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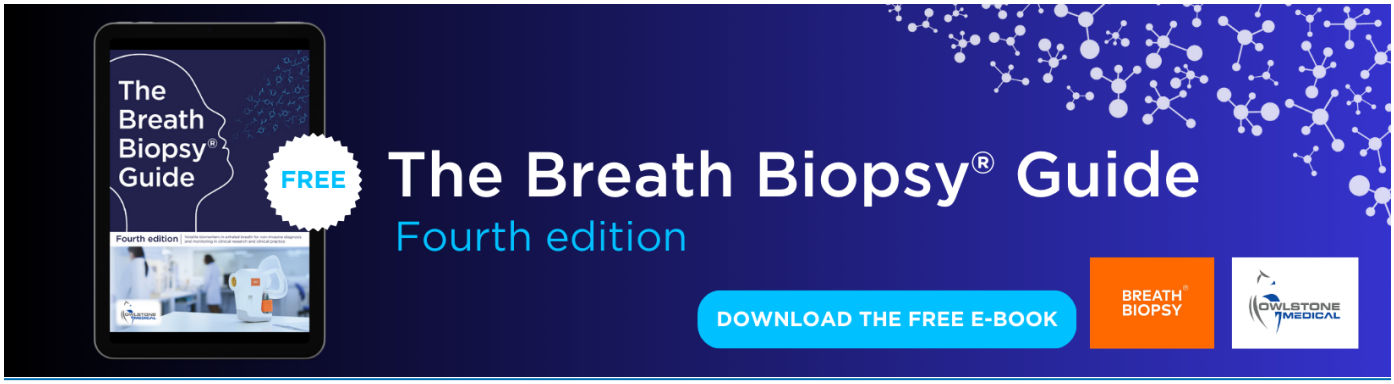

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An advanced review of climate change mitigation policies in Germany, France, and the Netherlands

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Abstract

Mitigation of climate change requires comprehensive policy arrangements. This article applies a systematic analysis framework comprising 'vertical policy hierarchy—horizontal policy path—policy instruments' with Germany, France, and the Netherlands as study cases, and first-hand policy and data from government websites collected, clustered, and matched. The study conducts a comparative analysis of the three countries' systems, pathways, instruments, and their effectiveness in climate change mitigation. The findings indicate that, firstly, all three countries have relatively well-developed policy systems (laws, regulations, strategies, plans, and policy instruments) based on the six vertical policy hierarchy defined by government governance structure. Secondly, the three countries exhibit commonalities and disparities in seven sectors: energy, transport, buildings, industry, agriculture, forest, and waste. The commonalities stem from EU laws and directives, while disparities arise from resource endowments and emission structures. Thirdly, regarding policy instruments, the commonalities among the three countries are reflected in the dominance of Financial/Fiscal Mechanisms as the primary approach, the leadership position of Governance Mechanisms, the comprehensive coverage of Regulatory Reform, and the massive expenditure in the Direct investment. Individually, (1) the German Regulatory Reform primarily addresses energy resource transformation; France focuses on controlling the transport sector emissions; while the Netherlands commits to renewable energy generation. (2) Germany leads in terms of Commercialization Mechanisms. (3) Financial/Fiscal Mechanisms encompass all sectors, while Germany examplifies the transportation sector digitization, France's provision of ecological housing loans, and the Netherlands' support for sustainable agriculture. (4) France distinguishes itself with a forward-thinking approach towards Governance Mechanism including climate financial risks, ESG (Environmental, Social, and Governance) standards. Fourthly, the significant policy instruments analysis demonstrates that the climate governance of three countries incorporates not only direct or indirect efforts in emission reduction, but also considerations of institutional requirements, fairness, economic effectiveness, synergies, and transformative potential in policy considerations.

1. Introduction

In 2015, the Paris Agreement was adopted, with the aim of limiting the temperature increase to below 2 °C above pre-industrial levels and striving to restrict within 1.5 °C (UNFCCC 2015a). As of April 2023, the Nationally Determined Contributions (NDC) have been submitted by 194 parties (UNFCCC 2023). However, the submitted NDCs suggest that it is still unfeasible to restrict the temperature increase to

within 1.5 °C by 2030. This implies an urgent need for **climate mitigation policies** (IPCC 2022, 2023).

In effect, over the past two decades, there has been a continuous increase in the number of global climate mitigation policies (Bassi *et al* 2017, Le Quéré *et al* 2019). This can be attributed to several factors. Firstly, the United Nations Framework Convention on Climate Change and the Paris Agreement have created incentives for countries to mitigate climate change (Iacobuta *et al* 2018, Nascimento *et al* 2022). Secondly, the diffusion of policies by international organizations increases the possibility of countries replicating climate mitigation policies implemented by other countries (Fankhauser *et al* 2016). Thirdly, there has been a rise in public attention concerning the climate change (Shwom *et al* 2015).

Europe stands out as the region with the earliest and mostly effectively implemented climate mitigation policies on a global scale. For the past 30 years, countries such as France, Germany, and the Netherlands have demonstrated exceptional performance in reducing greenhouse gas emissions by over 10% (EEA 2020). As early as 1997, Germany established greenhouse gas reduction targets. The introduction of the Renewable Energy Sources Act (EEG) and the proposal of the Climate Change Act provided legal frameworks for energy reform and climate mitigation policies. Subsequently, a series of action plans were developed in Germany. Similarly, France established emission reduction plans in 1997. A great number of strategic plans were introduced in the 21st century. Laws such as The Energy Transition for Green Growth Act and the Energy-Climate Law were enacted, as a comprehensive climate legal system is being gradually established. In the Netherlands, systematic climate mitigation policies were formulated starting in 2011. Documents such as the Climate Agenda, Energy Agenda, and Climate Agreement were successively introduced, setting the direction for the Netherlands'.

However, systematic analytical frameworks for climate mitigation policies regarding a country centers on technical reports (Mathy *et al* 2015, HCC 2019, IEA 2020, 2021, Prognos *et al* 2020, Dambeck *et al* 2021) with a paucity in relevant literature. Presently, the climate mitigation policies studies primarily focus on NDC (Aldy *et al* 2016, Pauw *et al* 2018, Campagnolo and Davide 2019), climate laws (Dubash *et al* 2013, Scotford and Minas 2019, Eskander and Fhauser 2020, Averchenkova *et al* 2021), policy instruments (Schultze 1975, Jaffe and Stavins 1995, Nordhaus 2013, Wurzel *et al* 2013, Peñasco *et al* 2021, IPCC 2022), technological innovation (Wittneben 2012, Rockström *et al* 2017, Grubb *et al* 2021), social issues in climate governance (Kurz *et al* 2015, Verplanken and Whitmarsh 2021), and climate justice (Romero-Lankao *et al* 2018, Carley and Konisky 2020). Three primary aspects have been emphasized in the research of national-level climate mitigation policies. Firstly, a focus on whether a countries' climate mitigation policies can achieve NDC (e.g. Den Elzen *et al* 2019, Nascimento *et al* 2022). Secondly, the evaluation of a specific laws policy instrument (e.g. Berry and Laurent 2019, Eskander and Fankhauser 2020, Macchi and Zeben 2021). Thirdly, the attention concerning the emission reduction in specific sectors, such as energy (Lindberg *et al* 2019), transport (Lefevre *et al* 2021), industry (Scordato *et al* 2018), agriculture (Hönle *et al* 2019), etc.

With respect to the aforementioned issues, systematic studies or reviews concerning climate mitigation policies are mainly noted in technical reports, with limited academic research efforts at present. To address this gap (1) Firstly, this article presents a systematic analysis framework for climate mitigation policies, which adopts the 'vertical policy hierarchy-horizontal policy path-policy instruments' approach. The vertical policy hierarchy is structured based on the climate governance structures of each country, which include laws, regulations, strategies, plans, funds, and policy instruments. The horizontal policy paths consist of seven key emission reduction areas, namely energy, transport, buildings, industry, agriculture, forest, and waste, along with their corresponding greenhouse gas reduction targets and measures. The policy instruments are categorized into six major groups, namely Regulatory Reform, Market-based Mechanisms, Commercialization Mechanisms, Financial/Fiscal Mechanisms, Direct Investment, and Governance Mechanisms.

(2) Premised on the framework outlined above, this article conducts a comparative analysis of the scope and depth of climate mitigation policy systems, policy directions in key areas, and characteristics of policy instruments based on data collected from 31 government websites in Germany, France, and the Netherlands, which includes 103 laws, 125 ordinances/decrees, 47 strategies, 126 plans, and 408 policy instruments. To evaluate the effectiveness of policy instruments, the evaluation criteria proposed by the IPCC (2022) are employed, which include Environmental effectiveness, Economic effectiveness, Distributional effects, Co-benefits, negative side-effects, Institutional requirements, and Transformative potential. Through case studies that assess and compare the effectiveness of important policy instruments in the three countries, corresponding policy recommendations are proposed.

Due to the extensive scope of climate mitigation policies and the sheer number of policies involved, it is not practical to conduct a comprehensive evaluation of the effectiveness of all policies within the limitations of this article. Nevertheless, by examining the climate mitigation efforts of the three countries, this study can help bridge the current research gap and provide essential groundwork for future research.

The remaining sections of this article are organized as follows: Part 2 offers an overview of the data search, classification, matching, and methodology employed in this study. Part 3 presents an analysis and comparison of the vertical policy hierarchy, horizontal policy paths, and policy instruments of climate mitigation policies in Germany, France, and the Netherlands. Finally, Part 4 presents the conclusion of this study.

2. Data and methodology

2.1. Data collection and screening

The data collection and organization process for climate mitigation policies is divided into the following steps. Firstly, this study defines the climate mitigation policies of the three countries based on Germany's Climate Action Plan 2050, France's National Low Carbon Strategy, and the Netherlands' Climate Agreement, as well as subsequent revision documents. Subsequently, policy data is collected from websites of official government in three countries in two round. Finally, the climate mitigation policies are screened, summarized, and compiled to form a comprehensive climate mitigation policy database. As of December 2022, a total of 103 laws, 125 ordinances/decrees, 47 strategies, 126 plans, and 408 policy instruments have been collected and included in the database.

2.2. Analysis framework

This article presents a comprehensive framework for analyzing the 'vertical policy hierarchy-horizontal policy path-policy instruments' in a systematic manner. Initially, the governance of Germany, France, and the Netherlands starts from the enactment of laws by their respective legislative bodies. The central government, in line with mandated climate objectives set forth in these laws, then establish guiding national strategies. Administrative bodies subsequently issue regulations and commands, develop plans aligned with sector-specific targets, issue policies, and establish funds. In light of these governance structures, this article establishes six major vertical policy hierarchies, namely Act/Law, Ordinance/Decree, Fund, Strategy, Plan, and Policy Instrument. Furthermore, the article underscores that worldwide climate mitigation policies primarily concentrate on addressing high-emission sectors, including energy, transport, buildings, industry, agriculture, forest, and waste. The Horizontal Policy Path is derived from the objectives and policy directions specified in these seven areas, as exemplified by Germany's Climate Action Plan 2050, France's National Low Carbon Strategy, and the Netherlands' Climate Agreement (figure 1).

Finally, this study carries out a classification and appraisal of policy instruments in three countries. Six policies instruments categorization methods have been employed in this article: Regulatory Reform, Market-based Mechanisms, Commercialization Mechanisms, Financial/Fiscal Mechanisms, Direct Investment, and Governance Mechanisms (Peñasco *et al* 2021, IPCC 2022). The secondary and tertiary policy instruments have been expanded to facilitate comparative analysis of policies across different countries. Moreover, a specific policy instrument can lead a diverse outcomes. This article employs six evaluation criteria for policy instruments: Environmental effectiveness, Economic effectiveness, Distributional effects, Co-benefits, negative side-effects, Institutional requirements, and Transformative potential (IPCC 2022). These criteria are utilized to analyze the implementation effects of key policy instruments and to summarize experiences in the formulation of climate mitigation policies (figure 2).

3. Result

3.1. Vertical policy hierarchy

Figure 3 depicts the six vertical policy hierarchies in Germany, France, and the Netherlands. These hierarchies are arranged in a cascading and transmitting manner from the top to the bottom. It is noteworthy that all three countries possess well-established legal systems, clear long-term strategies, short-term plans, and corresponding policy instruments. However, Germany and France exhibit a higher degree of establishment and comprehensiveness in comparison to the Netherlands.

(1) The parliaments pass laws including climate laws and other related legal measures. According to Averchenkova *et al* (2017) and Rumble (2019). Climate laws establish statutory climate targets and allocate responsibilities. In June 2021, Germany revised its Climate Change Act, with the aim of reducing greenhouse gas emissions by 88% by 2040 and achieving net-zero emissions by 2045. Similarly, France's Energy-Climate Law, passed in November 2019, sets the target of achieving carbon neutrality by 2050. The Dutch Parliament also passed the Climate Act in 2019 to achieve carbon neutrality by 2050. In addition to climate laws, other laws related to climate mitigation serve as legal bases for sector-specific emission reduction policies, such as carbon emissions, taxation, transport, buildings, energy, and environment, etc.
(2) Government departments have the authority to issue ordinances or decrees aimed at restricting greenhouse gas emissions from various sources, such as automobiles and industries. They can also establish standards for the use of renewable energy, buildings, and infrastructure.
(3) National strategies and action plans are developed and implemented by various administrative departments to address specific sectors and achieve emission reduction targets.

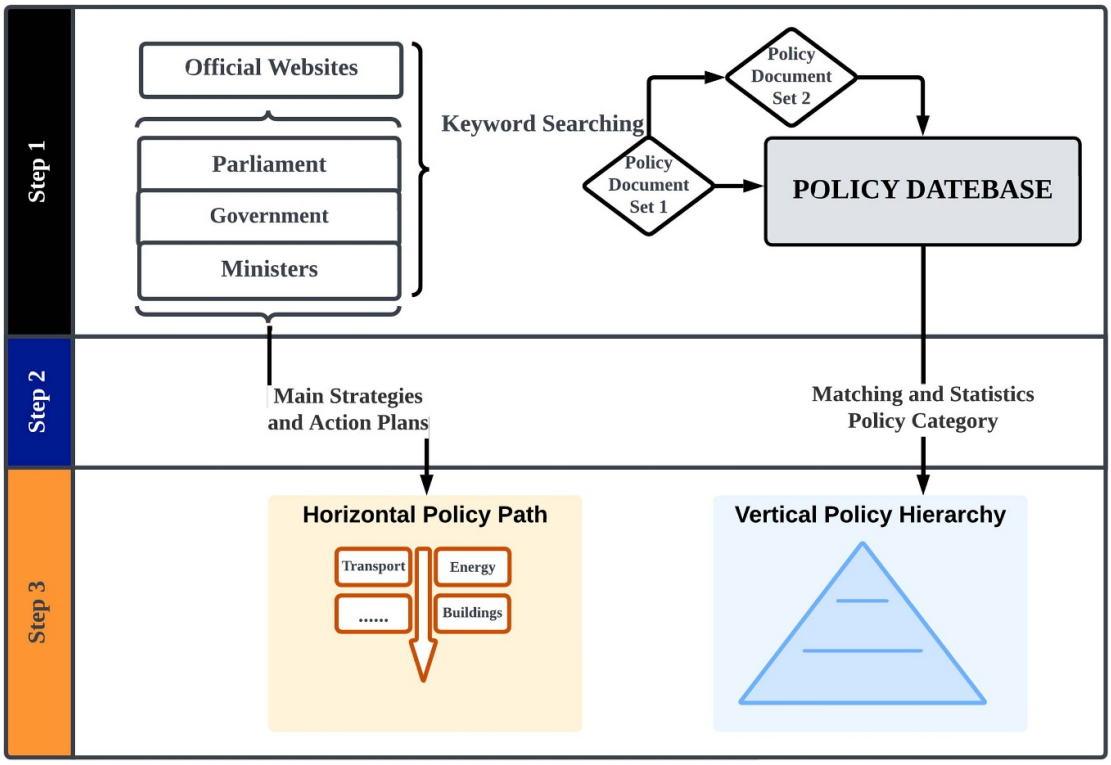

Figure 1. Policy analysis methodology.

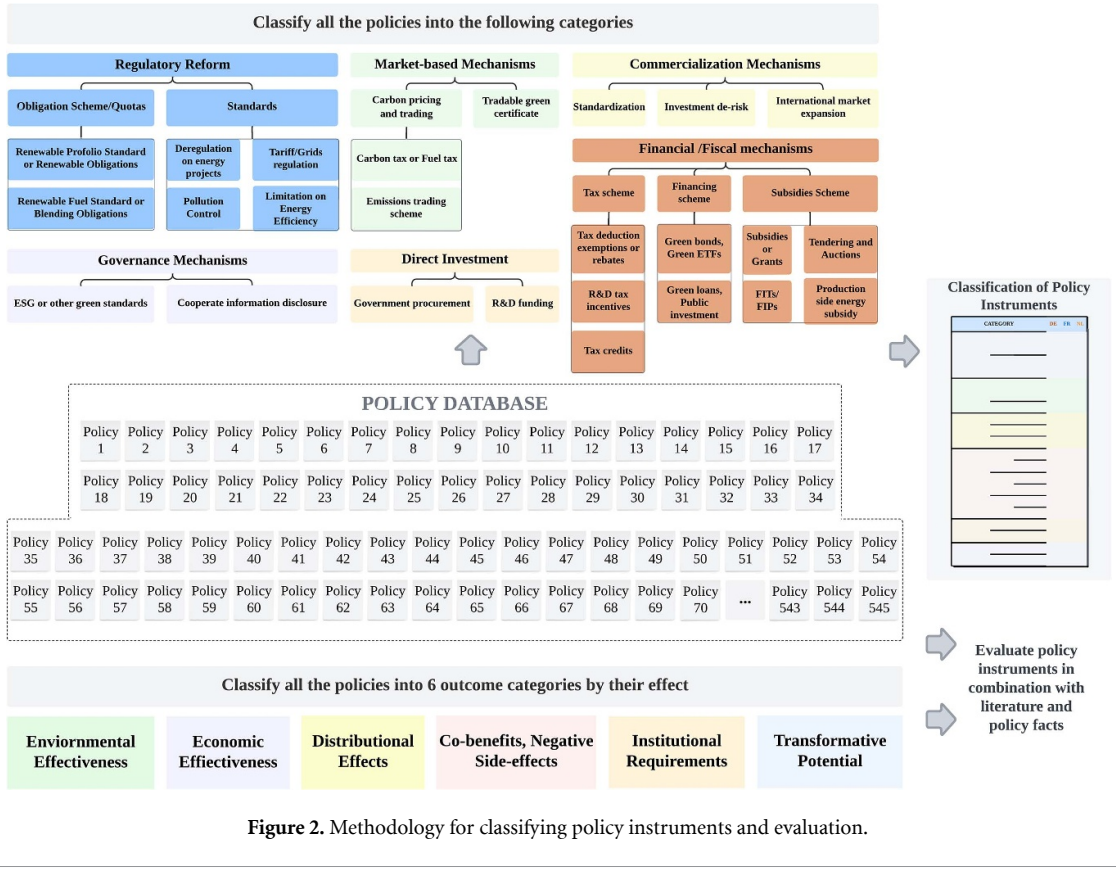

Figure 2. Methodology for classifying policy instruments and evaluation.

These plans provide systematic measures and timetables for achieving these targets in various sectors, as noted by Mathy (2007), Voß *et al* (2009), Bataille *et al* (2016), Levin *et al* (2018), and WRI (2020). Germany and France have more comprehensive strategies and plans

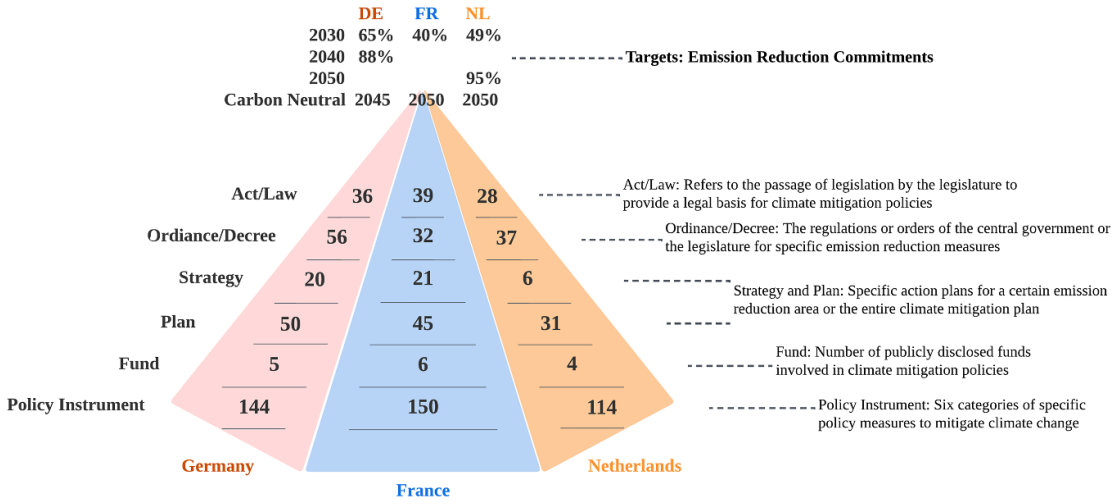

Figure 3. Statistic of vertical policy hierarchy for Germany, France and the Netherlands.

compared to the Netherlands, covering a wide range of areas such as energy, buildings, agriculture, industry, forest, and transport. These plans include policies and measures planned for the short, medium, and long term.

(4) The funds established by Germany, France, and the Netherlands for climate change mitigation reflect the areas and forms of financial support in the three countries. For instance, Germany's Green Climate Fund is designed to protect forests, while France's The Heat Fund encourages the replacement of fossil fuel facilities. The Dutch Green Fund, on the other hand, focuses on energy transition, sustainable agriculture, circular economy, and other related areas.

(5) Policy instruments refer to the specific means of implementing climate mitigation policies, and a detailed classification and evaluation of these instruments can be found in section 3.3.

3.2. Horizontal policy path

This paper has accomplished the horizontal policy trajectory by means of a conflation of objectives and policies in seven pivotal sectors of emission reduction, namely energy, transport, buildings, industry, agriculture, forest, and waste. This trajectory functions as a strategic instrument to realize both immediate and enduring objectives of emission reduction (figure 4).

At the horizontal hierarchy of climate mitigation policy trajectory, Germany, France, and the Netherlands exhibit shared characteristics that are influenced by EU directives, as well as distinctive dissimilarities that stem from their resource endowments and emission structures. The three nations prioritize different areas and policies within the same sectors. On the one hand, they are all subject to the EU legal framework and policy guidance, which mandate the implementation of the EU Emissions Trading System (EU ETS), climate action regulations, and renewable energy directives. The European Green Deal, which was announced in 2019, established specific targets and provided supportive measures for a host of sectors in Europe. The pathway maps of EU member states have identified several consistent policy directions, including energy transition financing, circular economy, building retrofitting, intelligent transportation, and biodiversity. However, the policy trajectories of the three aforementioned countries diverge significantly due to differences in their greenhouse gas emission structures. They all prioritize the sectors that contribute the most to national greenhouse gas emissions. Germany places a strong emphasis on enhancing energy efficiency and phasing out fossil fuel power generation. France concentrates on transforming transportation vehicles and developing charging infrastructure as the main leverage points. The Netherlands regards circular economy, offshore wind energy, and solar energy as the key breakthroughs.

Energy Sector. The energy sector is a significant contributor to greenhouse gas emissions, accounting for 30% of total emissions in Germany. The German government has committed to achieving zero emissions in electricity production by 2050, with measures such as adopting the renewable energy, implementing combined heat and power generation, and gradually phasing out coal-fired power generation. In contrast, greenhouse gas emissions in the French energy sector account for only 11.7% of total emissions. France plans to further develop nuclear energy and other renewable energy sources, optimize the energy mix, improve energy efficiency, and smooth the electricity demand curve. The Netherlands, renowned for offshore wind power, will provide favorable conditions for offshore wind energy utilization while also strengthening onshore renewable energy production and developing hydrogen energy. Additionally, all three countries prioritize the EU Emissions Trading

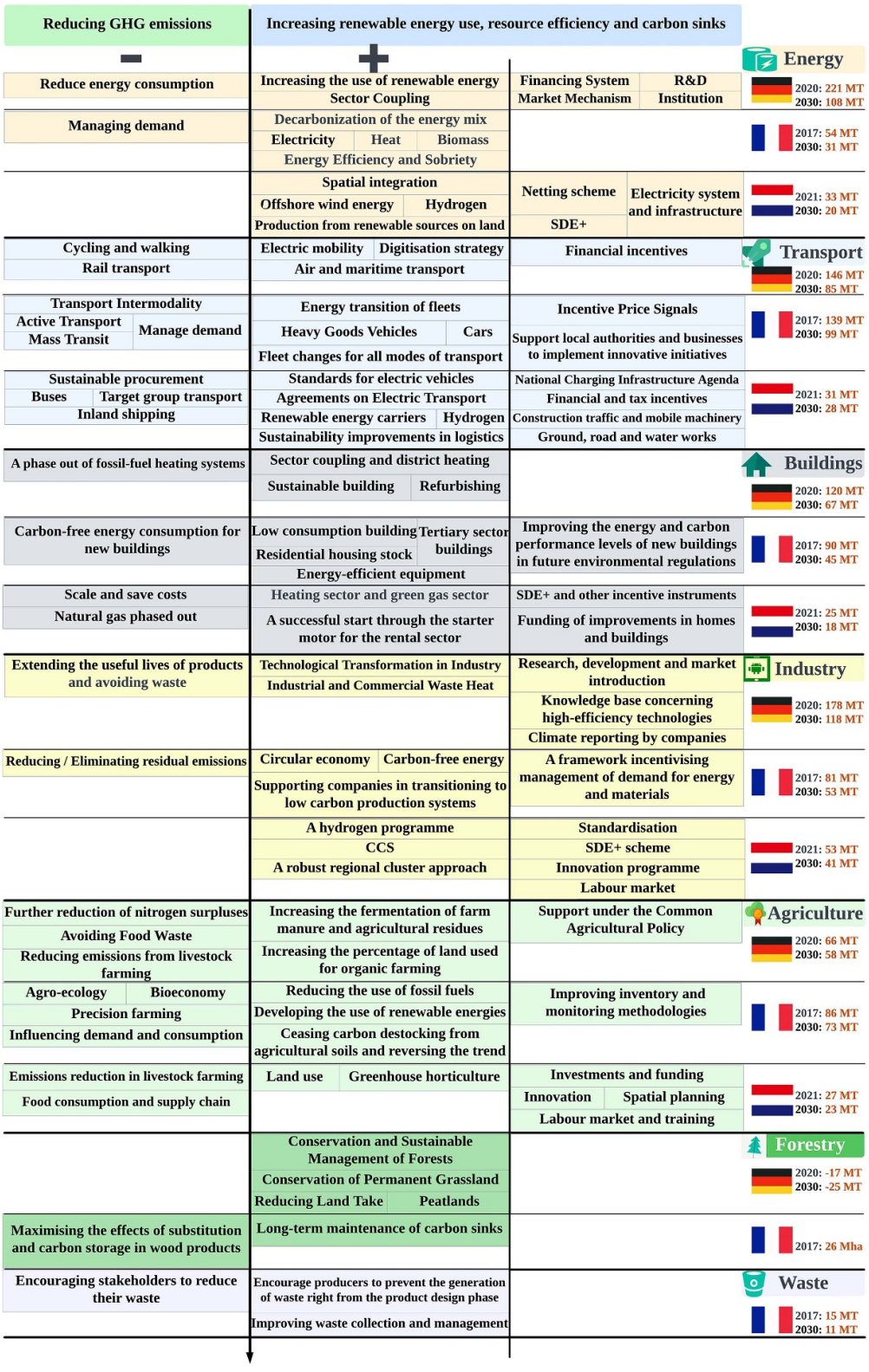

Figure 4. Horizontal policy path for climate mitigation policies in Germany, France and the Netherlands.

System (EU ETS) and employ carbon pricing to reduce greenhouse gas emissions.

Transport Sector. The current emissions stemming from Germany are still notably distant from the 2030 targets. To combat this, Germany will concentrate on bolstering battery research and development, subsidizing the electric vehicle industry, providing financial assistance for the development of public transportation and cycling, and emphasizing the digitization of the transport industry. In France, the transport sector is responsible for 30% of the total emissions, with 90% of greenhouse

gas emissions originating from fossil fuel use. To address this, France has proposed policies to encourage the transition of transportation vehicles' energy sources, transform transportation modes, promote the use of public transportation and bicycles, and strengthen management of transportation demand. The Netherlands has set its sights on increasing the share of renewable energy use in the transport sector, developing electric passenger transport and vehicles, improving the logistics system, and advocating for individual green travel.

Buildings Sector. The buildings sector in Germany currently exhibits a significant gap in emissions when compared to the targets as well. To address this, Germany will update the standards for zero-energy buildings and improve building energy efficiency. Germany has prioritized policies that focus on the interconnection between the buildings sector and the energy, industry, and transport sectors. For instance, waste heat from buildings can be utilized to charge electric vehicles, and heat generated by large-scale heat pumps or solar thermal systems can be used to heat the grid. In France, the buildings sector accounts for a relatively high proportion (19%) of greenhouse gas emissions, and France has proposed to reduce emissions by leveraging zero-carbon energy sources, improving energy efficiency, and extending the lifespan of buildings. In contrast, the Netherlands has placed emphasis on reducing building costs through innovative solutions, developing building standards, providing renovation subsidies for businesses and individuals, and gradually phasing out natural gas to reduce greenhouse gas emissions.

Industry Sector. The industrial and commercial sectors represent the second-largest source of emissions in Germany. Given the significant electricity consumption in these sectors' production activities, emissions reduction is closely linked to the energy sector. To address this, the German government aims to leverage the role of the EU ETS in the industrial and commercial sectors and implement measures to improve energy efficiency, such as energy auditing instruments, financial incentives, and product labeling. Similarly, France utilizes the EU ETS to regulate industrial emissions, supports the transition of companies to low-carbon production, encourages low-carbon technology development, and focuses on the circular economy. In the Netherlands, the industrial sector is the largest source of greenhouse gas emissions. The Dutch government collaborates with businesses to stimulate emission reduction through innovation, hydrogen energy, regional clusters, carbon taxes, and the 'SDE+' program.

Agriculture Sector. Germany's agricultural focus is centered on reducing emissions and enhancing resource efficiency. A biostrategy has been proposed to curtail fossil fuels as well as fertilizer application, augment the proportion of organic farming land, and harness agricultural residues for energy production. The agricultural sector in France is responsible for nearly 20% of the country's greenhouse gas emissions. To address this, France has set its sights on improving agricultural ecology, fostering low-carbon energy production, and promoting the bioeconomy. The Netherlands is committed to reducing emissions from livestock farming and food. To achieve this, the country has devised a biomass energy roadmap, enhanced land use efficiency, and encouraged greenhouse horticulture.

Forest Sector. Germany has set its sights on achieving net-negative emissions after attaining net-zero emissions, as one of the few countries to propose such a strategy (Buylova *et al* 2021). To achieve this, Germany is prioritizing sustainable forest management, which includes safeguarding peatlands and grasslands; while curtailing land development in line with the sustainable development strategy. The French government is concentrating on optimizing supply-demand management in forest in the short, medium, and long term. As for the Netherlands, there are currently no specific policy pathways in place for the forest sector.

Waste Sector. While Germany and the Netherlands have not adopted the Waste Sector as a separate issue of their climate change mitigation strategies, both have introduced policies aimed at reducing food waste. While waste is not explicitly targeted as part of their climate mitigation strategies, France has proposed a comprehensive approach to waste management that encompasses waste reduction by waste owners, waste prevention by producers, and efficiency improvements in waste reuse and disposal processes at all stages (Buylova *et al* 2021).

3.3. Policy instruments and evaluation

3.3.1. Classification of policy instruments

In this section, classification and comparison of 408 policy instruments in Germany, France, and the Netherlands were conducted, and the differences and collective trends in the use of policy instruments by these three countries were summarized (figure 5).

3.3.1.1. Regulatory reform

Regulatory Reform refers to the establishment of rules and targets through regulations and standards that energy producers and polluters must comply with. This category includes standards for renewable energy production and final use (Falk *et al* 2020, Boehm *et al* 2022, IRENA 2023), environmental pollution (Hall *et al* 2021, Graver *et al* 2022, Pavlenko and O'Malley 2022, Sen and Miller 2022), tariff/grid regulation (Falk *et al* 2020, IEA 2021), and energy efficiency limitations (CAT 2022, IEA, IRENA and UN Climate Change High- Champions 2022).

CATEGORY			DE	FR	NL
Regulatory Reform	Obligation schemes/quotas	Renewable portfolio standard or Renewable obligations *(in power generation)*	√ (4)	√ (1)	√ (1)
		Renewable fuel standard or Blending obligation *(in end-use fuel sold)*	√ (1)	√ (3)	√ (2)
	Standards	Deregulation on energy projects	√ (4)	√ (2)	√ (3)
		Tariff/Grids regulation	√ (4)	√ (5)	√ (1)
		Pollution Control	√ (8)	√ (11)	√ (5)
		Limitation on Energy Efficiency	√ (2)	√ (2)	√ (1)
	Regulatory Reform / Total		15.97%	15.33%	11.40%
Market-based Mechanisms	Carbon pricing and trading	Carbon tax or Fuel tax	√ (5)	√ (6)	√ (3)
		Emissions trading scheme	√ (11)	√ (4)	√ (3)
		Tradable green certificate	√ (1)		
	Market-based Mechanisms / Total		11.81%	6.67%	5.26%
Commercialization Mechanisms		Standardization	√ (8)	√ (2)	
		Investment de-risk		√ (1)	
		International market expansion	√ (2)		
	Commercialization Mechanisms / Total		6.94%	2.00%	0.00%
Financial/Fiscal Mechanisms	Tax scheme	Tax deduction, Exemptions or Rebates	√ (10)	√ (4)	√ (7)
		R&D tax incentives			
		Tax credits	√ (2)	√ (4)	√ (1)
	Financing scheme	Green bonds, Green ETFs	√ (1)	√ (1)	√ (1)
		Green loans, Public investment	√ (7)	√ (7)	√ (6)
	Subsidies scheme	Subsidies or Grants	√ (23)	√ (30)	√ (36)
		Feed-in tariffs (FITs) and feed-in premiums (FIPs)	√ (2)	√ (2)	
		Tendering and auctions	√ (6)	√ (14)	√ (6)
		Production-side energy subsidy	√ (5)	√ (2)	√ (6)
	Financial/Fiscal Mechanisms / Total		38.89%	42.67%	55.26%
Direct Investment		Government procurement	√ (7)	√ (10)	√ (9)
		R&D funding	√ (18)	√ (7)	√ (6)
	Direct Investment / Total		17.36%	11.33%	13.16%
Governance Mechanisms		ESG or other Green standards	√ (12)	√ (20)	√ (15)
		Cooperate information disclosure	√ (6)	√ (19)	√ (7)
	Governance Mechanisms / Total		12.50%	26.00%	19.30%

Figure 5. Classification of policy instruments in Germany, France and the Netherlands.
Figure Note: The sum of the six categories of policy instruments in each country may be greater than 100 %, because the same policy may belong to multiple types of policy instruments.

Regulatory Reform policies in In Germany are primarily concerning increasing the share of renewable energy, phasing out fossil fuels, and implementing the European Union's energy efficiency directives. The energy sector is responsible for over 30% of the total emissions, with the majority coming from the combustion of mineral fuels. To address this, the German government has set a target of achieving an 80% share of renewable energy in total electricity consumption by 2030, and phasing out coal-fired power

generation by no later than 2038, with some lignite and hard coal power plants were already closed in 2021. Once coal-fired power generation is eliminated, Germany will achieve net-zero emissions in its power supply. Additionally, Germany has implemented a range of measures to accelerate the deployment of renewable energy, including modifying land planning to meet onshore wind power land requirements, streamlining the approval process for renewable energy projects, and expediting grid planning and approval.

In France, Regulatory Reform policies are primarily aimed at controlling pollution and accelerating the generation of renewable energy. These measures include regulations on vehicle emissions, fuel composition requirements, waste incineration bans, and achieving a decarbonized power structure. France distinguishes itself by predominantly relying on nuclear power and renewable energy sources for its electricity generation. However, France encounters significant emissions from its transport sector, wherein approximately 90% of the fuel consumed is derived from fossil fuels. In response to this challenge, the French government has implemented renewable fuel utilization directives and established stringent monitoring systems to track emissions originating from the transport sector. Notably, in 2018, a remarkable 93% of France's electricity production was carbon-free with the next step committed to the increased integration of renewable energy recovery methods while also enforcing regulations to prohibit uncontrolled waste disposal practices.

Several measures have been implemented by the Netherlands in terms of Regulatory Reform. These measures encompass the prohibition of coal-fired power generation, the implementation of emission control in the transport sector, the acceleration of wind power construction and integration, the reduction of thresholds for renewable energy production, such as biomass energy, and the implementation of the European Union's energy efficiency directives. The Netherlands banned coal-fired power generation, thereby further increasing the proportion of wind and solar power generation. Additionally, regulations have been set on the quantity of biofuels available in the market and vehicle emissions in the transport sector.

3.3.1.2. Market-based mechanisms

Market-based Mechanisms refer to the market-based approach with the imposing of carbon taxes on economic activities and the establishing of emission trading systems to reduce greenhouse gas emissions (FSR Climate 2019, Bayer and Aklin 2020, Best *et al* 2020, Rafaty *et al* 2020, Green 2021, World Bank 2022).

The implementation of carbon taxes, such as vehicle emissions energy production, etc, has been observed in Germany, France, and the Netherlands. These countries have also adopted the European Union Emissions Trading System (EU ETS) to regulate greenhouse gas emissions from energy-intensive industries, including power, gas, steel, and aviation. To fulfill the commitment of reducing greenhouse gas emissions by 55% compared to 1990 levels by 2030 and achieving net-zero emissions by 2050, the EU Climate Law was enacted in July 2021. Enhancing the EU ETS is one of the comprehensive measures to achieve this target. In April 2023, the EU formally incorporated shipping into the EU ETS and introduced measures such as the Carbon Border Adjustment Mechanism and the establishment of the European Social Climate Fund.

3.3.1.3. Commercialization mechanisms

The implementation of Commercialization Mechanisms involves policies that are designed to promote marketization, create overseas demand, and increase cross-border investment returns for domestic enterprises. These policies include encouraging the standardization of green technologies, facilitating international market expansion, and providing project financing through loan guarantees and green equity, among others (UNFCCC 2015b, IEA, IRENA and UN Climate Change High- Champions 2022, IPCC 2022).

To achieve its 2045 goals, Germany has identified CCS technology and hydrogen as important pathways. The National Hydrogen Strategy, which was introduced in 2020, includes 38 measures that focus on promoting hydrogen industrial production, expanding the hydrogen market, and establishing a reliable regulatory framework. Germany is also expanding its international presence in the hydrogen sector through collaborations in technology development and establishing hydrogen value chains. To this end, bilateral agreements and hydrogen projects have been signed with countries in the Middle East and Australia. Germany also introduced the carbon capture, utilization and storage (CCUS) Demonstration and Application Act to validate the feasibility and safety of CCS technology and establish standards for investigation, operation, monitoring, decommissioning, and liability.

3.3.1.4. Financial/Fiscal mechanisms

The objective of Financial/Fiscal Mechanisms is to incentivize stakeholders in the low-carbon transition to reduce greenhouse gas emissions by providing them with higher returns or lower transformation costs through tax schemes, financing schemes, and subsidy schemes.

Tax incentives aimed at promoting electric vehicles, building renovations, and clean transport have been implemented in Germany, France, and the Netherlands. During the COVID-19 pandemic, these countries have provided enhanced support for small and medium-sized enterprises. Germany has

introduced tax reductions or refunds for the installation of renewable energy heating systems, the promotion of electric vehicles, and the use of public transport and long-distance rail. France's tax incentives focus on housing renovations, promoting hybrid electric vehicles, and upgrading buildings for small and medium-sized enterprises. The Netherlands has implemented tax reductions or refunds to increase renewable energy electricity consumption, promote electric vehicles and bicycles, and foster research and development of energy-saving technologies.

With respect to financing schemes, green bonds are being implemented in these three countries, with a focus on transport infrastructure construction and the promotion of renewable energy. However, each country has its own emphasis. Germany prioritizes digitization of the transport sector, France focuses on housing loans, and the Netherlands places importance on clean agriculture loans. Germany has implemented federal green bonds and provides favorable financing policies for the commercialization of renewable energy, cleaner agricultural equipment, the renovation of railway networks, and digitization. France began implementing its green bonds earlier than Germany, with financing committed to energy transition, clean vehicles, infrastructure construction, and eco-housing loans. The financing in the Netherlands emphasizes sustainable and cleaner agriculture in addition to promoting renewable energy heating and energy-efficient buildings in its financing.

The most commonly used policy instrument in these three countries is the subsidies scheme, which covers almost all necessary areas. The aforementioned subsidies include the promotion of renewable energy in the buildings sector, housing renovation, and allowances; subsidies for renewable energy generation; the advancement of electric vehicles and public transportation in the transport sector; and support for clean equipment in the agricultural sector. These subsidies have notably expanded in both scale and scope in the examined countries since 2019 due to the significant impact of the COVID-19 pandemic and the increased public scrutiny to tackle the climate crisis.

3.3.1.5. Direct investment

Direct investment is an important policy instrument adopted by governments to address climate change, as it can be seen as providing public goods to combat the 'public bad' of climate change. This form of investment includes investments in infrastructure (Jaramillo *et al* 2022, Ragon *et al* 2022), providing cleaner heating systems and public transport services (Grazi and Van den Bergh 2008), and funding low-carbon technologies (Metz 2009).

Direct investment is a crucial measure for these three countries to directly participate in the green transition. The German government has always emphasized the research and development of high energy efficient and low-emission technologies and has implemented over 18 policies to fund cutting-edge research in areas such as electric vehicles, batteries, digital transport, hydrogen, and climate change. In addition to investing a significant amount of funds in the construction of charging infrastructure, bicycles, and other facilities, France has also introduced a series of measures for government public procurement, including the purchase of electric vehicles and clean electricity. The Netherlands encourages more business engagement in the research and development of CCUS (carbon capture, utilization, and storage) and renewable energy technologies, while the government primarily focuses on direct investment in building renovations.

3.3.1.6. Governance mechanisms

Governance mechanisms refers to the set of standards for the promotion of corporate social responsibility investments, promoting climate justice, and establishing specific standards for corporate social responsibility information disclosure. Policies include disclosing corporate data related to climate change (Evain *et al* 2018, O'Dwyer and Unerman 2020), disclosing energy efficiency information of products (Gössling and Buckley 2016, Camilleri *et al* 2019), and the promotion of voluntary emission reduction agreements (Mundaca and Markandya 2016, Cornelis 2019), among others.

Germany, France, and the Netherlands are recognized as leading countries in the utilization of governance mechanisms within the realm of climate governance. Specifically, Germany has implemented a robust sustainable building assessment system, along with setting clear benchmarks for renewable energy initiatives, energy audits, and emission regulations applicable to businesses and institutions. In a similar vein, France has established mandates for enterprises to procure environmentally friendly vehicles, implemented standards for airspace management, and enacted social responsibility investment guidelines for financial asset management. Likewise, the Netherlands has put forth proposals for social responsibility investment criteria, reporting standards concerning corporate emissions, and regulations pertaining to environmentally conscious procurement practices. In terms of climate commitment issues, France has been particularly successful. Various industries, including trade, tourism, aviation, and food sectors have made climate commitments voluntarily or with government support. In terms of information disclosure, all three countries have introduced measures such as energy efficiency labels, energy consumption labels, emission reduction labels, and fuel labels. These measures will

promote increased attention to the climate crisis by businesses and the public and lead to changes in production and consumption behaviors.

3.3.2. Evaluation of policy instruments

Assessing the effectiveness of climate mitigation actions in a country cannot be solely based on the number of policy instruments employed. The evaluation of 408 policy instruments presents a complex and challenging task. Previous research has indicated that the quantity of policies can impact the outcomes of climate change mitigation (Eskander and Fankhauser 2020). However, the effectiveness and stringency of policies vary across different countries or regions (Compston and Bailey 2016, Green 2021, Burck *et al* 2023). Additionally, policy feasibility, credibility, and characteristics are among the other factors that can influence policy effectiveness (Averchenkova and Bassi 2016, Schmidt and Sewerin 2019, Jewell and Cherp 2020). Additionally, a multidimensional assessment approach is necessary for evaluating policy instruments (Huitema *et al* 2011, Ansolabehere and Konisky 2016, Stokes and Warshaw 2017, Deng *et al* 2018, IPCC 2022). However, there is currently no widely recognized or applied method for comparing policy effectiveness (Compston and Bailey 2016, Tosun and Schnepf 2020, Fekete *et al* 2021, Dubash *et al* 2022, Burck *et al* 2023). Therefore, analyzing the strictness and effectiveness of 408 policy instruments is not the problem to be solved in this section, but the direction of future research.

The primary focus of this section is to evaluate the significant policy instruments of the three countries through case studies, which combine literature and policy facts. To conduct a multidimensional comparative analysis of the effectiveness of crucial policy instruments in Germany, France, and the Netherlands, this section employs the six assessment criteria proposed by the IPCC (2022) in 'Climate Change Mitigation of Climate Change.' The section identifies the strengths and weaknesses of the policy instruments and provides corresponding policy recommendations.

The six assessment criteria for policy instruments are as follows: environmental effectiveness, economic effectiveness, distributional effects, co-benefits and negative side-effects, institutional requirements, and transformative potential.

3.3.2.1. Germany

Firstly, the policy of phasing out coal-fired power generation by the German government has been effective in terms of environmental impact and has taken into account distributional effects, thereby playing a significant role in the smooth transition of Germany's energy sector. Coal-fired power plants have been a crucial component of the German energy system, providing almost half of the country's electricity consumption. The German government has made the decision to terminate coal-fired power generation by no later than 2038, which will have a significant impact on the balance of the energy system (Parra *et al* 2019). The transition process necessitates addressing issues such as employment, public pressure, and the economy. To tackle these challenges, Germany has established the Commission on Growth, Structural Change and Employment, comprising experts and stakeholders from industry, associations, labor unions, academia, and politics. The commission has been entrusted with the responsibility of devising strategies for the gradual phase-out of coal-fired power plants and providing savings plans for unemployed workers.

Secondly, the carbon pricing policy implemented by Germany and the EU Emissions Trading System (EU ETS) have played a pivotal role in reducing emissions and driving transformation across various sectors. These policies have been effective in terms of environmental impact, economic efficiency, positive synergistic effects, and transformative potential. Studies have shown that the EU ETS has led to a reduction in emissions from Germany's electricity sector through carbon prices and quotas (Schäfer 2019). Carbon pricing has also had a positive impact on the efficiency of Germany's manufacturing sector and power plants (Löschel *et al* 2019, Germeshausen 2020). Furthermore, carbon/energy taxes are gradually replacing labor taxes, thereby reducing labor costs. For instance, Germany's ecological tax has contributed to the creation of more employment opportunities, known as the double dividend (Murtagh *et al* 2013, Freire-González and Ho 2019).

Thirdly, the substitution of renewable energy for conventional energy in Germany has been significantly accelerated through the formulation and practical implementation of relevant renewable energy policies, including funding, subsidies, and pilot projects, which have been supported by extensive research. This has resulted in the realization of Germany's 100% renewable energy system, which has long-term transformative potential and positive synergistic effects (Hansen *et al* 2019, Oei *et al* 2020). Germany's renewable energy policies have provided funding for research and development of renewable energy from the outset. In the 1970s and 1980s, subsidies for demonstration projects were provided, and scaling-up occurred in the 1990s, which significantly accelerated innovation in green products through Germany's subsidies (Stucki *et al* 2018). The global solar photovoltaic industry has been expanded through feed-in tariffs, which have significantly reduced production costs, promoted automation and scalability, and increased its competitivity compared to fossil fuels (Lauber and Jacobsson 2016, Buchholz *et al* 2019). Similar efforts have been made for wind

energy, with early research and demonstration projects playing a crucial role in its promotion, indicating good long-term transformative potential and synergistic effects (Chaudhary *et al* 2015, Dai and Xue 2015, Lacal-Arántegui 2019).

Moreover, Germany's transformative policies in the transport sector have had a profound impact on the structure of its transport industry, facilitating the achievement of energy transition goals and offering positive synergistic effects and transformative potential. Germany aims to leverage information technology and the Internet of Things to enhance the digitalization level of the transport sector and reduce mobility demand (Canzler and Wittowsky 2016). Studies suggest that Germany's transport policies can lead to the electrification of private cars by 2030 (Schmid and Knopf 2012).

Finally, Germany's energy audit policies for small and medium-sized enterprises have been effective in reducing energy consumption by 5%–70% (Kluczek and Olszewski 2017). Policies for buildings have also been successful in decreasing air pollution and having a positive impact on public health (MacNaughton *et al* 2018), demonstrating direct environmental effects and positive synergistic effects.

3.3.2.2. France

Firstly, in regards to the disclosure of greenhouse gas emissions by businesses, France places a particular emphasis on this matter. In 2013, transport service companies were required to provide reports on their greenhouse gas emissions, and by 2015, a law was enacted mandating all companies to disclose their emissions reports. France subsequently introduced laws requiring corporate climate reporting and investor climate reporting, making it one of the first countries to mandate financial institutions to disclose climate risks. These policies have the potential to encourage businesses to take greater responsibility in addressing climate change and have a transformative impact on the environment. However, the stringency of these policies needs to be strengthened, as the scope and detail of disclosures by companies vary. For example, a significant proportion of companies fail to report physical risks (Evain *et al* 2018).

Secondly, the role of nuclear power in achieving a balanced and stable energy transition in France is significant, owing to the coherence of policies and public support. In response to the oil crisis in the 1970s, France developed a nuclear strategy to address energy security concerns. The development of small modular reactors and significant progress in the flexibility of nuclear power plants have been achieved. This progress has been accompanied by widespread political support, a coherent nuclear waste policy, and effective management and decision-making (Metlay 2016). The French energy system has maintained continuous balance and stability (FTI Consulting 2018), providing a solid foundation for the green transformation of the country's energy sector.

Furthermore, the implementation of carbon tax policies in France has encountered challenges in promoting public acceptance while ensuring fairness. The French public has expressed strong dissatisfaction and resistance to the implementation of carbon tax policies. The increase in fuel costs due to the rise in carbon taxes triggered the iconic 'Yellow Vest' movement in France (Berry and Laurent 2019, Lianos 2019). This movement involves issues of income inequality and other social concerns. The costs and benefits of carbon taxes vary among different groups, and between urban and rural areas. There is a contradiction between public concerns about climate change and their expectations regarding costs. The French government needs to enhance its communication efforts and increase public acceptance of carbon taxes (Douenne and Fabre 2020), while also giving due consideration to the fairness and economic effectiveness of the policies.

Finally, France aims to increase the proportion of renewable energy in its electricity generation. It is crucial for France to integrate into the European grid and import renewable energy (Brown *et al* 2018). However, this may have implications for energy security and the sustainability of energy production outside the European Union (Daioglou *et al* 2020, Mandley *et al* 2020). Therefore, policymakers need to consider the potential negative synergistic effects of such policies.

3.3.2.3. The Netherlands

Firstly, the impact of climate litigation on climate change mitigation policies in the Netherlands has been significant. Governments and legislative bodies can use their administrative or legislative powers to make commitments to reduce greenhouse gas emissions. However, such commitments and their accompanying policies must consider environmental effectiveness, transformative potential, and institutional requirements. In recent years, climate litigation has become an important means of either promoting or impeding the Dutch government's response to climate change (Roy and Woerdman 2016, Mayer 2019, Paiement 2021, Sindico *et al* 2021). The Urgenda vs State of the Netherlands case constitutes a landmark example. The District Court made a judicial request that the emission reduction target of 17% set by the Dutch government was deemed inadequate in representing a just and equitable contribution from the Netherlands. Consequently, the court issued a directive to the Dutch government, mandating a minimum reduction of 25% in emissions by the conclusion of 2020, and further requiring the implementation of supplementary measures to attain this objective. This ruling was ultimately supported by the Supreme Court in 2019. Since 2015, significant changes have

been observed in climate policies in the Netherlands. These changes include the introduction of climate legislation and the decision to close all remaining coal-fired power plants by 2030 (Verschuuren 2019, Wonneberger and Vliegenthart 2021).

Moreover, the Dutch government has made remarkable progress in promoting a circular economy and has emerged as a leading example in this domain. The circular economy is a crucial strategy for reducing society's demand for energy and materials, and the Dutch government has demonstrated maturity in implementing circular economy policies, achieving good environmental effectiveness and transformative potential. According to the Organisation for Economic Co-operation and Development (OECD 2019), if the world continues to follow traditional production and consumption patterns, the increasing demand for energy and materials could lead to severe environmental consequences by 2060. However, the circular economy presents a more sustainable alternative by reducing environmental harm while maintaining the same level of demand. The Netherlands Environmental Assessment Agency has proposed an innovative circular strategy, which includes Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover energy (Potting *et al* 2018). Additionally, the government offers green loans, tax incentives, and research and development subsidies for circular economy projects and technologies. Finally, the sustainable public procurement policy advocated by the Dutch government is a notable example of effective climate change mitigation policy. This policy is characterized by its distinct features, evident effectiveness, and wide-ranging scope.

Since 2005, the Dutch government has implemented sustainable public procurement policies that cover various aspects such as green public procurement, bio-based public procurement, ESG, and the circular economy. This has resulted in environmental effectiveness and positive synergistic effects. Firstly, the implementation of green public procurement measures serves to curtail the detrimental ecological effects stemming from both corporate production and government consumption (Melissen and Reinders 2012, Cerutti *et al* 2016, Ghisetti 2017). If all public authorities in the Netherlands were to adopt national sustainable public procurement standards, it could potentially reduce carbon dioxide emissions by a significant 3 million tons (ICLEI 2021). Secondly, businesses that attain commendable levels of emission reduction can obtain a competitive edge through sustainable public procurement, thereby fostering an incentive for more companies to actively reduce their greenhouse gas emissions (Rietbergen and Blok 2013, Rietbergen *et al* 2015). Finally, public procurement programs that prioritize green technologies have the potential to stimulate technological innovation (Baron 2016, Peñasco *et al* 2021).

4. Conclusions

Effective climate change mitigation requires improved institutional arrangements and policy design. Systematic studies or reviews concerning climate mitigation policies of a country are mainly noted in technical reports, with limited academic research efforts at present. This article addresses this gap by establishing a systematic framework, the 'vertical policy hierarchy-horizontal policy path-policy instruments,' to analyze and compare climate mitigation policies in Germany, France, and the Netherlands.

Regarding the six vertical policy hierarchies based on the governance structures, it is noteworthy that Germany, France, and the Netherlands all possess detailed legal systems, strategic planning, and a wide range of policy instruments. In comparison to the Netherlands, Germany and France have implemented earlier and larger-scale initiatives, resulting in more robust policy frameworks. Specifically, Germany, France, and the Netherlands have respectively enacted 36, 39, and 28 laws related to climate change mitigation through their legislative bodies. Additionally, the administrative bodies of these countries have issued 56, 32, and 37 Ordinances/Decrees covering various areas such as greenhouse gas emissions, taxation, energy production, and energy efficiency. Furthermore, it is worth noting that the administrative departments in Germany and France have implemented 70 and 66 strategies and plans, respectively, which is approximately 30 more than the Netherlands. These strategies and plans establish short-term, medium-term, and long-term policy goals and directions for sectors such as energy, buildings, industry, transport, agriculture, and forest. Finally, under well-developed top-level designs, Germany, France, and the Netherlands currently possess 144, 150, and 114 policy instruments, respectively. These instruments can be categorized into six categories: regulatory reform, market-based mechanisms, commercialization mechanisms, financial/fiscal mechanisms, direct investment, and governance mechanisms.

In terms of the horizontal policy path division based on seven key sectors, namely energy, transport, buildings, industry, transport, agriculture, forest, and waste, Germany, France, and the Netherlands exhibit both similarities and differences. These similarities are due to the unified directives from the European Union, while the differences stem from resource endowments and emission structures. The three countries have different areas of emphasis, and even

within the same sector, there are varying policy priorities. Firstly, the commonalities observed between the three countries stem from their shared adherence to the EU legal framework and policy orientation. All three nations emphasize aspects that involve financing energy transition, promoting circular economy practices, facilitating building retrofitting initiatives, implementing intelligent transport systems, and safeguarding biodiversity. On the other hand, the individual differences among these countries arise from variations in their emission structures. Germany places a significant emphasis on enhancing energy efficiency, phasing out the usage of fossil fuels, and embracing digitalization within the transport sector. France, on the other hand, considers the transformation of transport modes and the development of charging infrastructure as pivotal factors in their approach. Meanwhile, the Netherlands capitalizes on its advantages in offshore wind energy and solar power, prioritizing the reduction of emissions within the industrial sector.

At the level of the six categories of policy instruments, the three countries share both similarities and differences: Financial/Fiscal Mechanisms are the primary approach. Governance Mechanisms are more mature compared to other countries. Regulatory Reform covers a more extensive range of aspects. Significant resources are allocated to support research and development and infrastructure construction. The number of policy instruments employed by Germany, France, and the Netherlands are 144, 150, and 114, respectively. The proportions of instrument usage are similar. Firstly, Financial/Fiscal Mechanisms are the primary means employed to stimulate energy transition and emission reduction in these countries. Secondly, Governance Mechanisms accounts for 20% of the instruments, reflecting the close cooperation between the government and businesses in addressing climate issues and the maturity of ESG instruments. Thirdly, Regulatory Reform covers a more extensive range of aspects, including emission control, energy efficiency, energy use, and energy production. Fourthly, the substantial investment in research and development of emission reduction technologies, as well as direct investment in infrastructure construction maximize societal benefits.

Regarding the use of policy instruments, the three countries exhibit distinct characteristics. Firstly, in terms of Regulatory Reform, Germany primarily replies on phasing out coal-fired power generation and accelerating the deployment of renewable energy. France primarily utilizes regulatory measures to control emissions in the transport sector, while the Netherlands leans towards biomass, wind, and solar power generation. Secondly, Germany takes a leading position in Commercialization Mechanisms, emphasizing the commercialization of hydrogen energy and international market development. Additionally, Germany has conducted early research and development on CCS technology. Thirdly, while tax, loan, and subsidy policies in the three countries cover areas such as buildings, transport, energy, and agriculture, they exhibit different emphases. Germany places a stronger emphasis on digitalization in the transport sector, France values eco-housing loans, and the Netherlands focuses more on sustainable agriculture. Fourthly, in terms of Governance Mechanisms, France is one of the earliest country to address climate-related financial risks. It incorporates emission reductions into corporate ESG considerations and has proposed a series of ESG standards. Many industries have made emission reduction commitments through voluntary or negotiated means.

Assessing the effectiveness of climate mitigation actions in a country cannot be solely based on the number of policy instruments employed. The focus of the research concentrates more on the effectiveness and stringency of these policies. However, it proves to be more complex and challenging. Therefore, this article evaluates the crucial policy instruments of the three countries through case analysis, incorporating literature and policy facts, employs the six assessment criteria for a multidimensional comparative analysis of the crucial policy instruments in Germany, France, and the Netherlands.

The evaluation of significant policy instruments reveals that, firstly, when impacts when pursuing rapid energy transition, it is necessary to not only assess the environmental effects but also the positive or negative effects, the economic effects, and the distributional effects. The German government has demonstrated a consultative approach with stakeholders and has developed progressive strategies in its policy of phasing out coal-fired power generation. In contrast, France's carbon tax policy encountered strong public opposition, necessitating further consideration of the policy's impact on different regions and groups. The Dutch government's public procurement policy has not only reduced greenhouse gas emissions but also incentivized technological innovation and voluntarily reduced emissions by companies. In addition, the policies should not only focus on current greenhouse gas emission reductions but also consider the long-term transformative potential of policies and the investment in emission reductions with a longer-term perspective. For instance, Germany's continued investment in renewable energy research and development in the early stages, France's significant contribution to setting corporate climate responsibility standards, and the Netherlands' advanced practices in the circular economy and public procurement. These policies all exhibit excellent transformative potential. Last but not least, Institutional requirements pose the primary challenge for any country's emission reductions. Germany's early introduction and multiple revisions of energy and transport laws are a prime example of excellence, laying a solid foundation for

Germany's low-carbon transformation. On the other hand, there are instances such as the Urgenda vs State of the Netherlands case, its ruling Required the government of the Netherlands to enhance its contribution and produce more effective policies, thus underscoring the significance of institutional requirements.

The effective implementation of climate mitigation policies requires a tailored approach that is based on their respective governance structures. This approach involves engaging multiple stakeholders, improving the legal system, formulating long-term strategies and phased plans. The policies formulated should not only consider environmental effectiveness and transformative potential but also address synergistic effect, fairness, economic effectiveness, etc, and ensure the effectiveness and compliance of the policies.

Climate change has emerged as a significant factor impacting the future world economy and social development. The longitudinal and horizontal comparative analysis of climate mitigation policies in Germany, France, and the Netherlands, along with the evaluation of their policy instruments, has resulted in a research framework and conclusions that will aid in the development of more rational and feasible climate and economic policies by governments worldwide. Furthermore, this study will facilitate the synergistic advancement of climate policies and sustainable development in the post-Paris era.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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