies with each other whilst being part of a broader system of policies (Young, 2010; Coupette et al., 2021). Yet, there is limited research on climate change mitigation governance at national level with network approaches. Lastly, our empirical contribution stems from the novelty of analysing policies that both support and limit mitigation. Literature encourages research attending the spectrum of policies impacting climate change mitigation, both those aiming to decarbonise and those preventing decarbonisation (Capano and Howlett, 2020; Sewerin et al., 2022). This is guided by frameworks to delineate policy mixes according to the impacts that policies have on a specific policy area

1 Models show that it is possible to halt CO_2 emission and mitigate the climate crisis by adopting ready-to-deploy renewable energy technologies and phasing out fossil fuels. Scholars argue that geoengineering and carbon removal technologies significantly pose the risk of mitigation deterrence (Zickfeld et al., 2023; Brad et al., 2024). Accordingly, this study focuses on ready-to-deploy technologies (Allwood et al., 2019).

2 Rather than employing the term "environmental governance," this study follows Biermann's argument that "Earth system governance" allows us to overcome the dichotomy of humans vs. nature, to instead focus on socio-ecological dynamics (Biermann, 2021). Against this backdrop, we refer to Earth system governance.

(Ossenbrink et al., 2019; Rogge and Stadler, 2023). Yet, these calls have limited empirical responses (e.g., Schmidt and Sewerin, 2019; Kosow et al., 2022). These empirical assessments, however, do not include multiple policies that limit the impacts under analysis due to empirical constraints in the study of large-N policy mixes (Howlett and Del Rio, 2015; Sewerin, 2020). As such, rather than siloing policies supporting or limiting mitigation, we respond to these calls by applying ecological epistemology to the study of institutions. So, we analysed both policies as a single policy system populated as a large-N study (Leach, 2021). We consider the overlap-interactions between policies and conceptualise the policy landscape as a heterogeneous space with a diverse policy population.

Electricity generation is a relevant example of a policy landscape where it is necessary to unveil antithetical policy goals (Stokes, 2020). It is a space where measures aiming for CO_2 emission reduction co-exist with policies providing subsidies to the fossil fuel industry. For example, Norway, one of the early adopters of carbon taxes, also has significant tax breaks to the oil industry (Lepic, 2020; Farstad et al., 2022). This observation suggests that contradictory messages inhabit the electricity space. The UK offers an ideal case study to unravel these dynamics in the electricity generation space.[3] It is both a high-emitting jurisdiction and considered at the forefront of climate change mitigation policy (Lockwood, 2021; Stephenson and Allwood, 2023). It was one of the first countries to adopt climate legislation, whilst expanding its deployment of ready-to-deploy renewables, particularly of offshore wind (Lovell et al., 2009; King, 2018). Yet, a number of policies supporting the oil and gas industry are in place aimed at expanding fossil fuel extraction onshore (coal mines) and offshore (oil and gas exploration) (Allwood et al., 2019; Somerville, 2021; Harvey, 2022). Hence, the UK presents a constellation of policies underpinning the progress toward halting CO_2 emissions, yet little is known about how these competing policies interact with each other.

We proceed as follows. Drawing on the literature on policy mixes and policyscapes, institutional interaction and policy coherence for Earth system governance, we propose a framework to study the system of policies affecting climate change mitigation (Section 2). We then summarise how network theory contributes to and enriches the study of interactions within climate policyscapes (Section 3). Next, we built our novel network model, populated with legislative (Section 4). Section 4 also outlines how we operationalised overlap-interactions in climate policyscapes to conduct a network analysis. We then report central results (Section 5) and discuss these findings in the context of Earth system governance for climate change mitigation (Section 6).

3 In the UK electricity generation has historically been highly centralised because of the high bureaucratisation of the sector (Valenzuela and Rhys, 2022; Pearson and Watson, 2023). The behaviour of these actors is affected by the adopted legislation, which intend to place regulatory pressure and affect how electricity is generated – including in terms of which fuel is used, consequently impacting the emission of CO2. Thus, the electricity space is populated with a wide array of dispersed, yet intricate policies. To this end, studying such cases bridges the above-mentioned theoretical and methodological relevance with empirical significance necessary to advance climate change mitigation.

2 Climate policyscapes and interactions

As complex systems, climate policyscapes are greater than the sum of their parts. For example, the simultaneous adoption of two climate policies can produce non-linear effects beneficial to climate change mitigation, whilst the co-presence of a policy in support of fossil fuel extraction and a policy to deploy renewable energy technologies can have undermining effects to decarbonisation. As such, there is limited knowledge on the link between the components within the climate space. To address this knowledge gap, we build a conceptual framework using various bodies of literature. First, we focus on the concepts of policy mixes and policyscape for climate change mitigation. Second, we discuss overlap-interactions between policies, zooming in on coherence as link between policies by touching upon the concept of policy coherence.

2.1 Setting the scene: climate policyscapes

A growing body of literature explores the presence of multiple policies addressing environmental concerns in the same context. Policymakers adopt, for example, investments, regulations, taxes, and more policies to decarbonise a jurisdiction. This observation highlights that most high-emitting jurisdictions have sets of policies aiming to mitigate climate change. Thus, scholars contend that policies exist and operate as part of a policy-mix or policyscape (Wurzel et al., 2019; Therville et al., 2020; Zabala, 2021; Elsässer et al., 2022). This argument reflects both theoretical and empirical observations. From a theoretical perspective, addressing socio-ecological crisis, e.g., climate change, requires more than a single policy (Gunningham and Sinclair, 1999). Indeed, the complexity of climate change and its mitigation calls for a multitude of changes in societies, hence societal transformations (Feola, 2015; Moore et al., 2021). For example, neoclassical environmental economists consider policies pricing CO_2 emissions essential to decarbonise societies (van den Bergh and Savin, 2021; van den Bergh and Savin, 2023; van den Bergh et al., 2024). Further evidence from other scientific fields, however, demonstrates that unless carbon pricing is paired with other policies, it has limited impact on decreasing CO_2 emissions (Rosenbloom et al., 2020a,b; Lilliestam et al., 2021; Green, 2021b). Similarly, only adopting policies targeting individual behavioural change produces insufficient results in mitigating the climate crisis (Bhardwaj et al., 2020). Overall, halting the climate crisis calls for societal transformations engaging with various actors from a diverse range of sectors, which requires a configuration of multiple policies (Hanna and Victor, 2021).

National governments recognise the need for diverse climate mitigation efforts. Most countries are addressing climate change mitigation with a policy portfolio populated with more than one policy. Several policies have been adopted and implemented over the years (Eskander and Fankhauser, 2020). As a result, more than one policy is in effect at the same time and in the same place. Empirical studies reveal the evolution of policy mixes by unfolding their population overtime. Scholars pursue large-N studies that quantify the evolution of policy population in jurisdictions by proposing measurements of policy density, i.e., the number of policies in a policy mix (Schaffrin et al., 2015; Schmidt and Sewerin, 2019; Burns et al., 2020). The results from these studies illustrate how jurisdictions have been layering climate policies over time, especially by adopting multiple policies at once. This suggests that climate policies are adopted in groups and simultaneously. Yet, it does not delve into the dynamics within such systems of policies. Thus, it is crucial to untangle the population of policies affecting the climate mitigation process and the modes of interaction between policies, as well as their effects.

Scholars propose different methodologies to delineate a system of policies and define its population. Ossenbrink et al. (2019) argue that the boundary of a policy mix depends on a conceptual choice of the researcher. Using this approach, a researcher delineates a mix according to the assemblage defined by policymakers (top-down) or the impact on the policy problem addressed (bottom-up) (*ibid.*). The top-down approach populates mixes with policies that policy-makers cluster together in policy plans or packages, whilst the bottom-up approach results in mixes of policies that have an impact on the specific issue. In environmental and climate research, however, most empirical studies align with a top-down or a top-down and bottom-up hybrid delineation and population of policy mixes (*ibid.*), with very few exceptions of studies employing a bottom-up approach (e.g., Schmidt and Sewerin, 2019). There are, however, calls to employ bottom-up approaches to unfold policy mixes and understand the policy-population addressing environmental issues (Sewerin, 2020). Scholars agree that there are empirical constraints in researching policy mixes due to the large-N of units of analysis when a policy mix is delineated from the bottom-up (*ibid.*, Howlett and Del Rio, 2015). Hence, there is limited knowledge on policy mixes focusing on climate change mitigation that are populated also by policies that are not to via top-down or hybrid approaches climate policy mixes. This is a critical point to address. For example, social policies and industrial policies have an impact in how societies transform to mitigate the climate crisis (Meckling, 2021; Hirvilammi et al., 2023). These policies can impact CO_2 emissions by promoting the training of workers in the renewable energy industry instead of the fossil fuel industry. Nevertheless, their lack or limited inclusion into top-down climate policy mixes by policymakers often results in excluding these policies from analysis. Policies impact mitigation regardless of how they are assembled by policymakers, yet limited research undertakes this epistemology of climate change mitigation (Harcourt, 2018). This has created a gap both in the conceptual and empirical literature.

Policies collectively exist and behave as a system, meaning they are more than the sum of policies. As such, they should be studied as part of a mix or policyscape rather than as single entities (Gunningham and Sinclair, 1999; del Río and Cerdá, 2017; Kern et al., 2019; Rosenbloom et al., 2020a). Researching systems of policies requires understanding the interplay amongst policies, which echoes network theories from complexity sciences (Pattberg and Widerberg, 2019; Leach, 2021). Importantly, the assessment of mixes or policyscapes is not the equivalent of merging the assessments of the policies comprising the system (Orsini et al., 2013; Capano and Howlett, 2020). Therefore, studying systems of policies calls the analysis of policy interactions. Whilst there are numerous studies progressing the conceptual understanding of mixes (Rogge and Reichardt, 2016; Schmidt and Sewerin, 2019), there is limited attention to the links and connections between policies (Bouma et al., 2019; Capano and Howlett, 2020). To understand how multiple policies co-exist and operate together in the process of climate change mitigation, it is crucial to investigate interplays between the policies as well. Overlooking this aspect poses the risk of assuming that a system of policies is equivalent to the sum of various policies. Untangling various links between policies allows us to paint a macro-picture of the institutional dynamics affecting the mitigation of the climate crisis.

To explore how policies are connected with each other, this study turns brings together the concepts of policy mixes and policyscapes (Gebara et al., 2019). Scholars in the environmental social sciences attend the study of policyscapes as a "composition of policies 'in the mix' [whose analysis is focused on] how they interact to mutually shape each other's effectiveness in a landscape" (*ibid.*, pg. 187). This concept allows to expand the study of policy mixes by focusing on interactions within a landscape addressed by a composition of policies. As such, researching a policyscape includes the analysis of a policy mix with an interaction-oriented lens, which remains understudied in the literature. Our study concerns the interactions between policies affecting climate change mitigation in the electricity generation space of the UK, which is the landscape under analysis. Thus, we will refer to the *climate policyscape* to represent the multiple policies co-existing in the same landscape and affecting climate change mitigation (Barton et al., 2013; SoRelle, 2016; Therville et al., 2020). In line with the policy mixes literature, a climate policyscape is defined from the bottom-up and populated by all the policies affecting the mitigation process in the electricity generation space. The dynamics occurring within a policyscape include also longitudinal connections between policies (*ibid.*; Ptak et al., 2023). By employing a historical overview of policyscapes, it is possible to capture an evolutionary macro-picture of the climate policyscape. This, however, remains understudied in the Earth system governance literature. Thus, it is important to explore the history of climate policyscapes, including how these policies interact with each other.

2.2 Overlap-interactions to untangle climate policyscapes

Elements of a system link with each other via a range of different modes of interaction (Meadows, 2008). Classic literature on the institutional analysis unpacks institutional interactions across the global climate and energy regime complex. Institutional interactions are defined by Sanderink & Nasiritousi (2020, p. 3) as "situations in which the policy processes, knowledge, norms, or functions of two or more institutions are connected". Scholars have explored various channels through which institutions interact to develop different taxonomies of institutional interactions. Young (1996, 2002) argues that attention should be focused on the channels through which interactions emerge and evolve, e.g., via pursuing a common goal (political interactions) or by intersecting on the ground at the implementation stage (functional interactions). Stokke (2001) and Oberthür and Gehring (2006) build upon these and expand on further channels through which institutions connect. These studies highlight how the presence of a mode of interaction between two institutions does not mean that the same two institutions interact also via other channels. For example, two institutions can politically interact because they address the same goal in their official documents, but do not functionally interact at the impact level – or vice versa. Hence, it is important to unveil multiple ways through which institutions interact with each other, also when they are not part of a top-down assembled arrangement. This argument applies also to the study of policy interactions, as policies can connect with each other in different ways.

Research on interactions mostly considers global systems. A growing body of literature studies the climate-energy nexus and the Sustainable Development Goals (SDGs) by applying the concept of interactions (Nasiritousi et al., 2020; Sanderink, 2020; Zelli et al., 2020; Bogers et al., 2022; Coenen et al., 2022). Such interactions are identified by the degree of coherence between different elements of global socio-institutional systems. There is research assessing the interactions between SDGs (Tosun and Leininger, 2017), SDGs and Nationally Determined Contributions (NDCs) (Janetschek et al., 2019), and SDGs and Transnational Climate Initiatives (TCIs) (Coenen et al., 2022). Overall, the findings from these studies illustrate the high degree of interaction between the elements of global socio-institutional systems. Yet, interactions also occur at other scales. These have been analysed in the policy mixes and policy coherence literature, which however consider systems of policies mostly delineated with top-down approaches rather than bottom-up. An example is Milhorance et al. (2020b), who investigated the coordination between the various policies in the Brazilian climate change adaptation plan. The work by Trencher and van der Heijden (2019) takes a broader perspective and research interactions within the policy mix for energy efficiency at city-level. Their analysis focuses on the intent of policymakers in the interactions between policies. Whilst these studies enrich the policy interaction literature, they attend the interactions within top-down defined systems. This poses the risk of overlooking interactions between policies that affect climate change mitigation but are not part of an explicitly intended climate plan by policymakers. Thus, it is important to understand if and how policies interact with each other also in cases they are not intendedly designed to interact, interactions which Young calls *overlaps* (1996).

Notwithstanding the overarching strategic intent of policymakers, policies can overlap with each other by sharing or clashing in their on-the-ground applications. An overlap-interaction entails that two policies interact by addressing the same means, regardless of their objectives. Thus, the two policies interact with each other on the bases of the way instruments are applied to mitigate climate change in the electricity generation space, as per Capano and Howlett's (2020) taxonomy of policy elements (Sewerin et al., 2022). The climate change mitigation field has done important research on the interactions between different national policies. Yet, these studies tend to focus on the interactions between two types of policy instruments rather than on the interactions in a system of several policies. For examples, scholars have considered how carbon pricing policies connect with innovation funding, renewable energy obligations, and other subsidies, amongst others (Braungardt et al., 2021). Other studies investigated the role of complementary policies to innovate (Pless, 2022). These, however, tend to focus solely on interactions between two policies. Therefore, it is relevant to expand this knowledge to explore the multiple interactions across a climate policyscape.

Overlap-interactions stem from both alignment and misalignment between two policy means as per their legislative texts. This approach allows us to analyse different ranges of (mis)alignment and study overlap-interactions in a climate policyscape. A climate policyscape includes a wide range of policies affecting climate change mitigation – from policies in support of the expansion of fossil fuels to those in support of decarbonisation (Green and Staffell, 2021; Peñasco et al., 2021). Therefore, there is possibility for overlap-interactions as policy alignment, and overlap-interactions as policy misalignment. Figure 1 illustrates different cases of (mis)alignment between policies. In this figure, policies A and B are policies whose means advance climate change mitigation, and C and D are policies whose means hinder climate change mitigation. When two policies supporting mitigation share their means they overlap (interaction 1 in Figure 1) and, similarly, when two policies impeding mitigation share their means, they also overlap (interaction 3 in Figure 1). Yet, when a policy in support of climate mitigation and a policy that hinders mitigation address the same issue but with an opposite mean, there is a policy clash (interaction 2 in Figure 1). A practical example would be the case of a policy aiming to place a carbon price on gas-fuelled electricity that co-exists with a policy providing financial subsidies to the gas industry. Against this backdrop, this paper conceptualises an overlap-interaction as two policies addressing the same energy source for electricity generation (either fossil fuel or renewable energy source) in their "policy mean," in line with the policy design literature. In addressing the same energy source, the two policies either support or hinder the uptake of the source.

Conceptualising overlap-interactions as modes of policy interactions echoes the concept of policy coherence (Howlett and Rayner, 2007). Policy coherence is understood as "the ability of multiple policy goals to co-exist with each other and with instrument norms in a logical fashion" (Howlett, 2019, p. 33). Accordingly, policy coherence engages with the presence of multiple policies towards achieving an impact, such as climate change mitigation. As overlap-interactions occur when policies have their means aligned, they potentially produce coherence across a climate policyscape. Coherence is an important metric in policy studies because it "enhance[s] synergies and reduce[s] conflicts between other interacting policy domains" (Nilsson et al., 2012, p. 395). As coherence requires alignment between policy means (Howlett and Rayner, 2007), it is critical to expand the study of coherence beyond top-down policy mixes and explore the degree of policy coherence across wider climate policyscapes (Kosow et al., 2022). This makes it possible to create a complete picture of the institutional structure affecting climate change mitigation.

To this end, to untangle the climate policyscape it is important to analyse the degree of policy coherence both advancing and hindering

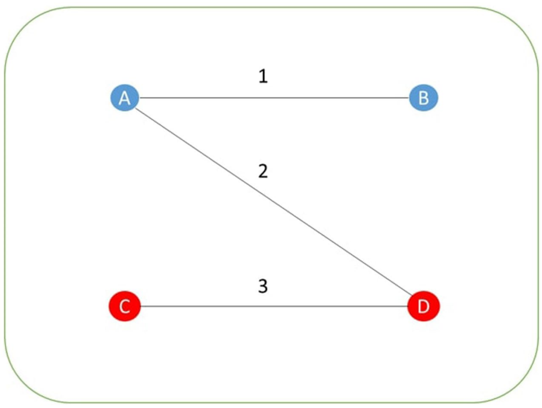

FIGURE 1
Alignment and misalignment between policies.

climate change mitigation. Yet, coherence between policies supporting mitigation is not equivalent to mitigation itself, and vice versa. Therefore, we do not evaluate the effects of coherence. Instead, we explore how coherent climate policyscapes are with reference to uptake of renewables, phase out of fossil fuels, or support of the fossil fuel industry. To do so, this study identifies the overlap-interactions between policies by employing a network lens, which we discuss in the following section.

3 Network theory for climate policyscapes

Analysing individual policies overlooks the complexity of climate change mitigation. There is burgeoning work that employs network theories to analyse Earth system governance by conceptualising socio-institutional structures as systems (Duit et al., 2010; Kim, 2013; Morin et al., 2017; Schlüter et al., 2023). It builds upon the argument that the architecture governing climate change mitigation is a complex (Macintosh and Wilkinson, 2016; Biermann and Kim, 2020; Kim, 2020; Leach, 2021). Within a complex system, institutions are autonomous elements that interact with each other, contributing to emergent behaviours with non-linear impacts on climate change mitigation (Ebbesson, 2010; Leach, 2021; Estrada, 2023). Policies are elements part of broader systems, such as climate policyscapes. Adopting a system perspective allows us to understand the relationships between policies and explore their interactions. Systems are composed of elements that interact with each other, which network theory conceptualises as nodes being connected with each other through links. Against this backdrop, framing this research with network theory allows us to untangle the complexity of climate policyscapes as systems composed of policies in interaction with each other (the nodes) via overlap-interactions (the links).

Network theory supports the study of complex systems by bringing attention to the relationships between its elements, to understand the role that each element plays within the system (Mitchell, 2006). The system is analysed as "an abstract structure capturing only the basics of connection patterns between its components" (Kim, 2013, p. 980). When network theory is applied to large-N studies, it captures the macro-picture of a system rather than delving into the processes behind the relationships between the system's elements (Coupette et al., 2021). As such, an increasing and substantial number of scholars of environmental policy and law apply network theory to the study of the Earth system governance.

When studying a climate policyscape as a network, it is important to think of the components of the system as connected via links. Researchers propose a plethora of links that operate in the Earth system governance. For example, legal citations can be used as a proxy for the presence of an interaction between international agreements (Kim, 2013; Wernli et al., 2023). Taking this approach, Kim (2013) demonstrates the complexity of the multilateral environmental agreement system by analysing the institutional interconnections with the lens of network theory. At the national level, Fowler et al. (2007) uses citations between court cases in the US to evaluate the authority of previous decisions by the Supreme Court.

It is possible to identify links between policies using social network analysis (Paterson, 2019). This network approach calls for participatory methodologies (*ibid.*; Oostdijk et al., 2019). For example, Pittman and Armitage (2019) build a governance network through interviews with different actors in coastal ecosystems, demonstrating the fragmentation of the policyscape. Recent work by Milhorance et al. (2020a) undertakes a network analysis of top-down defined policy mixes to explore the level of coordination between different policies in Brazil's National Adaptation Plan. They map the relationships between the different components of the system by assessing the interactions identified in policy documents and observed by local actors (Vallet et al., 2020).

These studies provide critical contribution to the application of network theory to Earth system governance. Yet, it is important that this body of literature identifies and evaluates policy interactions beyond plans and strategies. As demonstrated by the literature on climate policyscapes and policy coherence, policies do not exist in isolation. For example, recent work by Coenen et al. (2022) researches the interactions between climate actions and the Sustainable Development Goals with network analysis. The network is mapped by identifying co-occurrences between the system's components. Secondary sources are important data for network analysis. For example, Mazzega (2021) highlight the potential of identifying linguistic and terminological linkages across spheres of Earth system governance. This helps understand the socio-institutional dynamics otherwise overlooked when systems are delineated in a top-down or hybrid manner. The application of network theory significantly furthers the understanding of Earth system governance, including policies and planning for climate change mitigation.

The study of climate policyscapes benefits from network theory. It allows to identify different modes of interlinkages between policies (Kim, 2013). As two policies can be connected with each other through a variety of channels, it is suitable to study the range of overlap-interactions that occur between policies, amongst other modes of policy interaction. This allows us to unpack the heterogeneity of climate policyscapes. By conceptualising climate policyscape as including a broad policy population, it is also possible to investigate whether there are clusters of policies that interact primarily between each other, rather than with other policies (Stuart, 2020). To do this, the policyscape is analysed to detect spaces where a number of policies are densely connected with each other, whilst being distant from the others. This is a crucial part of the study of policy mixes or policyscapes as it overcomes the risk of studying those systems as sum of different policies, rather than as a system (Meadows, 2008). As Orsini et al. (2013, p. 27) argues, "[a] system has properties that differ from those of its constitutive part." Network theory and its methods offer a critical lens by fleshing out the relationships between policies to unveil the weight of the various elements in a climate policyscape. To this end, this research employs network theory by analysing climate policyscapes as systems composed of policies that interact with each other via overlap-interactions.

4 Data and methods

This study uses co-occurrences of fossil fuels and renewable energy technologies in legislative texts as proxies for the history of overlap-interactions across the UK climate policyscapes. To do this, we employ content and network analysis of 231 legislative policy texts. The combination of these two methods allows us to analyse qualitative data (the policy texts) and untangle their overlap-interactions, extracted from their policy means. This is a relevant mixed-methods approach because it uses text-as-data to unveil connections between elements of a system (an example of such application is Coenen et al., 2022). Against this backdrop, this methodological choice helps meet the objective of this paper. It does so by employing content analysis to populate climate policyscapes with legislative policies and identify overlap-interactions between these policies, whilst applying network analysis to unveil the pattern in how policies overlap-interact with each other.

4.1 Data collection

To populate climate policyscapes, we consulted the National Achieves of the UK and applied a search string designed to capture relevant legislation (The National Archives, 2024). We searched in the National Archives for legislative documents mentioning any of the following terms: "climate OR energ* OR electr* OR oil OR petroleum OR gas OR coal OR solar OR wind." The National Archives has the most extensive collection of UK legislation, which allows us to browse relevant legislation for this study. The results were filtered to include results from 1956 to 2022. This choice was motivated by the aim of capturing broad climate policyscapes. Using a climate policy database for our data collection would have posed the risk of us overlooking legislation relevant to the mitigation process, such as the one in support of expanding the fossil fuel industry, as well as other supporting mitigation but not explicitly assembled in top-down climate policy mixes. To do so, we screened for any legislation mentioning "climate," but also "energ*" and "electr*" to collect sectoral data relevant for this study. Adding fuels ("oil," "petroleum," "gas," "coal") and ready-to-deploy renewable energy technologies ("solar," "wind") allowed us to include key elements to halt CO_2 emissions in the electricity generation space in the dataset. Some legislation regulates these elements affecting climate change mitigation without being a explicitly intended for mitigation. Moreover, this search string allows us to include legislation that hinders mitigation by maintaining or advancing the use of fossil fuels for electricity generation. Thus, this methodology allows to align with the bottom-up approach of defining a policy mix, to consequently populate a climate policyscape for electricity generation. The result of this search string included 9,108 legislative documents, which were screened to evaluate whether they had potential impact in the mitigation process.

This research was applied to the two main forms of legislation in the UK: primary legislation (UK Public Acts), and secondary legislation (UK Statutory Instruments) (The National Archives, 2023). The specifications restricted our data to the national governance level (the UK), rather than sub-national (devolved parliaments and local governments). The search string applied to the primary legislation gave 819 results, and the one to the secondary legislation gave 8,288 results. In case of secondary legislation, we included the legislation when it met one of the following criteria:

- *Additional specification:* the secondary legislation provides practical measures to the primary legislation that are not specific in the primary legislation in terms of fossil fuels and ready-to-deploy renewable energy technologies. An example is secondary legislation that updates the terms on CO_2 savings for energy companies in electricity generation.

- *Novel measures:* the secondary legislation proposes novel legislation in terms of fossil fuels and ready-to-deploy renewable energy technologies. For example, it is secondary legislation that grants consent for building an offshore wind farm, or gas station.

The screening process undertook different considerations. We screened the results of our search to evaluate whether a piece of legislation belonged to the conceptualisation of climate policyscape developed for this study. For example, we came across legislation that addressed the administration of oil spills in high sea waters. Whilst they were relevant acts for environmental protection, they fell beyond the scope of the climate policyscape we built for this study, which focuses on electricity generation. Similarly, legislation to limit the right to protest is relevant in the study of climate change mitigation. We, however, excluded it as the scope of our study was to unfold legislation that directly speaks to fuels and technologies affecting climate change mitigation in the electricity space.

For legislation that has been amended over the years, we assessed whether the amendment was significant enough to create a new data-entry in the dataset. Our assessment of the significance of the amendment was based on to whether an amendment changed the rationale or objective or the involvement of fossil fuels and/or ready-to-deploy renewables in the legislation. Such amendments were also flagged in the legislative texts. If an amendment was not significant, the data-entry of a legislation remained one only. Yet, if the amendment was flagged as significant, we included it in the dataset.

Following these steps, the result included 231 pieces of legislation, which were organised into a novel dataset (Supplementary Appendix S1). These legislative documents were used as to the nodes within the networks of climate policyscapes.

4.2 Qualitative content analysis

We analysed the legislative documents with qualitative content analysis. The data was systematically unpacked by screening the content of the legislative pieces with the software NVivo. We coded legislative text referring to fuels or technologies that affect the process of climate change mitigation. The analysis followed a codebook developed to identify each act's characteristics based on overlap-interactions (Supplementary Appendix S2). These included:

- Type of fossil fuel addressed by the legislation (general/unspecified fossil fuels, oil, gas, coal);

- How the fuel is addressed (halt the use of the fuel, maintain or expand the use of the fuel);

- Type of ready-to-deploy renewable energy technology addressed by the legislation (general/unspecified renewable energy technologies, solar PV, wind).[4]

4 As mentioned at footnote 1, this study builds upon the epistemology that mitigating the climate crisis is possible with technologies already present. Moreover, this study focuses on the electricity generation space. As such, we consider only technologies pertinent to the generation and supply of electricity (i.e., transportation policies, policies for energy demand, etc. are not included in the study). Yet, we acknowledge that societal transformations for climate change mitigation require a set of policies beyond the scope of fuels and technologies for electricity generation.

FIGURE 2
Spectrum of policies affecting climate change mitigation in the electricity generation space.

An example of this coding practice can be found in the Supplementary Appendix S3.

We classified a policy depending on where it was positioned in the climate change mitigation spectrum (Figure 2).[5] On the left-hand side of Figure 2, *fossil policies* are the ones we interpret as hindering climate change mitigation. They do so by addressing the maintenance or expansion of the fossil fuel industry and fossil fuel use in electricity generation either in the aims of legislative documents, or in the corpus of the text. *Climate policies* are on the right-hand side of Figure 2. They support mitigation by addressing the phase out of fossil fuels, energy efficiency and conservation from an electricity generation perspective, CO_2 emission reduction, or the uptake of ready-to-deploy renewables. In case the legislation included both elements supporting and hindering mitigation, it was categorised as *ambiguous policy* (in the centre of Figure 2).

Having classified the policy population by type (climate, fossil, and ambiguous policy), we then categorised the policies according to the fossil fuel and/or renewable energy technology they address. This fuel/technology categorisation covers: (1) general fossil fuels, (2) coal, (3) gas, and (4) oil/petroleum, (5) general renewable energy technologies, (6) solar PV, (7) wind. In case a policy addresses more than one fuel and/or renewable, we classify the policy with multiple fuel/technology categories. This step allows us to unveil more granular aspect of the climate policyscape evolution between 1956 and 2022. We then ran descriptive statistics to present historical data and identify patterns in the temporal evolution of climate policyscapes.

Qualitative content analysis is an interpretative methodology, meaning it is susceptible to positionality bias (Lincoln and Guba, 1985). To address this, one author screened the legislative texts in two different rounds, 6 months apart. In doing so, they intended to triangulate the results. Throughout the first round of coding, they gained information on the climate policyscape that led to a more comprehensive picture of the policyscape itself by the end of the first coding round. Adding a second round of coding validated the initial understanding of climate policyscapes. In case of inconsistencies between the first and the second round, one author consulted secondary sources to increase their understanding of the policy. The few instances where this occurred related to fossil fuel taxation policies whose language in the legislative text was ambivalent, clarified by secondary sources. Undertaking two rounds of qualitative content analysis significantly increased reliability of the coding.

5 Policies aiming at climate change mitigation via geoengineering and carbon removal are included in climate policyscapes, however they are categorised as ambiguous policies. This is because they intend to mitigate the climate crisis with technologies that are not ready for deployment and which allow the presence of fossil fuels for electricity generation. Hence, they provide a mixed signal to the process of climate change mitigation (Brad et al., 2024).

At this point, the data was coded and organised in a dataset serving as basis to identify overlap-interactions (links in the network) and to run a network analysis.

4.3 Identification of overlap-interactions

Overlap-interactions occur when two legislative documents address the same fuel or technology in their policy-means. To establish an overlap-interaction, we considered the whole legislative text, not only the explanatory memorandum. This methodology allowed us to include overlap-interactions between policies that would not be identified otherwise. Some texts – especially energy acts and financial acts – did not mention fuels and technologies in their aims, whilst they were regularly mentioned throughout other sections of their text. By screening whole legislative texts rather than focusing on the aims identified by the government who created the item, we gained a comprehensive picture of policies populating climate policyscapes and of their overlap-interactions that would otherwise have been overlooked. Against this backdrop, we employed an interpretative research approach in populating climate policyscapes and in identifying overlap-interactions.

We also surveyed which policies were adopted each year, which were their fuel and/or technology addressed in their "policy means," and how these were targeted (i.e., supporting or limiting the uptake of that fuel and/or technology for electricity generation). When two pieces of legislation in the same year addressed the same mean(s),[6] there was the empirical basis for an overlap-interaction. The type of overlap-interaction depended on whether two legislative pieces addressed the same mean(s) (see text footnote 7) in the same manner, i.e., towards CO_2emission reduction or towards fossil fuels expansion. When the overlap-interaction is based upon addressing the same fuel or technology in support of mitigation, the overlap-interaction was coded as *climate-symbiotic*. When an overlap-interaction was based on addressing the same fuel or technology hindering mitigation, the overlap-interaction was coded as *fossil-symbiotic*. Therefore, overlap-interactions were un-directed links between legislative documents based on the co-occurrence of the same fuel and/or technology mean in two legislative texts.

We adopted a critical realist approach in our study of overlap-interactions by going beyond the scope of this binary coding to evaluate whether an overlap-interaction was beneficial or harmful to climate change mitigation (Geels, 2022). By identifying overlap-interactions we were able to discern the legislative structures of

6 In case a legislative document refers to more than one source for electricity generation, each one is coded and offers the basis for an overlap-interaction with other legislation.

climate policyscapes, rather than evaluate its effects on the ground. The temporal lens of this study allowed us to identify overlap-interactions between policies that were co-existing in the same climate policyscape, even if their adoption timeline differed. Our objective was to assess the population of climate policyscapes and its temporal evolution from 1956 to 2022. Therefore, we did not research the politics of the overlap-interactions, e.g., explaining if an overlap-interaction is intended as policy feedback, or policy sequencing, etc.

Overlap-interactions correspond to the links in the network analysis. Kim (2013, p. 980) explains that network analysis "uncovers the underlying system architecture by reducing the system to an abstract structure capturing only the basics of connection patterns between its components". Our study employs overlap-interactions as proxy for relationships between legislative documents. Identifying these overlap-interactions allowed us to untangle the complexity of climate policyscapes by abstracting a channel through which the different elements of policyscape-system interplay with each other. Therefore, identifying overlap-interactions was a fundamental methodological step to analyse the network structure of climate policyscapes.

4.4 Network analysis

Running a network analysis requires populating a system with nodes and identifying links between them. We used climate and fossil policies as nodes, and we did so by employing the respective legislative texts as population of climate policyscapes. Each year under analysis corresponded to one climate policyscape, which we populated with legislation in place that year. The links between the nodes corresponded to the overlap-interactions mentioned in the previous section (either *climate-symbiotic* or *fossil-symbiotic*). Having populated networks with nodes and identified the links between them, we analysed climate policyscapes as networks.

As an initial step towards a network analysis, we ran descriptive statistics to identify the historical evolution of climate policyscapes. First, we visualised how many policies were adopted and populated climate policyscapes from 1956 to 2022. We paid particular attention to the type of policies (climate, fossil, and ambiguous policies) and the means of these (different fuels and technologies addressed in the policy document). Second, we identified the years when the policy adoption peaked and delved into the policyscape details of these years. Specifically, we explored the presence of possible patterns in how policies interact with each other. We did so by studying frequency of overlap-interactions between climate, fossil, and ambiguous policies. These two steps allowed us to gain a macro-picture of the population of climate policyscapes and its dynamics.

Our network analysis considered the three types of nodes outlined in section 4.2: climate, fossil, and ambiguous policies. These were linked with each other through the overlap-interactions identified in the qualitative content analysis. The links were either *climate-symbiotic* or *fossil-symbiotic* overlap-interaction. To gain a deeper understanding of the diversity populating climate policyscapes, we compared different reconfigurations of the same climate policyscape. First, we considered only *climate-symbiotic overlap-interaction* in the 2022 climate policyscape. Second, we ran a network analysis that fleshed out only *fossil-symbiotic overlap-interactions* in the same climate policyscape. Third, we analysed the climate policyscape of 2022 with both *climate-and fossil-symbiotic overlap-interactions*. By running comparative exercises, we gained further insights into the plethora of dynamics within a climate policyscape.

We constructed and visualised the networks with the software R and Gephi, which provided visual and statistical insights. Measures of average degree, density, and modularity allowed us to untangle how the nodes behave within the network. We ran these in order to compare how climate and fossil policies behaved within the 2022 climate policyscape. Our qualitative content analysis did not apply metrics to the legislative texts, instead it classified them as climate, fossil, or ambiguous policies. As that analysis provided the nodes to the network analysis, the nodes were unweighted. Therefore, we removed the tie weights, and we analysed an unweighted network. As mentioned above, our network was undirected as the links under analysis stemmed from the co-occurrence of the same means rather than from a cause-effect relationship.

5 Results

Having presented our methodology, we now offer insights into the findings from the various analyses we ran. First, we show the results from descriptive statistics of the population of the climate policyscapes from 1956 to 2022. Second, we detail patterns of overlap-interactions between legislative documents over time. Finally, we illustrate the results from the network analysis of the 2022 climate policyscape.

5.1 Climate policyscapes: evolution of the population

The first results we present regard the composition of climate policyscapes and their evolution over the years. We find that the population of climate policyscapes has diversified over the years. In terms of fossil policies (Figure 3), policies in support of the oil industry have dominated the policyscape. Policies supporting the use of coal for electricity generation expanded in the 1970s and 1980s, whilst those favouring gas-generated electricity grew rapidly in the 1990s. Since the early 2010s, the adoption of policies hindering the deployment of ready-to-deploy renewables have started to populate climate policyscapes.

The composition of the UK climate policyscape is diversified across policies in support of the process of climate change mitigation (Figure 4). Policies phasing out fossil fuels and, specifically, oil expansion have been growing significantly in the climate policyscapes over the decades. Since the 1990s, there was a tendency for governments to adopt policies hindering the gas industry amongst the various fossil fuel industries. As expected, since the year 2000, (the year of adoption of the Climate Change Act, Bulkeley, 2015), the policy landscape has been increasingly populated with policies aiming to uptake ready-to-deploy renewables. Wind energy technologies have been the most targeted form of renewable energy in the climate policyscapes since the mid-2010s.

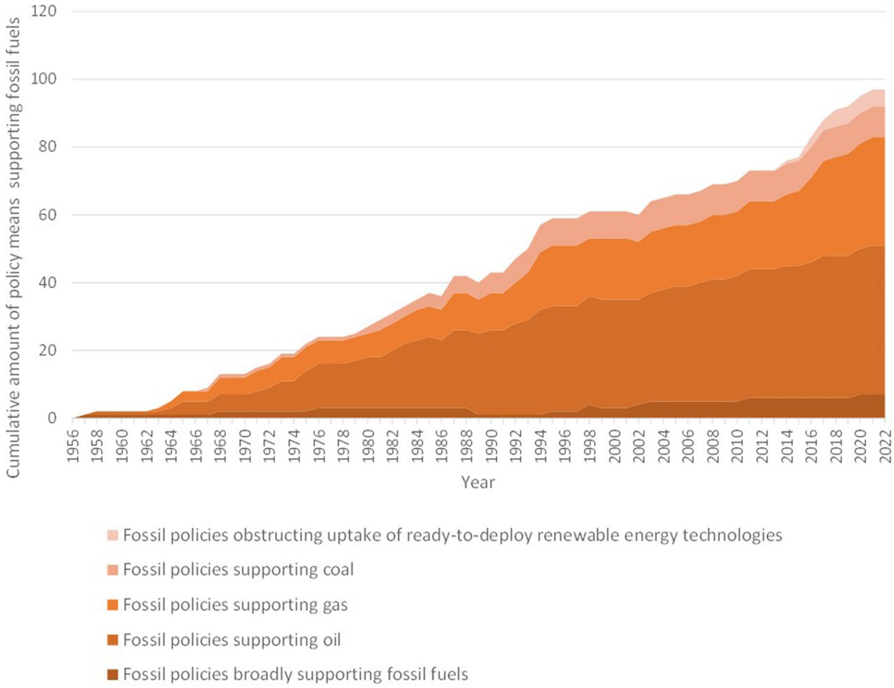

FIGURE 3
Evolution of fossil policies in the UK climate policyscape. Source: own analysis.

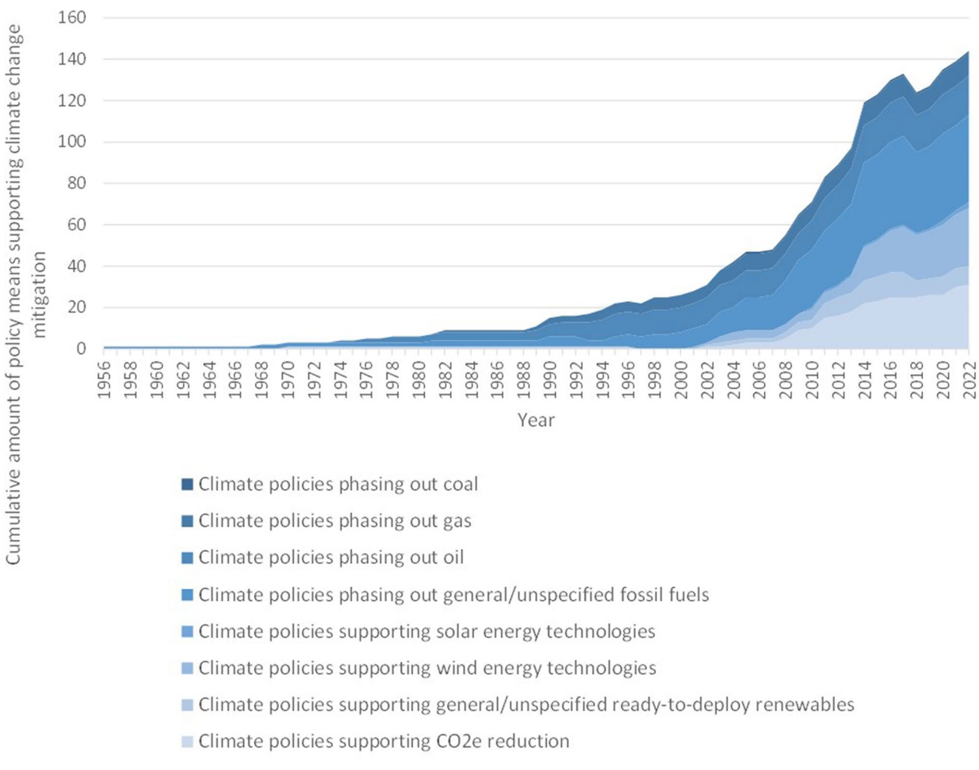

FIGURE 4
Evolution of climate policies in the UK climate policyscape. Source: own analysis.

Comparing the historical population of climate policyscapes shows that policies supporting mitigation and policies hindering mitigation now equally compose the policyscape (Figure 5). Three patterns are evident. First, fossil policies have been steadily adopted up to 2022. Second, climate policies have had an exponential growth that allowed them to equally compose the climate policyscape. Indeed, in 2010 the number of climate policies in the policyscape was higher than the one of fossil policies. This proportion has been maintained since then. Finally, the number of policies carrying mixed messages about mitigation, i.e., ambiguous policies, has been increasing since the mid-2000s. The qualitative content analysis highlights that such legislation tends to be Financial Acts or Energy Acts, which foster the fossil fuel industries whilst providing support to deploy renewables for electricity generation.

Comparing the adoption of new fossil policies with the adoption of new climate policies highlights two points. On the one hand, fossil policies have had more steady numbers in terms of policy adoption (Figure 6). On the other hand, climate policies tend to be adopted in specific moments (Figure 7). After 2008, there was a growth of adopted legislative documents supporting climate change mitigation, as expected from the Climate Change Act. For example, in 2013 the climate policy population was 70, whereas in 2014 of 85. These are significant increases in the population of a climate policyscape and, overall, we can observe that the population of climate policies steeply increases in 2004, 2008, 2014, and 2016. This suggests that a policy plan or package addressing mitigation was adopted in that year, which is reflected in the adoption of multiple legislation.

The data results presented in this section serve as basis to identify the nodes of the 2022 climate policyscape (5.3).

5.2 Climate policyscapes: overlap-interactions

Having presented our findings in terms of climate policyscapes population, we now describe the trends concerning overlap-interactions between policies. We observe the policyscape dynamics in the years with highest climate policy adoption, as these years altered the equilibrium of the climate policyscapes. In the year 2000, the UK adopted the Climate Change Program, which drove the adoption of climate policy in the following years. It is noticeable that 2004 was the first year when the policyscape was composed by more than one third by climate policies. We note that in 2008 and 2014 the rate of adoption of fossil policies relatively reduced, whilst the rate of climate policy adoption steeply increased.

In 2016 was the year the policyscape was composed of more climate policies than fossil ones. As the Paris Agreement was negotiated in 2015, this observation suggests that global contextual factors are correlated with the proportion of climate and fossil policy adoption. The Paris Agreement, which the UK signed and ratified, requires that the parties commit to climate actions by submitting climate national plans, i.e., the Nationally Determined Contributions (NDCs). Whilst the is critique on the role that NDCs have in halting the climate crisis, scholars observe a global increase in climate policy adoption post-Paris Agreement (Nachmany and Mangan, 2018; Roelfsema et al., 2020). This is the case also for the UK. To provide a context prior to the Climate Change Program (2000), we supplemented this analysis by also including the year 1990 in our descriptive statistics of *climate-symbiotic* and *fossil-symbiotic* overlap-interactions.

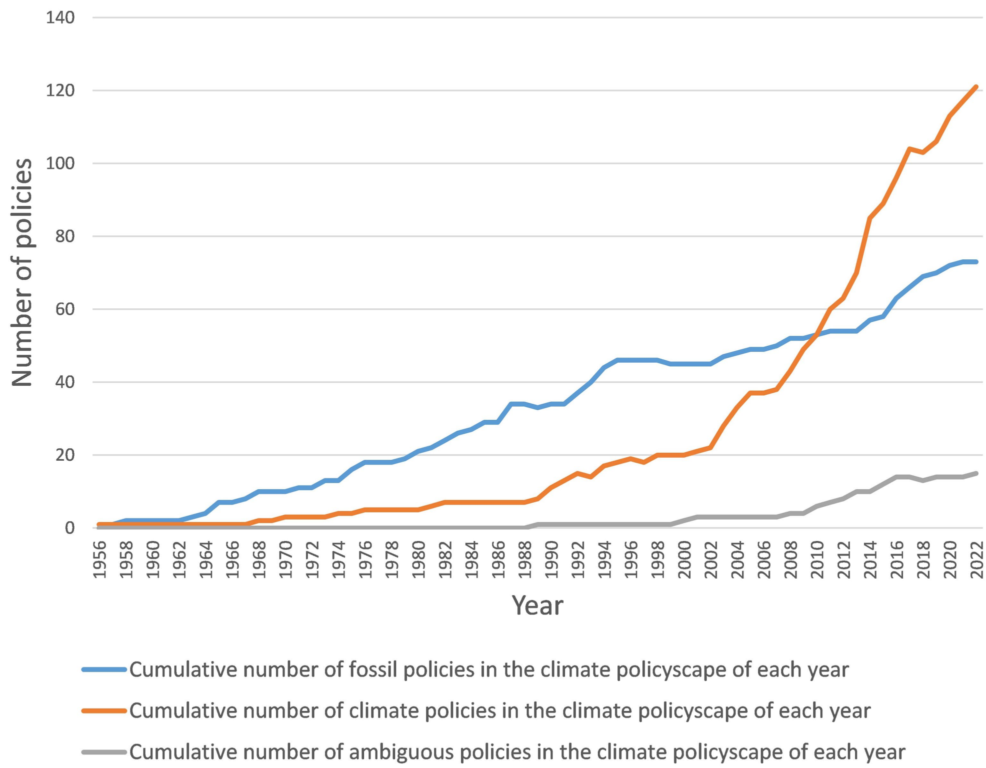

FIGURE 5
Historical evolution of climate policyscape comparing the cumulative number of climate, fossil, and ambiguous policies. Source: own analysis.

 10.3389/fclim.2024.1386061

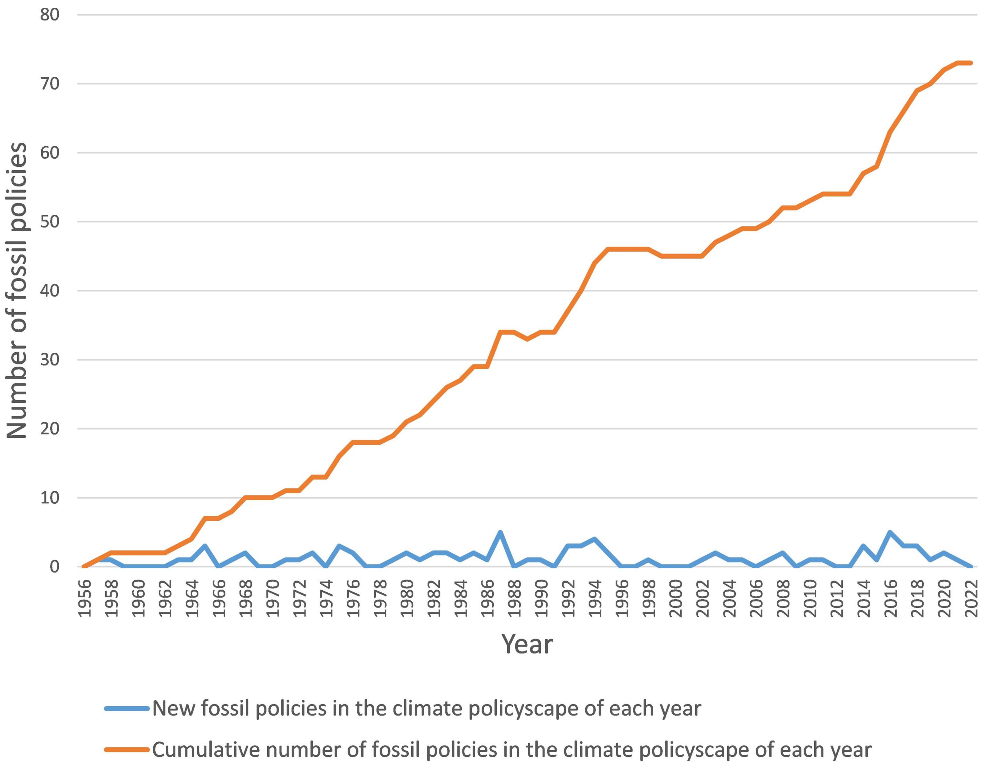

FIGURE 6
Fossil policies: newly adopted and cumulative population in the climate policyscapes 1956–2022. Source: own analysis.

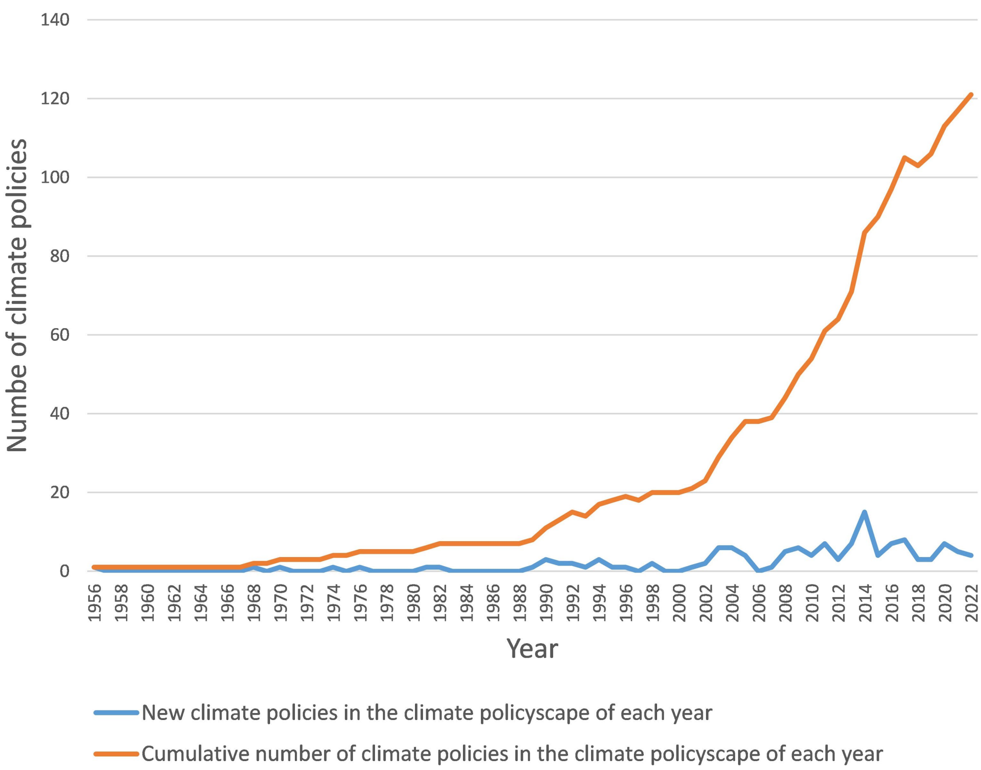

FIGURE 7
Climate policies: newly adopted and cumulative population in the climate policyscapes 1956–2022. Source: own analysis.

We choose 1990 based on our observation that it is another example of a year when climate policies have a steep adoption rate. Nevertheless, fossil policies remain dominant in the climate policyscape of that year. We conclude this descriptive analysis with the case of *climate-symbiotic* and *fossil-symbiotic* overlap-interactions in 2022 (Table 1).

It is striking that the highest number of *fossil-symbiotic* overlap-interactions falls in the scope of the oil industry. It is worth noting that gas-fuelled electricity also gained a considerable number of *fossil-symbiotic* overlap-interactions over the years, while *fossil-symbiotic* overlap-interactions for coal remain steady. *Climate-symbiotic* interactions are more diversified in their patterns. *Climate-symbiotic* overlap-interactions hindering the adoption of oil-fuelled electricity and targeting the emission reduction for electricity generation are widely present. It is also notable that the number of *climate-symbiotic* overlap-interactions for offshore wind uptake rose steeply over the years.

Having painted a general descriptive macro-picture of climate policyscapes from 1956 to 2022, we turned our attention to the dynamics within the current climate policyscape. Legislative documents and overlap-interactions serve, respectively, as nodes and links in the subsequent network analysis.

5.3 Network analysis of the 2022 climate policyscape

As discussed in section 4.4, we undertook three network analyses of the 2022 climate policyscape. Initially we analyse the network of *climate-symbiotic overlap-interactions* and *fossil-symbiotic overlap-interactions* in the climate policyscape. This allowed us to compare how diverse types of interlinkages behave within a network populated by the same nodes. We then ran a network analysis of the whole climate policyscape to untangle the dynamics of every overlap-interaction. The climate policyscape of 2022 is populated with 213 legislative documents (the nodes). They are connected by 1933 links in case of climate-*symbiotic* overlap-interactions and 1,350 in case of fossil-*symbiotic* ones.

We ran network analysis for two networks: (1) the network of *climate-symbiotic overlap-interactions* and *fossil-symbiotic overlap-interactions*. We conducted descriptive statistics of the two networks (Table 2). Our first finding of note is that the average degree of overlap-interactions in a *climate-symbiotic* network is higher than in the *fossil-symbiotic* network. This metric means that each node in the climate-*symbiotic* network has more links than in the fossil-*symbiotic* one. This finding can be explained by the content analysis of the legislative documents, which shows that legislation supporting mitigation tends to have a broader range of means. Legislation hindering mitigation, instead, either addresses a group of fossil fuels or prevents the uptake of wind energy technologies. Our second key finding was that *climate-symbiotic* overlap interactions have higher degrees of density than *fossil-symbiotic* overlap-interactions. The graph density (meaning, the number of links that exist in comparison to how many links are possible) of the climate-*symbiotic* network was 0.086, as compared to the 0.06 for the *fossil-symbiotic* network. This shows that the nodes part of *climate-symbiotic* overlap-interactions interact more with each other than the nodes part of *fossil-symbiotic* overlap-interactions. The degree of density, overall, is high for both types of overlap-interactions. We expected this result because the nodes are cohesive by design. The climate policyscape is populated with legislative documents mentioning technologies or fuels relevant to climate change mitigation. The overlap-interactions are between nodes addressing such technologies and fuels. Within this network, we detect links stemming from overlap-interactions between legislation that address the same technologies or fuels. Thus, the high degree of density is justifiable by how the network was built. Finally, *climate-symbiotic* overlap-interactions present higher rates of modularity compared to *fossil-symbiotic overlap*-interactions. This suggests that the former have denser connections between the nodes within their cluster in comparison to the ones in the *fossil-symbiotic* space. *Fossil-symbiotic* overlap-interactions, however, have a positive value in their modularity score, meaning that the nodes in these interlinkages also behave in groups within the climate policyscape, yet not at the same extent amongst *climate-symbiotic* overlap-interactions.

We then conduct network analysis of the complete climate policyscape of 2022 and conduct descriptive statistics of this network (Table 3). We observe a significant increase in modularity. This points towards a significant rate of overlap-interactions between clustered policies. Nodes part of *climate-symbiotic* overlap-interactions tend to behave in a group, similarly *fossil-symbiotic* overlap-interactions. This finding indicates that nodes connected via *climate-symbiotic* and *fossil-symbiotic* overlap-interactions operate in groups by forming clusters.

6 Discussion

Our study highlights the incoherence of UK climate policyscapes. We show that policies hindering mitigation are highly represented in climate policyscape, yet their dynamics differ from policies supporting mitigation. Against this backdrop, expanding the conceptual understanding of climate policyscapes is a promising avenue to explore the complex policy system affecting climate change mitigation.

6.1 Legislation hindering climate change mitigation, another picture of climate policyscapes?

Including fossil policies in climate policyscapes offers a novel perspective on the governance of climate change mitigation. It expands the macro-picture of the policy population affecting mitigation. Studies on policy mixes have so far taken a top-down or hybrid approach to the assessment of policy plans for renewables uptake. When fossil policies are included in the picture, we can see that they occupy a large space in the climate policyscape. Hence, the level of incoherence within the policyscape increases significantly. This poses questions on how to assess the characteristics of large-N studies of policy mixes that have been proposed in the literature, especially coherence and consistency.

We have shown that the top-down delineation of policy mixes hides the incoherence in climate policyscapes. This means that the investigation of climate policyscapes requires critical reflection: firstly, on how the policyscape or policy mix is populated; and secondly, on the variety of the policy population under analysis.

TABLE 1 Number of policy overlap-interactions in climate policyscapes by fuel and technology in selected years.

Year	Fossil-symbiotic overlap-interactions					Climate-symbiotic overlap-interactions: preventing CO_2 emissions by phasing out fossil fuels in the electricity generation space				Climate-symbiotic overlap-interactions: CO_2 emission reduction in the electricity generation space	Climate-symbiotic overlap-interactions: uptake of ready-to-deploy renewable energy technologies		
	General fossil fuels	Oil	Coal	Gas	Obstructing uptake of ready-to-deploy renewable energy technologies	General fossil fuels	Oil	Gas	Coal		General renewables	Wind	Solar
1990	0	300	15	55	0	10	15	3	0	0	0	0	0
2004	10	528	36	153	0	66	78	28	0	1	1	6	0
2008	10	630	36	171	0	210	78	28	0	10	3	6	0
2014	15	741	36	210	0	780	153	45	0	231	55	120	0
2016	15	780	36	300	3	861	171	45	0	300	66	190	0
2022	21	946	36	496	10	861	171	55	0	465	36	378	3

When looking only at policies that have been developed as part of the same plan or strategy, we are likely to see a high degree of coherency and consistency as they are planned to operate together towards a common objective. On the contrary, if we expand the mix with policies that affect the same policy mean but are not planned to work together, we see higher rates of incoherence and inconsistency (Kosow et al., 2022). The outcomes of this type of analysis are largely dependent on the way that the researcher assembles the policy system and the delineation they place on an issue, such as climate change mitigation.

The governance of climate change mitigation is fragmented across different policy domains (Biermann and Kim, 2020). When the governance of climate change mitigation is conceptualised across all the relevant institutions, there is a lower likelihood of coordination. The policies adopted by different institutions are likely to carry different messages, unless there is a top-down attempt to create coherence across the policyscape. As a consequence, policy mixes delineated by top-down approaches tend to be biased towards finding coherence, whereas bottom-up mixes tend to signal how (un) coordinated different institutions are when addressing issues such as climate change mitigation (Sianes, 2017; Kosow et al., 2022). Focusing on top-down mixes carries the risk of evaluating them as coherent without acknowledging that they are so by design. Thus, engaging with large-N studies of policies affecting climate change mitigation allows us to unveil antithetical policy arrangements that would have otherwise been overlooked by solely focusing on top-down defined climate policy mixes. Empirically challenging (Howlett and Del Rio, 2015; Sewerin, 2020), large-N studies of policies require the pursuit of text-as-data methods. These provide the methodological tools to systematically analyse extended systems of policies and unfold the dynamics within them (Taeihagh, 2017; Biesbroek et al., 2022; Dugoua et al., 2022; Goyal et al., 2022; Sewerin et al., 2023; Adipudi and Kim, 2024).

In practice, climate policyscapes are not simply a collection of climate, fossil, and ambiguous policies. They are also reflective of the ambiguous means present in individual policies. Individual policies often convey a multitude of messages at once, especially overarching policies. Energy Acts and Financial Acts are clear examples of ambiguous policies that pursue incoherent mitigation messages. They simultaneously create tax breaks for the fossil fuel industry whilst adopting a carbon price to limit the use of fossil fuels. Incoherence is embedded within such policies.

The policy means of Energy Acts and Financial Acts carry messages to a diverse range of actors with various interests. This is also true of other overarching policies such as industrial and trade policies. In order to capture and dissect the policy messages hindering mitigation, it is critical that researchers expand the pool of policies under analysis. Otherwise, there is a risk of excluding policies affecting mitigation, and considering ambiguous policies "climate" ones, whilst they foster the fossil fuel industry.

Our study shows that, although climate policies are highly interactive and operate as a cluster, the climate policyscape is similarly populated with interacting fossil policies. We contend that researching antithetical messages in individual, overarching policies demonstrates further layers of mitigation incoherence. We encourage further studies in policy areas not explicitly labelled as "climate policies" by policymakers. This helps evaluate the (in)coherence of climate policyscapes in high emitting jurisdictions.

TABLE 2 Descriptive statistics of network analyses of climate-symbiotic and fossil-symbiotic overlap-interactions in the UK climate policyscape of 2022.

Measure	Climate-symbiotic interactions	Fossil-symbiotic interactions
Number of nodes	213	213
Number of links	1933	1,350
Average degree	18,15	12,676
Graph density	0,086	0,06
Connected components	97	128
Modularity	0,569	0,239
Average clustering coefficient	0,946	0,912

TABLE 3 Descriptive statistics of a network analysis of the UK climate policyscape of 2022.

Measure	Climate policyscape
Number of nodes	213
Number of links	3,752
Average degree	35,23
Graph density	0,166
Connected components	16
Modularity	0,616
Average clustering coefficient	0,936

6.2 Insights from a historical analysis of climate policyscapes

Engaging with climate policyscapes highlights that policies for climate change mitigation exceed the first climate laws of the early 2000s. As mentioned in previous sections, we expected to observe higher rates of fossil policy adoption from the 1950s to the 1980s in comparison with the adoption of climate policies. This is reflected in how the climate policyscapes populated in these timeframes as these were the decades when the fossil fuel industry further established itself in the UK and worldwide. During this period, the fossil fuel industry gained status and the scientific community provided considerable evidence of the socio-ecological harm caused by burning fossil fuels. Nevertheless, the adoption of the Clean Air Act in 1956 shows that there were environmental concerns in the UK policy space, as the Act aimed to reduce air pollution caused by burning fuels. By comparing how a fossil timeline runs next to a climate one, we are able to see that the climate and fossil policies evolved at different rates.

A pivotal moment for climate action was in the year 2000, when the Climate Change Program was adopted (Bulkeley, 2015). Since then, we observed a rapid escalation in climate policy adoption driven by knowledge advances and the increased attention to the climate crisis globally. We also noticed that climate policies tend to be adopted in "chunks," i.e., several climate policies adopted at once (Rai, 2020). Climate mitigation is a multifaceted process, which requires encompassing societal transformations. Institutions intend to translate these into different legislative measures, also in light of the increasing degree of bureaucratisation of climate action. Policymakers tend to plan climate policy packages rather than constantly adopting climate policies. This tendency shows a less consistent policy adoption pattern.

There has also been a steady adoption of fossil policies, even when concerns on climate change mitigation entered the UK policy space. Currently, there is a dominant presence of fossil policies supporting oil and gas. The coal industry phased out in the UK in the 1990s, in parallel to when the supply of gas for electricity generation was privatised, i.e., the dash for gas (Winskel, 2002; Carter, 2014; Somerville, 2021). The evolution of climate policyscapes sees how fossil policies for gas overcame fossil policies for coal.

We see that the policy adoption of fossil policies has been running in parallel to the one of climate policies, suggesting that their evolution was independent from one another. Potential reasons for this difference are that: (1) the adoption of climate policies is more publicised and contested than the one of fossil policies and (2) that climate policies tend to be adopted collectively as part of plans or strategies (Paterson et al., 2023; Patterson, 2023). Policies in support of fossil fuels aim to maintain a socio-economic status quo, whereas policies for climate change mitigation aim to disrupt a system whilst transitioning to another. Climate policies operate in groups requiring simultaneous adoption as transitions stem from diverse actions pursued in parallel or in sequence (Rosenbloom et al., 2020a). Therefore, the required policy action to mitigate the climate crisis is substantially different from the one to maintain the fossil fuel industry. Delving into such details is a key part of the exploration of how policyscapes are populated via institutional inertia (i.e., policies are adopted but are not of reference anymore) or if there are legacy policies that add further layers of policies to the climate policyscape.

Our network analysis suggests that the climate and fossil policies operate in clusters within the current policyscape, which evolved independently. Moving beyond policies explicitly intended by policymakers as climate policies leads to questions about how parallel histories of climate change mitigation are presented. Our study highlights that there are contradictory messages across different policy spaces that have persisted over time. These insights would be overlooked by focusing only on top-down policy mixes rather than taking a bottom-up approach using climate policyscapes. Not acknowledging the different policy rhythms in a policyscape risks creating a homogenous understanding of how climate policyscapes evolve and of insufficiently addressing the fossil policy space, which builds upon a steady policy adoption process.

6.3 Overlap-interactions: clusters and sparseness

Employing network analysis allows us to untangle climate policyscape dynamics that otherwise would remain overlooked. We see promising avenues in applying this method to the study of climate laws and policies. The number of links between fossil policies in the climate policyscape is slightly less than between climate policies. To enrich our understanding of dynamics within the climate policyscape beyond descriptive statistics, we need to measure how clustered overlap-interactions are. Policies supporting mitigation are more interconnected with each other within their cluster, in comparison to policies hindering mitigation. This indicates that policies for climate change mitigation tend to behave as a group.

A higher degree of modularity suggests that the repeal of one climate policy has a stronger impact to the dynamics across the cluster of climate policies in comparison to repealing one fossil policies. As climate policies are generally planned and adopted in clusters, repealing one policy has a heavy weight on the group dynamics. Climate change mitigation requires societal transformations that are not achievable with a silver bullet policy. Therefore, multiple policies need to be adopted and operate together to decarbonise societies. What could appear as a fragmented policy picture tends to be a planned policy portfolio designed by policymakers. This is exemplified in the means mentioned in legislative texts, which are designed to interplay with each other. Controversially, fossil policies are adopted to maintain a socio-institutional structure that has been in place for a longer period. Therefore, the policy adoption process intends to layer fossil policies rather than stirring policy change. This means that the behaviour of fossil policies differs from the one of climate policies, whose role in the climate policyscape is to transform a system.

Overall, our findings show that limiting the analysis of policyscapes or mixes to their policy density leads to an analytical omission. *Climate-symbiotic* overlap-interactions and *fossil-symbiotic* overlap-interactions differ in their dynamics, as demonstrated by the modularity in the networks. Our study suggests that climate policyscapes are populated with several modes of overlap-interactions. Our analysis builds on content analysis of legislative texts, assuming overlap-interactions are homogenous.

6.4 Limitations

This study has five limitations that we intend to highlight. First, our conceptualisation and analysis are built around mentions in legislative texts of fuels and/or technologies with an impact on the mitigation process. As a consequence, we are omitting policies that do not mention these factors but have a role in mitigating the climate crisis regardless. We encourage further studies that build climate policyscapes also with policies affecting mitigation without addressing fossil fuels, renewables, or CO_2 emissions to unveil the various layers of policy structures affecting climate change mitigation. Employing text-as-data methods are encouraged to replicate such large-N study (Dugoua et al., 2022; Sewerin et al., 2023).

Second, being a large-N study, we did not delve into the details of each node (i.e., legislative document) and each link (i.e., overlap-interaction). For example, we did not evaluate the level of stringency of each policy, nor if overlap-interactions lead to policy change or maintain policy stagnation. Our analysis did not explore the differences between each node and each link beyond the classification employed for the network analysis. We recommend further work exploring metrics to fully evaluate legislative documents and overlap-interactions populating climate policyscapes. For example, further research should distinguish between intentional and unintentional overlap-interactions to discern the extent to which they result from planned overlap-interactions. This would allow us to gain comprehensive pictures of the diverse dynamics between policies affecting climate change mitigation.

Third, our analysis was based on an unweighted and undirected network analysis. Therefore, we did not discern which policies are the source of the overlap-interaction and which ones are the targets. Directionality can stem from a range of factors (Kim, 2013). Building weighted and directed networks would enrich the analysis by further unpacking how overlap-interactions are orchestrated.

Fourth, we did not evaluate the effects of the overlap-interactions on mitigation. By adopting a critical realist ontology, we did not assume that a climate-*symbiotic* certainly results in mitigation. Further studies should explore the effects of overlap-interactions on a range of effects, e.g., uptake of technologies, change in the energy matrix for electricity generation, social justice, and fairness in the costs of decarbonised electricity, etc. This would allow us to understand how diverse overlap-interactions impact the process of mitigation via sustainable transformations.

Finally, coherence is generally considered either a value-free or a positive condition in a policy mix. This leads to calls for policy coherence to enhance a recent space in the climate policyscape. Critical social science scholars, however, underline that coherence tends to reproduce current institutional practices and structures (Sianes, 2017; Yunita et al., 2022). Societal transformations to halt climate change require significant changes in climate policyscapes to facilitate the uptake of ready-to-deploy renewable energy technologies (e.g., solar PV, offshore and onshore wind) and the phase out of fossil fuels (Bernstein and Hoffmann, 2019). This requires policy dismantling to disrupt older and more robust policy portfolios that allow for the expansion of fossil fuels. Against this backdrop, future research should consider the analysis of modes of overlap-interactions not based on policy coherence.

7 Conclusion

Our study shows that the policy system affecting climate change mitigation in the electricity generation space is heavily populated with policies hindering mitigation. These policies have been steadily adopted since the 1950s, whereas policies to mitigate the climate crisis have been adopted more irregularly and in clusters. This highlights systemic issues in the UK climate policycape. Policies in support of fossil fuels are deeply embedded in the policy landscape, as they have been layering and sequencing each other for a longer time than policies for climate change mitigation. This means that the governance of climate change mitigation requires disrupting policy foundations that are supporting fossil fuel production and consumption, as well as the adoption of policies to strengthen policies supporting decarbonisation, including renewable energy policies.

Climate policyscapes are incoherent systems where policies explicitly adopted for climate change mitigation co-exist with policies supporting the fossil fuel industry, preventing deep societal decarbonisation. As a consequence, climate policy research focusing solely on top-down or hybrid assembled climate policy mixes provides a skewed picture. Studies of policy systems (including policy mixes) must adopt bottom-up approaches, not to overlook impactful measures because of the how they are labelled in public policy spaces by policymakers. Against this backdrop, policy integration literature can benefit from expanding climate policy mixes studies, in order to include measures from different policy areas and yet affecting the same issue (Nilsson et al., 2012; Runhaar et al., 2020). This would help move beyond the explicit intent of policymakers in defining "climate policies" and place the climate crisis at the centre of such studies.

Employing network analysis allowed us to identify overlaps-interactions between policies in the 2022 climate policyscape. We observed that the *climate-symbiotic* overlap-interactions differ from *fossil-symbiotic* ones. They do so by behaving as a group within their cluster, in contrast to fossil policies. This echoes our concern that policy mixes studies require further attention to the interactions between policies, rather than assessing a mix as the sum of different policies. This tendency runs to the contrary objective of studying mixes, which is to appreciate the dynamics between different components. Network theory and adjacent methods help reveal the multiple levels of interactions between policies and appreciate the population heterogeneity in systems of policies.

In conclusion, we observe an incoherent picture of climate policyscapes, both historically and currently. To advance climate action institutional inertia must be overcome by dismantling policy structures in support of the fossil fuel industry, whilst halting further adoption of such policies. Further research is crucial to capture the broad picture of climate policyscapes and demonstrate the degrees of incoherence present outside of top-down assembled policy plans.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

VZ: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. KB: Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement 853168).

Acknowledgments

The authors are extremely grateful to James Patterson for his invaluable comments. They thank Brian Dermody and Ashok Vardhan Adipudi for kindly answering our questions about network analysis. The authors gratefully acknowledge the participants of the 2023 Earth System Governance Conference for their feedback. They thank Mark Dehlsen, Cille Kaiser, and Denitsa Marchevska for their constructive comments on previous drafts of this manuscript. The authors would like to thank two reviewers for their relevant and helpful comments that helped improve the quality of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2024.1386061/full#supplementary-material

References

Adipudi, A. V., and Kim, R. E. (2024). The latent net effectiveness of institutional complexes: a heuristic model. *Philos. Transact. A Math. Phys. Eng. Sci.* 382:20230161. doi: 10.1098/rsta.2023.0161

Allwood, J., Azevedo, J., Clare, A., Cleaver, C., Cullen, J., Dunant, C., et al. (2019). *Absolute Zero*. Cambridge: Apollo-University of Cambridge Repository.

Barton, D. N., Blumentrath, S., and Rusch, G. (2013). Policyscape—a spatially explicit evaluation of voluntary conservation in a policy mix for biodiversity conservation in Norway. *Soc. Nat. Resour.* 26, 1185–1201. doi: 10.1080/08941920.2013.799727

Bernstein, S., and Hoffmann, M. (2019). Climate politics, metaphors and the fractal carbon trap. *Nat. Clim. Chang.* 9, 919–925. doi: 10.1038/s41558-019-0618-2

Bhardwaj, C., Axsen, J., Kern, F., and McCollum, D. (2020). Why have multiple climate policies for light-duty vehicles? Policy mix rationales, interactions and research gaps. *Transp. Res. A Policy Pract.* 135, 309–326. doi: 10.1016/j.tra.2020.03.011

Biermann, F. (2021). The future of 'environmental' policy in the Anthropocene: time for a paradigm shift. *Environmental Politics* 30, 61–80. doi: 10.1080/09644016.2020.1846958

Biermann, F., Bai, X., Bondre, N., Broadgate, W., Arthur Chen, C.-T., Dube, O. P., et al. (2016). Down to earth: contextualizing the Anthropocene. *Glob. Environ. Chang.* 39, 341–350. doi: 10.1016/j.gloenvcha.2015.11.004

Biermann, F., and Kim, R. E. (2020). *Architectures of earth system governance*. Cambridge: Institutional Complexity and Structural Transformation. Cambridge University Press.

Biesbroek, R., Wright, S. J., Eguren, S. K., Bonotto, A., and Athanasiadis, I. N. (2022). Policy attention to climate change impacts, adaptation and vulnerability: a global assessment of National Communications (1994–2019). *Clim. Pol.* 22, 97–111. doi: 10.1080/14693062.2021.2018986

Bogers, M., Biermann, F., Kalfagianni, A., Kim, R. E., Treep, J., and de Vos, M. G. (2022). The impact of the sustainable development goals on a network of 276 international organizations. *Glob. Environ. Chang.* 76:102567. doi: 10.1016/j.gloenvcha.2022.102567

Bouma, J. A., Verbraak, M., Dietz, F., and Brouwer, R. (2019). Policy mix: mess or merit? *J. Environ. Econ. Policy* 8, 32–47. doi: 10.1080/21606544.2018.1494636

Brad, A., Haas, T., and Schneider, E. (2024). Whose negative emissions? Exploring emergent perspectives on CDR from the EU's hard to abate and fossil industries. *Front. Clim.* 5:1268736. doi: 10.3389/fclim.2023.1268736

Braungardt, S., Bürger, V., and Köhler, B. (2021). Carbon pricing and complementary policies—consistency of the policy mix for decarbonizing buildings in Germany. *Energies* 14:7143. doi: 10.3390/en14217143

Bulkeley, H. (Ed.) (2015). *Charting climate change governance in the United Kingdom. In accomplishing climate governance*. Cambridge: Cambridge University Press.

Burns, C., Eckersley, P., and Tobin, P. (2020). EU environmental policy in times of crisis. *J. Eur. Publ. Policy* 27, 1–19. doi: 10.1080/13501763.2018.1561741

Capano, G., and Howlett, M. (2020). The knowns and unknowns of policy instrument analysis: policy tools and the current research agenda on policy mixes. *SAGE Open* 10:215824401990056. doi: 10.1177/2158244019900568

Carter, N. (2014). The politics of climate change in the UK. *WIREs Climate Change* 5, 423–433. doi: 10.1002/wcc.274

Cashore, B., and Bernstein, S. (2022). *Bringing the environment Back in: Overcoming the tragedy of the diffusion of the commons metaphor. Perspectives on politics*. Cambridge: Cambridge University Press.

Coenen, J., Glass, L.-M., and Sanderink, L. (2022). Two degrees and the SDGs: a network analysis of the interlinkages between transnational climate actions and the sustainable development goals. *Sustain. Sci.* 17, 1489–1510. doi: 10.1007/s11625-021-01007-9

Coupette, C., Beckedorf, J., Hartung, D., Bommarito, M., and Katz, D. M. (2021). Measuring law over time: a network analytical framework with an application to statutes and regulations in the United States and Germany. *Front. Phys.* 9:658463. doi: 10.3389/fphy.2021.658463

del Río, P., and Cerdá, E. (2017). The missing link: the influence of instruments and design features on the interactions between climate and renewable electricity policies. *Energy Res. Soc. Sci.* 33, 49–58. doi: 10.1016/j.erss.2017.09.010

Dugoua, E., Dumas, M., and Noailly, J. (2022). Text-as-data in environmental economics and policy. *Rev. Environ. Econ. Policy* 16, 346–356. doi: 10.1086/721079

Duit, A., Galaz, V., Eckerberg, K., and Ebbesson, J. (2010). Governance, complexity, and resilience. *Glob. Environ. Chang.* 20, 363–368. doi: 10.1016/j.gloenvcha.2010.04.006

Ebbesson, J. (2010). The rule of law in governance of complex socio-ecological changes. *Glob. Environ. Chang.* 20, 414–422. doi: 10.1016/j.gloenvcha.2009.10.009

Elsässer, J. P., Hickmann, T., Jinnah, S., Oberthür, S., and Van de Graaf, T. (2022). Institutional interplay in global environmental governance: lessons learned and future research. *Int. Environ. Agreem.: Politics Law Econ.* 22, 373–391. doi: 10.1007/s10784-022-09569-4

Eskander, S. M. S. U., and Fankhauser, S. (2020). Reduction in greenhouse gas emissions from national climate legislation. Nature. *Climate Change* 10, 750–756. doi: 10.1038/s41558-020-0831-z

Estrada, E. (2023). What is a complex system, after all? *Found. Sci.* doi: 10.1007/s10699-023-09917-w

Farstad, F. M., Hermansen, E. A. T., Grasbekk, B. S., Brudevoll, K., and van Oort, B. (2022). Explaining radical policy change: Norwegian climate policy and the ban on cultivating peatlands. *Glob. Environ. Chang.* 74:102517. doi: 10.1016/j.gloenvcha.2022.102517

Feola, G. (2015). Societal transformation in response to global environmental change: a review of emerging concepts. *Ambio* 44, 376–390. doi: 10.1007/s13280-014-0582-z

Fowler, J. H., Johnson, T. R., Spriggs, J. F., Jeon, S., and Wahlbeck, P. J. (2007). Network analysis and the law: measuring the legal importance of precedents at the U.S. Supreme Court. *Polit. Anal.* 15, 324–346. doi: 10.1093/pan/mpm011

Gebara, M. F., Sills, E., May, P., and Forsyth, T. (2019). Deconstructing the policyscape for reducing deforestation in the Eastern Amazon: Practical insights for a landscape approach. *Environ. Policy Govern.* 29, 185–197. doi: 10.1002/eet.1846

Geels, F. W. (2022). Causality and explanation in socio-technical transitions research: Mobilising epistemological insights from the wider social sciences. *Res. Policy* 51:104537. doi: 10.1016/j.respol.2022.104537

Goyal, N., Taeihagh, A., and Howlett, M. (2022). "Mapping the use of public policy theories in energy transitions research: a bibliometric review and computational text analysis" in *Routledge Handbook of Energy Transitions*. ed. K. Araújo (London: Routledge).

Green, J. F. (2021a). Does carbon pricing reduce emissions? A review of ex-post analyses. *Environ. Res. Lett.* 16:043004. doi: 10.1088/1748-9326/abdae9

Green, J. F. (2021b). Beyond carbon pricing: tax reform is climate policy. *Global Pol.* 12, 372–379. doi: 10.1111/1758-5899.12920

Green, R., and Staffell, I. (2021). The contribution of taxes, subsidies, and regulations to British electricity decarbonization. *Joule* 5, 2625–2645. doi: 10.1016/j.joule.2021.09.011

Gunningham, N., and Sinclair, D. (1999). Integrative regulation: a principle-based approach to environmental policy. *Law Soc. Inq.* 24, 853–896. doi: 10.1111/j.1747-4469.1999.tb00407.x

Hanna, R., and Victor, D. G. (2021). Marking the decarbonization revolutions. *Nat. Energy* 6, 568–571. doi: 10.1038/s41560-021-00854-1

Harcourt, B. E. (2018). The systems fallacy: a genealogy and critique of public policy and cost-benefit analysis. *J. Leg. Stud.* 47, 419–447. doi: 10.1086/698135

Harvey, F. (2022). UK's first new coalmine for 30 years gets go-ahead in Cumbria. The Guardian. Available at: https://www.theguardian.com/environment/2022/dec/07/uk-first-new-coalmine-for-30-years-gets-go-ahead-in-cumbria

Hickmann, T., van Asselt, H., Oberthür, S., Sanderink, L., Widerberg, O., and Zelli, F. (2020). "Institutional interlinkages" in *Architectures of earth system governance: Institutional complexity and structural transformation*. eds. F. Biermann and R. E. Kim (Cambridge: Cambridge University Press).

Hirvilammi, T., Häikiö, L., Johansson, H., Koch, M., and Perkiö, J. (2023). Social policy in a climate emergency context: towards an Ecosocial research agenda. *J. Soc. Policy* 52, 1–23. doi: 10.1017/S0047279422000721

Howlett, M. (2019). Procedural policy tools and the temporal dimensions of policy design. Resilience, robustness and the sequencing of policy mixes. International review of. *Public Policy* 1, 27–45. doi: 10.4000/irpp.310

Howlett, M., and Del Rio, P. (2015). The parameters of policy portfolios: verticality and horizontality in design spaces and their consequences for policy mix formulation. *Environ. Plann. C Gov. Policy* 33, 1233–1245. doi: 10.1177/0263774X15610059

Howlett, M., and Rayner, J. (2007). Design principles for policy mixes: cohesion and coherence in 'new governance arrangements'. *Polic. Soc.* 26, 1–18. doi: 10.1016/S1449-4035(07)70118-2

IPCC (2018). *Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Geneva: IPCC.

Janetschek, H., Brandi, C., Dzebo, A., and Hackmann, B. (2019). The 2030 agenda and the Paris agreement: voluntary contributions towards thematic policy coherence. *Clim. Pol.* 20, 430–442. doi: 10.1080/14693062.2019.1677549

Kern, F., Rogge, K. S., and Howlett, M. (2019). Policy mixes for sustainability transitions: new approaches and insights through bridging innovation and policy studies. *Res. Policy* 48:103832. doi: 10.1016/j.respol.2019.103832

Kim, R. E. (2013). The emergent network structure of the multilateral environmental agreement system. *Glob. Environ. Chang.* 23, 980–991. doi: 10.1016/j.gloenvcha.2013.07.006

Kim, R. E. (2020). Is global governance fragmented, polycentric, or complex? The state of the art of the network approach. *Int. Stud. Rev.* 22, 903–931. doi: 10.1093/isr/viz052

King, J. (2018). Offshore wind: A UK success story. Carbon Trust. Available at: https://www.carbontrust.com/news-and-insights/insights/offshore-wind-a-uk-success-story

Kosow, H., Weimer-Jehle, W., León, C. D., and Minn, F. (2022). Designing synergetic and sustainable policy mixes—a methodology to address conflictive environmental issues. *Environ. Sci. Pol.* 130, 36–46. doi: 10.1016/j.envsci.2022.01.007

Leach, M. C. (2021). Negotiating the descriptive–normative frontier of complexity research in the Anthropocene. *Front. Phys.* 9:665727. doi: 10.3389/fphy.2021.665727

Lepic, B. (2020). Norway: Tax relief to increase investments in oil and gas. Offshore energy. Available at: https://www.offshore-energy.biz/norway-tax-relief-to-increase-investments-in-oil-and-gas/

Lilliestam, J., Patt, A., and Bersalli, G. (2021). The effect of carbon pricing on technological change for full energy decarbonization: a review of empirical ex-post evidence. *WIREs Climate Change* 12:e681. doi: 10.1002/wcc.681

Lincoln, Y. S., and Guba, E. G. (1985). *Naturalistic inquiry*. Thousand Oaks: Sage.

Lockwood, M. (2021). A hard act to follow? The evolution and performance of UK climate governance. *Environ. Politics* 30, 26–48. doi: 10.1080/09644016.2021.1910434

Lovell, H., Bulkeley, H., and Owens, S. (2009). Converging agendas? Energy and climate change policies in the UK. *Environ. Plann. C Gov. Policy* 27, 90–109. doi: 10.1068/c0797j

Macintosh, A., and Wilkinson, D. (2016). Complexity theory and the constraints on environmental policymaking. *J. Environ. Law* 28, 65–93. doi: 10.1093/jel/eqv026

Maor, M., and Howlett, M. (2022). "Measuring policy instrument interactions in policy mixes: Surveying the conceptual and methodological landscape" in *The Routledge Handbook of Policy Tools*. ed. M. Howlett (London: Routledge).

Mazzega, P. (2021). Conceptual graphs and terminological idiosyncrasy in UNCLOS and CBD. *Front. Phys.* 9:664621. doi: 10.3389/fphy.2021.664621

Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea: Chelsea Green Publishing.

Meckling, J. (2021). Making industrial policy work for Decarbonization. *Global Environ. Polit.* 21, 134–147. doi: 10.1162/glep_a_00624

Milhorance, C., Bursztyn, M., and Sabourin, E. (2020a). From policy mix to policy networks: assessing climate and land use policy interactions in Mato Grosso, Brazil. *J. Environ. Policy Plan.* 22, 381–396. doi: 10.1080/1523908X.2020.1740658

Milhorance, C., Sabourin, E., Le Coq, J.-F., and Mendes, P. (2020b). Unpacking the policy mix of adaptation to climate change in Brazil's semiarid region: enabling instruments and coordination mechanisms. *Clim. Pol.* 20, 593–608. doi: 10.1080/14693062.2020.1753640

Mitchell, M. (2006). Complex systems: network thinking. *Artif. Intell.* 170, 1194–1212. doi: 10.1016/j.artint.2006.10.002

Moore, B., Verfuerth, C., Minas, A. M., Tipping, C., Mander, S., Lorenzoni, I., et al. (2021). Transformations for climate change mitigation: a systematic review of terminology, concepts, and characteristics. *Wiley Interdiscip. Rev. Clim.* 12:e738. doi: 10.1002/wcc.738

Morin, J. F., Pauwelyn, J., and Hollway, J. (2017). The trade regime as a complex adaptive system: exploration and exploitation of environmental norms in trade agreements. *J. Int. Econ. Law* 20, 365–390. doi: 10.1093/jiel/jgx013

Mosley, S. (2017). Clearing the air: can the 1956 clean air act inform new legislation? History & Policy. Available at: https://www.historyandpolicy.org/index.php/policy-papers/papers/clearing-the-air-can-the-1956-clean-air-act-inform-new-legislation

Nachmany, M., and Mangan, E.. (2018). Aligning national and international climate targets. London: Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science. Available at: www.lse.ac.uk/GranthamInstitute/publications

Nasiritousi, N., Sanderink, L., Skovgaard, J., van Asselt, H., Verkuijl, C., and Widerberg, O. (2020). "The performance of the climate-energy Nexus: assessing the effectiveness of the institutional complexes on renewable energy, fossil fuel subsidy reform, and carbon pricing" in *Governing the climate-energy Nexus: Institutional complexity and its challenges to effectiveness and legitimacy*. eds. F. Zelli, J. Skovgaard, K. Bäckstrand, N. Nasiritousi and O. Widerberg (Cambridge: Cambridge University Press).

Nilsson, M., Zamparutti, T., Petersen, J. E., Nykvist, B., Rudberg, P., and McGuinn, J. (2012). Understanding policy coherence: analytical framework and examples of sector–environment policy interactions in the EU. *Environ. Policy Gov.* 22, 395–423. doi: 10.1002/eet.1589

Oberthür, S., and Gehring, T. (2006). *Institutional interaction in global environmental governance: Synergy and conflict among international and EU policies*. Cambridge MA: MIT Press.

Oostdijk, M., Santos, M. J., Agnarsson, S., and Woods, P. J. (2019). Structure and evolution of cod quota market networks in Iceland over times of financial volatility. *Ecol. Econ.* 159, 279–290. doi: 10.1016/j.ecolecon.2019.01.035

Orsini, A., Morin, J.-F., and Young, O. (2013). Regime complexes: a buzz, a boom, or a boost for global governance? *Global Governance* 19, 27–39. doi: 10.1163/19426720-01901003

Ossenbrink, J., Finnsson, S., Bening, C. R., and Hoffmann, V. H. (2019). Delineating policy mixes: contrasting top-down and bottom-up approaches to the case of energy-storage policy in California. *Res. Policy* 48:103582. doi: 10.1016/j.respol.2018.04.014

Paterson, M. (2019). Using negotiation sites for richer collection of network data. *Global Environ. Polit.* 19, 81–92. doi: 10.1162/glep_a_00504

Paterson, M., Wilshire, S., and Tobin, P. (2023). The rise of anti-net zero populism in the UK: comparing rhetorical strategies for climate policy dismantling. *J. Comp. Policy Anal.: Res. Pract.* 1, 1–19. doi: 10.1080/13876988.2023.2242799

Pattberg, P., and Widerberg, O. (2015). Theorising global environmental governance: key findings and future questions. *Millennium* 43, 684–705. doi: 10.1177/0305829814561773

Pattberg, P. H., and Widerberg, O. E. (2019). Smart mixes and the challenge of complexity: lessons from global climate governance. In ErpJ. van, M. Faure, A. Nollkaemper and N. Philipsen *Smart mixes for transboundary environmental harm* (pp. 49–68). Cambridge University Press. Cambridge

Patterson, J. J. (2023). Backlash to climate policy. *Global Environ. Polit.* 23, 68–90. doi: 10.1162/glep_a_00684

Pearson, P. J. G., and Watson, J. (2023). The unfolding low-carbon transition in the UK electricity system. *Proc. Natl. Acad. Sci.* 120:e2206235120. doi: 10.1073/pnas.2206235120

Peñasco, C., Anadón, L. D., and Verdolini, E. (2021). Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments. *Nat. Clim. Chang.* 11, 257–265. doi: 10.1038/s41558-020-00971-x

Pittman, J., and Armitage, D. (2019). Network governance of Land-Sea social-ecological Systems in the Lesser Antilles. *Ecol. Econ.* 157, 61–70. doi: 10.1016/j.ecolecon.2018.10.013

Pless, J. (2022). *Are complementary policies substitutes? Evidence from R & D subsidies in the UK (SSRN scholarly paper 3379256)*. Amsterdam: Elsevier.

Ptak, E. N., Graversgaard, M., and Dalgaard, T. (2023). Navigating the nexus: the role of intermediaries in charting a new frontier of policy integration for agrifood and energy systems transformation. *Environ. Sci. Pol.* 139, 92–103. doi: 10.1016/j.envsci.2022.10.019

Rai, S. (2020). Policy adoption and policy intensity: emergence of climate adaptation planning in U.S. States. *Review Policy Res.* 37, 444–463. doi: 10.1111/ropr.12383

Roelfsema, M., van Soest, H. L., Harmsen, M., van Vuuren, D. P., Bertram, C., den Elzen, M., et al. (2020). Taking stock of national climate policies to evaluate implementation of the Paris agreement. Nature. *Communications* 11:2096. doi: 10.1038/s41467-020-15414-6

Rogge, K. S., and Reichardt, K. (2016). Policy mixes for sustainability transitions: an extended concept and framework for analysis. *Res. Policy* 45, 1620–1635. doi: 10.1016/j.respol.2016.04.004

Rogge, K., and Stadler, M. (2023). Applying policy mix thinking to social innovation: from experimentation to socio-technical change. *Environ. Innov. Soc. Trans.* 47:100723. doi: 10.1016/j.eist.2023.100723

Rosenbloom, D., Markard, J., Geels, F. W., and Fuenfschilling, L. (2020a). Why carbon pricing is not sufficient to mitigate climate change—and how "sustainability transition policy" can help. *Proc. Natl. Acad. Sci.* 117, 8664–8668. doi: 10.1073/pnas.2004093117

Rosenbloom, D., Markard, J., Geels, F. W., and Fuenfschilling, L. (2020b). Reply to van den Bergh and Botzen: a clash of paradigms over the role of carbon pricing. *Proc. Natl. Acad. Sci.* 117, 23221–23222. doi: 10.1073/pnas.2014350117

Runhaar, H., Wilk, B., Driessen, P., Dunphy, N., Persson, Å., Meadowcroft, J., et al. (2020). "Policy integration" in *Architectures of earth system governance: Institutional complexity and structural transformation*. eds. F. Biermann and R. E. Kim (Cambridge: Cambridge University Press).

Sanderink, L. (2020). "Renewable energy: a loosely coupled system or a well-connected web of institutions?" in *Governing the climate-energy Nexus: Institutional complexity and its challenges to effectiveness and legitimacy*. eds. F. Zelli, J. Skovgaard, K. Bäckstrand, N. Nasiritousi and O. Widerberg (Cambridge: Cambridge University Press).

Sanderink, L., and Nasiritousi, N. (2020). How institutional interactions can strengthen effectiveness: the case of multi-stakeholder partnerships for renewable energy. *Energy Policy* 141:111447. doi: 10.1016/j.enpol.2020.111447

Schaffrin, A., Sewerin, S., and Seubert, S. (2015). Toward a comparative measure of climate policy output. *Policy Stud. J.* 43, 257–282. doi: 10.1111/psj.12095

Schellnhuber, H. J. (1999). 'Earth system' analysis and the second Copernican revolution. *Nature* 402, C19–C23. doi: 10.1038/35011515

Schlüter, M., Brelsford, C., Ferraro, P. J., Orach, K., Qiu, M., and Smith, M. D. (2023). Unraveling complex causal processes that affect sustainability requires more integration between empirical and modeling approaches. *Proc. Natl. Acad. Sci.* 120:e2215676120. doi: 10.1073/pnas.2215676120

Schmidt, T. S., and Sewerin, S. (2019). Measuring the temporal dynamics of policy mixes – an empirical analysis of renewable energy policy mixes' balance and design features in nine countries. *Res. Policy* 48:103557. doi: 10.1016/j.respol.2018.03.012

Sewerin, S. (2020). "Understanding complex policy mixes: conceptual and empirical challenges" in *A modern guide to public policy*. eds. G. Capano and M. Howlett (Cheltenham: Edward Elgar).

Sewerin, S., Cashore, B., and Howlett, M. (2022). New pathways to paradigm change in public policy: combining insights from policy design, mix and feedback. *Policy Polit.* 50, 442–459. doi: 10.1332/030557321X16528864819376

Sewerin, S., Kaack, L. H., Küttel, J., Sigurdsson, F., Martikainen, O., Esshaki, A., et al. (2023). Towards understanding policy design through text-as-data approaches: the policy design annotations (POLIANNA) dataset. *Scientific Data* 10:896. doi: 10.1038/s41597-023-02801-z

Sianes, A. (2017). Shedding light on policy coherence for development: a conceptual framework. *J. Int. Dev.* 29, 134–146. doi: 10.1002/jid.2977

Somerville, P. (2021). The continuing failure of UK climate change mitigation policy. *Crit. Soc. Policy* 41, 628–650. doi: 10.1177/0261018320961762

SoRelle, M. E. (2016). "Politics of the Policyscape" in *Global encyclopedia of public administration, public policy, and governance*. ed. A. Farazmand (Berlin: Springer International Publishing).

Stephenson, S. D., and Allwood, J. M. (2023). Technology to the rescue? Techno-scientific practices in the United Kingdom net zero strategy and their role in locking in high energy decarbonization pathways. *Energy Res. Soc. Sci.* 106:103314. doi: 10.1016/j.erss.2023.103314

Stokes, L. C. (2020). *Short circuiting policy: Interest groups and the Battle over clean energy and climate policy in the American states*. Oxford: Oxford University Press.

Stokke, O. S. (2001). *The interplay of international regimes: Putting effectiveness theory to work. FNI Report 14/2001*. Lysaker: Fridtjof Nansens Institute.

Stuart, D. (Ed.) (2020). "Clustering and social network analysis" in *Practical data science for information professionals* (London: Facet).

Taeihagh, A. (2017). Network-centric policy design. *Policy. Sci.* 50, 317–338. doi: 10.1007/s11077-016-9270-0

The National Archives (2023). Understanding legislation. Available at: https://www.legislation.gov.uk/understanding-legislation

The National Archives (2024). The National Archives. Available at: https://www.nationalarchives.gov.uk/

Therville, C., Antona, M., and de Foresta, H. (2020). The policyscape of agroforestry within Mediterranean protected landscapes in France. *Sustain. Sci.* 15, 1435–1448. doi: 10.1007/s11625-020-00821-x

Tosun, J., and Leininger, J. (2017). Governing the interlinkages between the sustainable development goals: approaches to attain policy integration. *Global Chall.* 1:1700036. doi: 10.1002/gch2.201700036

Trencher, G., and van der Heijden, J. (2019). Instrument interactions and relationships in policy mixes: achieving complementarity in building energy efficiency policies in New York, Sydney and Tokyo. *Energy Res. Soc. Sci.* 54, 34–45. doi: 10.1016/j.erss.2019.02.023

Valenzuela, J. M., and Rhys, J. (2022). In plain sight: the rise of state coordination and fall of liberalised markets in the United Kingdom power sector. *Energy Res. Soc. Sci.* 94:102882. doi: 10.1016/j.erss.2022.102882

Vallet, A., Locatelli, B., Barnaud, C., Makowski, D., Quispe Conde, Y., and Levrel, H. (2020). Power asymmetries in social networks of ecosystem services governance. *Environ. Sci. Pol.* 114, 329–340. doi: 10.1016/j.envsci.2020.08.020

van den Bergh, J., and Savin, I. (2021). Impact of carbon pricing on Low-carbon innovation and deep Decarbonization: controversies and path forward. *Environ. Resour. Econ.* 80, 705–715. doi: 10.1007/s10640-021-00594-6

van den Bergh, J., and Savin, I. (2023). *Impact of carbon pricing on deep Decarbonization: A rejoinder to Lilliestam et Al. (2022) (SSRN scholarly paper 4352574).* Amsterdam: Elsevier.

van den Bergh, J., Van Beers, C., and King, L. C. (2024). Prioritize carbon pricing over fossil-fuel subsidy reform. *iScience* 27:108584. doi: 10.1016/j.isci.2023.108584

Wernli, D., Falcone, J.-L., Davidshofer, S., Lee, K., Chopard, B., and Levrat, N. (2023). Emergent patterns in global health diplomacy: a network analysis of the resolutions adopted by the world health assembly from 1948 to 2022. *BMJ Glob. Health* 8:e011211. doi: 10.1136/bmjgh-2022-011211

Winskel, M. (2002). When systems are overthrown: the 'dash for gas' in the British electricity supply industry. *Soc. Stud. Sci.* 32, 563–598. doi: 10.1177/0306312702032004003

Wurzel, R., Zito, A., and Jordan, A. (2019). Smart (and not-so-smart) mixes of new environmental policy instruments. In A. Nollkaemper, ErpJ. van, M. Faure and N. Philipsen *Smart mixes for transboundary environmental harm* (pp. 69–94). Cambridge University Press. Cambridge

Young, O. R. (1996). Institutional linkages in international society: polar perspectives. *Glob. Gov.* 2, 1–23. doi: 10.1163/19426720-002-01-90000002

Young, O. R. (2002). *The institutional dimensions of environmental change*. Cambridge MA: MIT Press.

Young, O. R. (2010). Institutional dynamics: resilience, vulnerability and adaptation in environmental and resource regimes. *Glob. Environ. Chang.* 20, 378–385. doi: 10.1016/j.gloenvcha.2009.10.001

Yunita, A., Biermann, F., Kim, R. E., and Vijge, M. J. (2022). The (anti-)politics of policy coherence for sustainable development in the Netherlands: logic, method, effects. *Geoforum* 128, 92–102. doi: 10.1016/j.geoforum.2021.12.002

Zabala, A. (2021). Comparing policy instruments for sustainability. *Nat. Sustain.* 4, 565–566. doi: 10.1038/s41893-021-00746-y

Zelli, F., Nasiritousi, N., Bäckstrand, K., Pattberg, P., Sanderink, L., Skovgaard, J., et al. (2020). "Analytical framework: assessing coherence, management, legitimacy, and effectiveness" in *Governing the climate-energy Nexus: Institutional complexity and its challenges to effectiveness and legitimacy*. eds. F. Zelli, J. Skovgaard, K. Bäckstrand, N. Nasiritousi and O. Widerberg (Cambridge: Cambridge University Press), 21–42.

Zickfeld, K., MacIsaac, A. J., Canadell, J. G., Fuss, S., Jackson, R. B., Jones, C. D., et al. (2023). Net-zero approaches must consider earth system impacts to achieve climate goals. *Nat. Clim. Change.* 13, 1298–1305. doi: 10.1038/s41558-023-01862-7