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Exploring the interdependence of climate, finance, energy, and geopolitics: A conceptual framework for systemic risks amidst multiple crises☆

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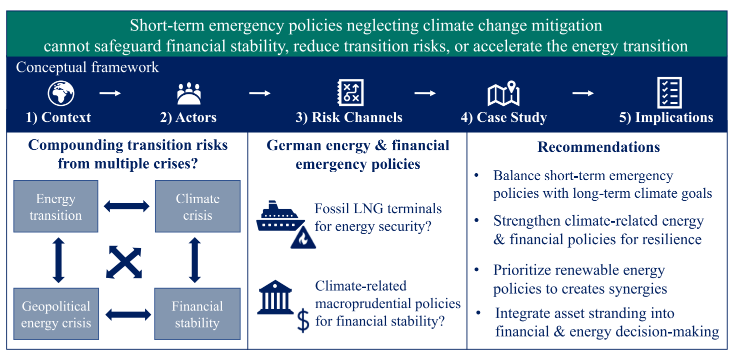
HIGHLIGHTS

- Conceptual framework to identify compounding risks' role in energy transition.
- Versatile tool that aids hypothesis evaluation, empirical analysis, and policy assessment.
- Transmission channels from climate and geopolitical crises to financial stability identified.
- Aligning policies with Paris Agreement vital for zero-emission transition, averting systemic risks.
- Fossil energy security policies impede energy transitions and financial stability.

GRAPHICAL ABSTRACT



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ABSTRACT

Navigating the transition toward a zero-emission and just future amidst multiple crises requires a nuanced understanding of potential hindrances to investments and energy transitions. As current approaches hardly consider the big picture of interacting crises, this study offers a framework to analyze the dynamics and risk channels between 1) the climate crisis, 2) financial (in)stability, 3) the geopolitical energy crisis, and 4) the energy transitions. Our framework reveals that the dynamics depends on the specific emergency policy. Hence, we apply the framework to a German Case study. Our findings reveal that fossil energy security policies and insufficient macroprudential policies can threaten the energy transition and financial stability exacerbating negative feedback loops. The discussion highlights that short-term emergency policies outweighing long-term climate goals fail to secure financial stability, reduce transition risks, or accelerate the energy transition. In conclusion, crises can catalyse the transition if short-term emergency policies are harmonized with long-term climate goals advocating for a coherent policy framework.

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1. Introduction

The transition toward a zero-emission future necessitates substantial investments and ambitious climate, energy, and finance policies. Given that nearly two-thirds of worldwide greenhouse gas emissions (GHG) stem from the energy sector, massive investments in the energy transition are imperative to achieve the climate goals [1] and a 100% renewable energy system [2].

The success of the transition is impeded by multiple crises, leading to compounding risks [3]. After the Covid-19 pandemic, the geopolitical energy turmoil caused by the Russian invasion of Ukraine in February 2022 has negatively impacted especially the energy transition. Sudden changes in energy supply, energy prices and political attention increased uncertainties [4–6]. Uncertainty typically leads to diminished investments, as enterprises seek to reduce vulnerability to potential adversities [7]. To guide successful transition policies amidst multiple crises, a nuanced understanding of the interlinked dynamics and resulting compounding risks is needed.

However, prevailing approaches employed to study complex challenges frequently exhibit a lack of considering the big picture of various components. This renders them insufficient for addressing the impacts arising from diverse crises, such as those originating from climatic shifts and pandemics [8,9,10,11], as well as the interplay between economic, financial, and fiscal ramifications [12]. Given these limitations and transition challenges, novel and holistic analysis approaches are needed.

In this context, this study offers a novel conceptual framework to disentangle the dynamics between four key developments, namely (1) *the climate crisis*, (2) *financial stability*, (3) *the geopolitical energy crisis*, and (4) *the energy transition*. We aim to systemically assess the impact of the climate and geopolitical energy crisis on energy transition and financial stability. To do so, we identify relevant actors, policies and risk transmission channels to guide decision-making in times of multiple crises. The framework is presented in the form of a step-by-step guide and consists of five consecutive steps. It can be applied to different national contexts and adjusted to future crises, as well as enhance quantitative assessment with numerical modeling tools. The conceptual framework contributes to filling the literature gap in different ways: first, it establishes a shared terminology to assess the interrelation between climate-related risks, financial stability, the energy transition and geopolitical crises. Second, it contributes to an advanced understanding of underlying dynamics by systematically identifying the diverse components and driving forces implicated in the process. Lastly, it provides a structured approach for systemically developing policy guidance for fostering the transition amidst multiple crises.

As a methodological finding, the framework reveals that the design of the specific crisis response policy determines whether the crisis has a positive or negative impact on the energy transition. To acknowledge this finding, we apply the framework to a German case study. We analyze new liquefied natural gas (LNG) terminals as an energy security measure in response to the geopolitical energy crisis in 2022 and concurrent climate-related macroprudential financial policies for managing climate risks.

Our case study reveals the following results: In Germany, macroprudential financial policies fall short to address climate risks, due to a focus on “soft” measures, rather than direct interventions. These policies, including Basel III regulations, are primarily tailored for short-term risks, overlooking climate risks in the long-term. Furthermore, building new LNG terminals is not an adequate energy crisis policy, as it is not in line with climate nor energy transition goals. It can exacerbate the transition risk of fossil asset stranding and carbon lock-in, therefore impeding the energy transition of phasing out fossil energy.

Moreover, the risk channel analysis yields the following key findings: First, disregarding climate-related risks, especially energy transition risks, might imply serious risks for financial and energy sectors. Second, if energy security policies in response to a (geopolitical) crisis are not harmonized with climate goals, they could hinder the energy transition. Third, risks to the financial and energy sectors contribute to financial instability and a delay of the energy transition. Finally, these dynamics can have a cascading effect on the economy and transition as a whole through fossil lock-ins and lack of green finance.

The remainder of the paper is organized as follows. We provide background information and describe the current crises in Section 2. Section 3 presents our conceptual framework in the form of a step-by-step guide. Section4 illustrates how the framework can be operationalized by applying it to a German case study of the energy crisis 2022 and concurrent macroprudential policies. We discuss our key findings in Section 5 and provide recommendations for decision-makers, as well as future research directions. The study ends with concluding remarks in Section 6.

2. Background: framing energy transition, climate and geopolitical risks' impacts and responses

2.1. Climate crisis and financial risks

Climate-related risks, encompassing transition and physical risks, are a subcategory of sustainability risks, including environmental, governance, and social risks [13]. Transition risks may arise from a sudden technological breakthrough that facilitates the reduction of greenhouse gas emissions, ambitious climate policies, or changes in expectations [14]. Physical risks stem from climate-induced extreme weather events like hurricanes, floods, and wildfires.

Despite the challenges associated with estimating climate-related financial risks, research suggests that these risks imply economic and financial costs, negatively impacting the functioning of banks and the financial system [15]. Physical risks have resulted in substantial losses for banks and insurers, while transition risks may lead to financial instability in the long run [16,17]. If fossil assets become effectively “unburnable,” their value could plummet. They might strand, thus posing a risk to financing the energy transition due to financial market instability [18].

Considering these climate-related challenges, central banks, financial supervisors, and regulators have begun to incorporate climate-related risks into their policymaking [19–21]. Various tools[1] can be used to reduce transition risks to the financial sector and contribute to fostering mitigation strategies [22]. Although applying these tools cannot substitute for sufficient climate policy [23], climate-related financial policies promoted by central banks and financial regulators can facilitate green finance and mitigate climate-related financial risks. Central banks' engagement in climate change mitigation can significantly affect the green bond market, among other things. By issuing green bonds, which enable capital sources to be linked to renewable energy projects, financial means get allocated to were most needed to achieve an orderly transition.

The literature widely recognizes the action of lower- and middle-income economies in climate-related financial policymaking due to their exposure to physical threats [19]. Advanced economies have primarily led climate-related financial policymaking since the early 2000s.

[1] To define climate-related financial policies, we use the definition presented in [20] according to which these are policies addressing the financial sector aimed at (I) identifying threats to – and safeguarding – financial stability in the presence of climate-related financial risks; labeled as green prudential regulations; (II) promoting green lending and investments through credit allocation and/or lending limits; labeled as green credit allocation policies; (III) promoting the creation of green or climate-aligned financial markets; labeled as green financial principles; (IV) promoting the public disclosure of climate-related financial risks; labeled as other disclosure requirements, e.g., climate-related disclosure requirements aimed at non-financial institutions such as insurance companies and pension funds; (V) promoting green lending through green bonds; labeled as green bonds taxonomy and issuing.

They aim mainly at non-financial institutions, pension funds, insurance companies, and green finance principles and guidelines to align their financial markets with climate change concerns.

2.2. Climate crisis and the energy transition

Sudden developments in the energy transition come with high transition risks and cascading implications for the economy. Stranding of fossil fuel assets is a significant transition risk, posing a considerable hurdle to the energy transition [24]. A global analysis indicates that 50% of fossil fuel assets may become stranded in a net-zero scenario by 2026 [25]. In particular, coal and gas assets are susceptible to potential impacts, with projections indicating that by 2040, around $400 billion worth of coal and gas capacities might strand, with $90 billion at risk by 2030 [26]. While assessing asset stranding is increasingly importing, the field of research about quantifying asset stranding is still nascent [27]. Existing literature highlights the expansion of natural gas infrastructure investments as a concern for the energy transition, noting that leakages and the climate impact of natural gas tend to be underestimated or neglected [28]. Such investments give rise to fossil lock-ins and economic risks, impeding progress toward climate objectives. Investments in repurposing the natural gas grid for the future admixture of fossil-based hydrogen also entail risks [29].

Policymakers have several tools to address energy transition risks. As described before, climate risks should be limited in at least two ways. First, [30] recommend reducing the vulnerability of financial institutes by performing stress tests that consider the energy sector's role. Since climate-related stress testing is a relatively immature research field, it comes with challenges. An alignment of the financial sector with the Paris Agreement's goals is advisable [31]. Second, effective climate and energy policies can help prevent asset stranding [32] and requires considering non-economic aspects, such as public acceptance [33].

2.3. The 2022 geopolitical energy crisis

The onset of the Russian aggression against Ukraine in February 2022 precipitated a significant shift in European energy supply dynamics. Before this conflict, Russia was Europe's primary provider of natural gas, crude oil, and coal. However, following the outbreak of hostilities, imports of these resources were swiftly curtailed throughout 2022. Specifically, the European Union (EU) officially boycotted Russian coal and oil exports, while Russia unilaterally reduced its natural gas exports to many, though not all, European importers. This cessation of supply is widely believed to be more than a temporary disruption, representing a lasting alteration to energy trade between the two parties.

The explosion of the Nordstream pipelines in September 2022 complicates the prospects of resuming energy supplies to pre-war levels. The physical challenges posed by this incident make it arduous to restore previous levels of energy supply. Consequently, removing Russian exports from the European market has triggered a sharp escalation in natural gas, oil, and coal prices. This price surge can be attributed to the perceived risk of supply shortages resulting from the elimination of Russian energy resources from the European market.

Yet, although Russia reduced step by step its exports of natural gas to Germany and West Europe, ultimately ceasing in summer 2022, a supply crisis did not materialize thanks to import diversification using the existing import infrastructure and some savings in energy demand. In addition to the absence of an energy supply disruption, economy-wide repercussions were milder than expected, with a reduction of the growth rate to approximately zero but no recession. For instance, Germany's comparatively good outcome in the geopolitical energy crisis can be attributed, in part, to the policy measures, implemented since February 2022 by the German government, such as minimum gas storage requirements and temporary fuel switch in the electricity and heat sector. Similar measures were taken by national governments in other European countries. Some national measures were transposed law from EU-wide measures.

3. Approach: a conceptual framework to analyze systemic risks for energy transitions and financial stability

Our study provides a conceptual framework for highlighting interconnected risks and crises to grasp their dynamics. The framework has policy relevance and depicts non-linear interactions, identifies risk and cascading effects.

3.1. A step-by-step guide for implementing the conceptual framework

In the following, we describe the conceptual framework that aims to disentangle the interdependent dynamics among (1) the climate crisis, (2) the geopolitical energy crisis, (3) financial (in)stability, and (4) the energy transition. Building upon the analysis presented in [34], our proposed framework consists of five consecutive steps, which are delineated as a step-by-step guide in Table 1. The guide is based on the applied policy research of [35]. From a methodological view, a conceptual framework is a structured approach that helps to guide research on compounding risks and multiple crises. Thus, the framework operates as a tool of thought to study the complex interrelations between key developments in a structured and innovative way.

Steps 1 to 3 encompass *contextual*, *diagnostic*, and *evaluative* research steps, each addressing distinct system levels. Step 1 involves a context analysis (see Section 3.2) defining the study's scope and context. In Step 2, an actor and effect analysis (see Section 3.3) is conducted to identify effects on key actors and aspects. Step 3 entails a risk channel analysis (see Section 3.4) exploring existing policy responses and risk transmission channels. Specific tasks are outlined for each step, along with pertinent questions to guide researchers. Steps 4 and 5 pertain to the application of the framework through a practical case study (see Section 4) and the interpretation of findings (discussed in Section 5).

3.2. Step 1: context analysis

The first step entails a contextual analysis. Beginning with a high-level perspective encompassing the system and policy levels, the aim is to define the study's scope and context by identifying key developments (see Table 1). These key developments can encompass long-term and short-term crises, risks, or political objectives. Visualisation is an effective way to represent this context (see Fig. 1).

Our analysis focuses on the *climate crisis* and the *geopolitical energy crisis* as long-term and short-term crises, examining their influence on the key aspects of *energy transition* and *financial stability*. The arrows indicate that these four key developments are interconnected in multiple ways, both directly and indirectly, often mediated by *the economy* placed at the center. This interconnectedness might also influence the broader net-zero transition. However, the specific direction and magnitude of these impacts largely depend on the policies adopted by individual countries in addressing their respective crises. Hence, we identified relevant policy groups for each key development, which provide the policy framework, shaping the trajectories of the key developments. Within the paper's scope, we identify four pertinent groups of policies: *(i) energy policies* driving the *(1) energy transition*, *(ii) climate-related policies* mitigating the (2) *climate crisis*, (iii) *Paris-aligned financial policies* promoting *(3) financial stability* by establishing a financial system aligned with Paris Agreement objectives, and (iv) *energy security policies* responding to the *(4) geopolitical energy crisis* by assuring energy security.

Consequently, each policy group pursues its distinct goals while influencing all key developments. For example, the impact of the geopolitical energy crisis on the energy transition can be either positive or negative, contingent upon the nature of the energy security policies. Policies prioritizing the rapid reduction of fossil fuel usage to curtail energy dependencies can be instrumental in fostering the energy

Table 1
Framework implementation guide.

Steps	Category	Task	Relevant questions	Level of analysis
1) Context analysis	Contextual	Define scope and context of the study	• Which key development should be included in the analysis? • What policy categories are relevant for these developments?	System and policy levels
2) Actors and effect analysis	Diagnostic	Identify main actors and relevant effects	• Who are the main affected actors? • What are the effects on the actors?	Governance levels
3) Risk channel analysis	Evaluative	Identify and analyze risk channels and policy responses in place	• What risk channels and impacts are pertinent? • Do these impacts foster or impede energy transitions and financial stability?	Risk channel and policy response level
4) Case study application	Practical	Identify target country and apply step 1–3	• Which country and specific crises response should be analyzed? • Which information are required to apply step 1–3?	Country level
5) Implications	Interpretative	Identify key learnings, future research directions and recommendations	• What policy changes are needed so that a crises response is aligned with energy transition and financial stability? • What are key learnings and directions for future research?	Policy level

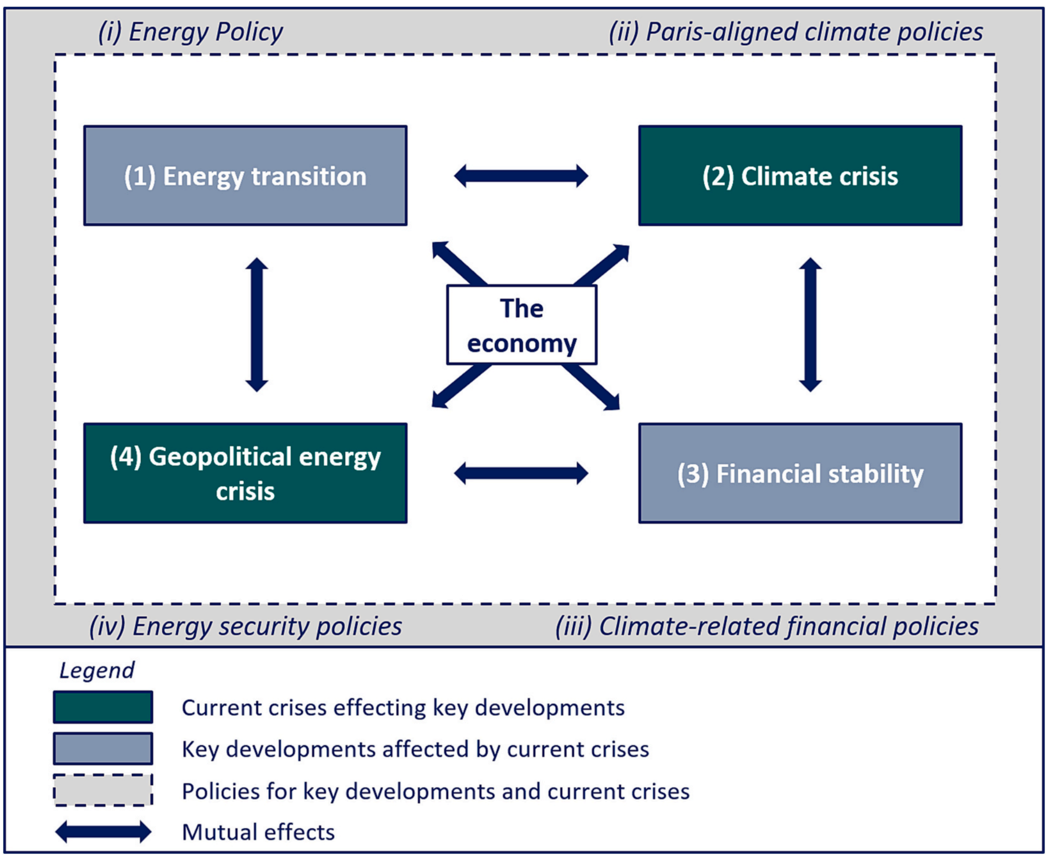

Fig. 1. Context analysis.

transition positively. Conversely, policies favoring short-term fossil-based strategies over long-term climate goals might impede the energy transition. Additionally, the effects of climate-related transition risks on financial stability and the energy sector hinge on the alignment policies with the goals outlined in the Paris Agreement.

3.3. Step 2: actors and effect analysis

Step 2 includes a diagnostic actor and impact analysis. This perspective operates from a governance level, seeking to identify the main actors involved and the impacts incurred (see Table 1). Identifying the actors impacted is standard practice within the transition risk financial literature. For instance, [14] point to equity investors, banks, and insurance companies as key financial actors affected, while companies, households, and government entities face macroeconomic consequences. Others highlight that businesses and households are susceptible to climate risks that can become financial risks [36].

Our focus narrows to three distinct governance levels: policy, sector, and company (Fig. 2). Given our intent to explore the effects of the climate crisis and geopolitical energy crisis on energy transition and financial stability, the latter two stand as central affected domains within the sector level. Noteworthy effects encompass carbon lock-ins and energy market instabilities. In response to ongoing crises, energy and financial policymaker need to deploy energy (security) and macroprudential policies. The magnitude of these effects hinges on specific country contexts and policy measures, which we comprehensively investigate in Section 4 using the example of Germany.

3.4. Step 3: risk channel analysis

Step 3 identifies risk transmission channels and assesses policy responses in place. This step serves as an evaluative endeavor. A pivotal

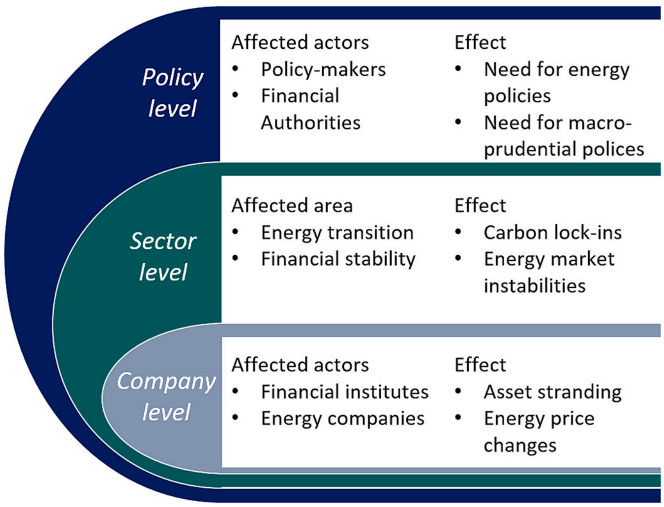

Fig. 2. Overview of main actors and impacts.

question driving the analysis of risk channels is to ascertain the relevant risk channels and their resultant impacts. Furthermore, it seeks to determine whether these impacts catalyse or hinder the energy transition and financial stability (see Table 1). This analysis of risk transmission channels is a widely adopted practice within the transition risk and financial literature [see, e.g., 14,37,38]. Its purpose lies in unraveling the intricate relationships and interactions among various elements and factors, shedding light on whether specific risks exacerbate or alleviate the effects of others. It offers insights into how a crisis originating in one domain can trigger a cascade of events across others.

Fig. 3 provides an overview of the risk transmission channels, delving into the interplay between energy security and financial policies against the backdrop of climate change and geopolitical energy crises. Specifically, we focus on the policy example of non-Paris aligned policies in the banking and finance sector related to the climate crisis and the example of pro-fossil energy security policies in the energy sector related to the geopolitical energy crises.

We discern four pivotal risk transition channels. Commencing with the climate crisis (channel 1) and the geopolitical energy crises (channel 2), we trace their interconnected paths leading to transition risks within the financial and energy sectors. These transition risks materialize as channel 3, manifesting in financial instability and energy transition risk. Channel 4 illustrates the spillover effects on the economy from financial instability and a delayed energy transition. Supplementary reinforcing effects are depicted with dashed arrows.

Starting with channel 1, climate-related drivers - like technological advancement, shifts in climate policies or consumer preferences - can result in transition risks. These risks may manifest, e.g., as asset stranding, which implication for the financial and energy sectors. The impact on the energy sector and other greenhouse gas (GHG) emissions-intensive industries varies depending on a country's economic structure and its financial system's sectoral exposure. Asset depreciation and a decline in profitability can lead to financial or credit-market losses and market liquidity risks. Rising energy prices or a growing investment need for renewable technology may affect the energy sector. The effect on the financial and energy sectors could be severe if financial policies are not aligned with the Paris Agreement. Despite the paper's focus on the energy and financial sectors, all economic sectors are vulnerable to transition risks, making it a crucial transmission channel.

Concerning *channel 2*, the Ukraine war raised awareness that geopolitical risks can affect energy supplies and cause market instability, manifesting as rising prices and fluctuating supplies. Contradicting prior climate policies, the energy security policies implemented as an emergency response might put the energy transition at risk. Focusing on fossil fuels to replace missing natural gas supplies, for example, building LNG infrastructure and installing new oil-burning installations with final consumers, might create new fossil lock-ins. Similarly, fiscal policies such as gas price caps, gas bill payments from the public budget decrease the incentives to switch to renewable electricity. Thus, fossil-based energy policies might create transition risks and delay the energy transition.

Concerning *channel 3*, a lack of Paris-aligned financial policies can adversely affect financial stability, green financing (channel 1), and fossil-based energy security policies (channel 2). The magnitude and timing of these risks could jeopardize financial stability, leading to a financial crisis. Financial instability also exacerbates the green finance gap, impeding investments required to enable the zero-emission transition, especially in the energy sector. Should financial instability arise, decision-makers' attention may shift away from climate risks, making it

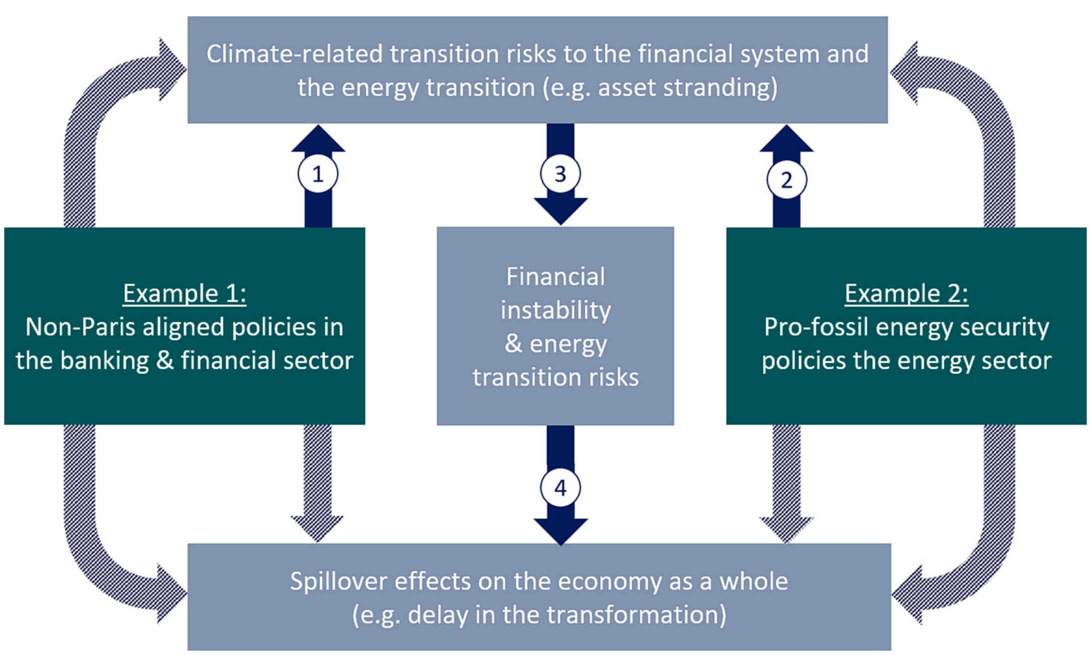

Fig. 3. Risk channel analysis.

difficult to finance the net-zero transition. Climate-induced financial instability may also catch the financial sector unprepared for a macroprudential response. Hence, a more prudent strategy is recommended, which involves embedding climate risks within both micro and macroprudential settings.

Concerning *channel 4*, given the prevailing climate and geopolitical crises, various factors have contributed to the risks associated with transitioning to a low-carbon economy. Specifically, financial policies not aligned with the Paris Agreement can lead to climate-related transition risks, such as asset stranding. Fossil-based energy security policies have been implemented in response to the geopolitical energy crisis and could further exacerbate these risks. Moreover, fossil lock-ins and financial instability could enforce the green finance gap (channel 3), thus reinforcing these risks. Given the interlinkages among economic sectors, spillover effects significantly impact the economy and the net-zero transition, particularly in hard-to-abate sectors like steel or cement. These sectors require significant investments for transformation or substantial amounts of renewable energy in the event of a delayed energy transition and financial instability.

The spillover and mutually reinforcing effects of the climate crisis, financial, and energy transition risks highlight the significance of considering the whole picture. Climate mitigation and the energy transition are critical for addressing financial instability, climate, and geopolitical crises. Moreover, climate mitigation and the energy transition may be jeopardized if policies focused on restoring financial stability and mitigating the negative economic repercussions of the geopolitical crisis outweigh previously established climate policies. Consequently, measures delaying climate mitigation and energy transitions are unlikely to foster financial stability.

While the transmission channels are presented in a specific order in the text and numbered in the figure, the effects are complex. They may occur in a different order or simultaneously. For clarity, we chose a specific order that aligns with our research focus.[2]

4. Results: framework application for the German case

This section represents step 4 of the step-by-step framework implementation. It consists of a practical case study application, for which we use Germany around the geopolitical crisis of 2022 as the country of analysis (see Fig. 1). In the following, we apply the first three steps of the framework. We do so in separate analyses of each transmission channel that evaluate the impact of energy and financial policies on climate change.

We begin with the contextual analysis as the first step to implementing the framework (Fig. 1). Germany's energy transition, the so-called *Energiewende*, encompasses a comprehensive and ambitious strategy to transition the nation's energy system from reliance on fossil fuels to renewable sources. This strategic approach encompasses decommissioning nuclear power and escalated utilization of renewable energy. Implementing this transition in Germany offers invaluable insights into the obstacles and opportunities of navigating multiple crises simultaneously.

Furthermore, Germany is the largest economy in Europe and ranks among the world's major industrial nations. Its industrial landscape encompasses diverse sectors with substantial energy-intensive operations, including the automotive, chemical, and manufacturing industries. Consequently, Germany presents an especially compelling case for investigating the potential repercussions of crises on the energy transition, as disruptions in other sectors can have far-reaching implications for the energy domain.

Germany has already confronted several crises that have impacted its energy transition. Among these were the global financial crisis of 2008, the European debt crisis, geopolitical tensions, and, more recently, the COVID-19 pandemic. Such crises have influenced various facets of the energy system, including investment patterns, policy frameworks, supply chains, and consumer behavior. Germany has implemented various policies to support its energy transition, encompassing feed-in tariffs, renewable energy targets, energy efficiency programs, and carbon pricing mechanisms. Analyzing the interplay between these policies and the challenges posed by crises can yield valuable insights into resilience and vulnerability.

Despite crises and challenges, Germany has made notable strides in augmenting its electricity mix's share of renewable energy. The country has started investing in grid infrastructure, energy storage solutions, and other technologies to facilitate the integration of renewables, even though there is criticism that progress in these fields should be faster [39]. Scrutinizing the impact of multiple crises on the reliability, flexibility, and resilience of the energy mix and infrastructure enables a comprehensive understanding of the long-term implications for the energy transition. Examining the German experience can equip policymakers, researchers, and practitioners with enhanced comprehension regarding the potential ramifications of multiple crises on the energy transition. Moreover, it can inform strategies to bolster resilience, adaptability, and sustainability in the face of future challenges.

With the energy crisis related to the Russian war in Ukraine, the focus of German energy policy largely changed in 2022. Building new LNG was only one of several measures in response to the geopolitical energy crisis. Other policies included the Gas Storage Act, effective in April 2022, establishing the basis for mandatory gas storage filling at very high levels, ensuring sufficient gas availability during winter. Additionally, the German government undertook diverse initiatives to decrease natural gas consumption. For example, in the power sector, coal- and lignite-fired power plants from the grid reserve/supply reserve were activated, and the nuclear phase-out was postponed by 3.5 months until mid-April 2023. As another contribution to enlarging electricity generation from sources other than natural gas, the regulatory framework for expanding renewables was improved to speed up the expansion of wind and solar PV capacities, e.g., by mandating regions to expand the land spaces available for renewable generation installations. Furthermore, several mandatory energy-saving measures, such as reducing room temperature in office buildings, were enforced during the winter of 2022/2023. In parallel, the German government negotiated the expansion of natural gas supplies from countries other than Russia, including LNG. To this end, the “LNG Acceleration Act” from May 2022 created the basis for the rapid development of LNG import capacities in Germany, where there had not been such terminals before. In addition to securing the energy supply, the German government implemented several financial relief packages to reduce the financial burden of high energy prices on citizens and businesses. For example, in Germany – in addition to similar efforts at the EU level – a gas price cap was introduced as of March 2023 for a portion of consumption, as proposed by a newly implemented Gas Price Commission.

However, since the summer of 2022, wholesale gas prices subsequently fell. In February 2023, a megawatt-hour (MWh) was just over 50 euros, significantly below the European gas price cap of 180 euros/MWh but still twice as high as the long-term average before the war.

In the following, we focus on two specific sets of policies for our case study analysis of Germany: (1) climate-related financial policies that respond to transition risks associated with the current climate crisis, as presented in Section 4.1; (2) the construction of new LNG terminals as an energy security policy and response to the geopolitical crisis (see Section 4.2). The risks associated with these policies contribute to financial instability and fossil lock-ins, as elaborated in Section 4.3. These risks also have potential spillover effects on the economy and the transition to a net-zero emissions trajectory, as discussed in Section 4.4. In each of the

[2] There are other effects that transcend the four channels mentioned above. These effects, which include the influence of pro-fossil energy policies on the overall economy, are represented in the figure through supplementary arrows. Owing to constraints imposed by spatial considerations, a comprehensive explanation of these intricacies is not provided within the textual discourse.

following sections, we identify the relevant actors (step 2) and analyze the risk channels in detail (step 3) in accordance with the implementation procedure in Fig. 1.

4.1. Channel 1: transmission of transition risks to the financial system and the role of climate-related financial policies

Regarding transmission channel 1, which pertains to the impact of climate-related transition risks on the financial system, recent empirical research indicates that German banks are susceptible to such risks. The research draws upon sectoral and aggregate bank data and greenhouse gas emissions data [40]. Notably, the German financial sector exhibits a significant degree of exposure to climate transition risks, with estimates ranging from 19.4% (for carbon critical sectors), 25.17% (for climate policy relevant sectors) to 32.56% (for loan carbon intensity), depending on the metric. In particular the manufacturing, energy, and transportation sectors exhibit high exposures. This emphasizes the crucial consideration of potential financial stability implications when devising a roadmap for renewable energy policy, as well as exit strategies from fossil fuel dependency. Additionally, it calls for further attention to future challenges related to Germany's ambitious natural gas investment plans.

The potential implications of transition risks on financial stability are contingent upon prevailing climate-related financial policies. An analysis of the incorporation of environmental, social, and governance (ESG) considerations in micro and macro-prudential frameworks showed that they inadequately address climate risks, including their cross-sectoral, global, and systemic implications [17]. Germany, like other advanced economies, has predominantly implemented soft climate-related and environmental financial measures in the 2010s. As shown in Table 2, the country has mostly adopted guidelines on how to deal with sustainability risks and disclosure requirements for non-financial institutions. This deficiency is evident in national and supra-national regulations, including those established under the Basel Accords, of which Germany is a member. Ongoing discussions underscore that Basel III must be more attuned to climate risks in its three pillar structures [see, e.g., 41], engendering apprehension about climate-induced financial instability [42]. While existing measures constitute a step in the right direction by providing somewhat favorable conditions for increasing green finance, they do not directly tackle the pressing issue of climate-related financial risks.

Table 2
Overview of climate-related financial policies implemented in Germany since 2000.

Year	Instrument	Name of the law	Responsible authority	Bindingness
2011	Green Financial Guidelines	German Sustainability Code	German Council for Sustainable Development	Mandatory
2015	Disclosure requirement for non-financial institutions	Supervision of insurance undertakings requires pension funds to report ESG and ecological considerations	Bafin	Guideline
2016	Disclosure requirement for non-financial institutions	Amendment to the German commercial code (Section 289b)	German Federal Government	Mandatory
2019	Green Financial Guidelines	Guidance Notice on dealing with sustainability risks	Bafin	Guideline
2020	Green Bonds	Green Federal Bonds	German Federal Government	Mandatory
2021	Green Financial Guidelines	Guideline on Sustainable Investment Funds	Bafin	Mandatory
2021	Green Financial Guidelines	Sustainable Finance Strategy	German Federal Government	Guideline

Source: Authors' elaboration on data retrieved from the Dataset for the climate-related financial policy index [43].

Implementing effective climate-related financial policies at the macro level is crucial to avoid potential disruptions and instabilities associated with transition risks. As noted by [44], a "prudent" approach is necessary because of the uncertainty surrounding the magnitude, timing, and nature of the effects of climate change on financial stability. Accordingly, governments and financial supervisors taking early action can significantly reduce the severity and nature of disruptions and risks to the economy and financial markets caused by climate change [45].

4.2. Channel 2: transmission of risks from geopolitics to the energy transition

Transmission channel 2 describes the impact of a geopolitical energy crisis on the energy transition. Here again, we observe the interaction between the policy, sector, and company levels (Fig. 2). Energy policy in response to the energy (supply) crisis might have a critical impact on future climate change mitigation and the progress of the energy transition. The challenge is that the current energy policy does not hinder mid- and long-term energy (transition) goals. Of course, the interactions are complex, but we want to highlight a few main points. In the following, we show that energy policies in Germany in response to the energy crisis of 2022 are partly not in line with climate goals and climate policies. Most importantly, the Russian war against Ukraine unexpectedly exacerbated energy market uncertainty and increased the perception of supply security needs. This has, in turn, led to policies setting up new natural gas infrastructure and supporting natural gas consumption, e.g., by building LNG import terminals and establishing new natural gas import relations partly enshrined by multi-year long-term contracts. The energy crisis substantially changed the expectations of policy, sector, and company actors and even questioned the previous commitments to the long-term phase-out of natural gas in Germany.

Because of the Ukraine war, Germany is aiming to decrease its energy dependencies, just like most other European countries. There are two main strategies: (i) to diversify energy imports and (ii) to decrease energy demand. Until 2021, half of Germany's gas imports came from Russia. In 2022, Germany turned to LNG imports to diversify gas imports, which were not previously used. The German government passed an "LNG acceleration law" to allow gas imports until 2043 [46]. Plans for public and private development of up to eleven LNG terminals were developed. Up to seven offshore Floating Storage and Regasification (FSRU) terminals are being built in the first phase. FSRUs are repurposed LNG ships that are chartered for a certain period. In a second step, the German law foresees the construction of onshore LNG terminals, allowing imports of natural gas until 2043 [46].

As of May 2023, six FSRU terminals are in operation or construction in Germany. The planned total capacity of the floating LNG terminals is more than 40 billion cubic meters (bcm), which is approximately half of Germany's annual natural gas consumption of ca. 90 bcm. There is a widespread consensus that FSRUs are appropriate for addressing a short-term, temporary supply crisis. However, this is a very costly instrument for the public budget. There is no transparency on the total costs for the state and the share of costs for the involved companies. For 2022, it was reported that the federal government had earmarked funds amounting to 6.6 billion euros for the floating terminals. By 2038, estimated costs totaling 9.7 billion euros are reported. Moreover, it is expected that the FSRUs will operate with relatively low capacity factors (utilization rates), making it hard to cover the operational costs of the floating terminals (charter rates, staff costs, etc.). This is already observed in 2023 [47]. There is also uncertainty on the exact terms of leases of the German FSRUs, but their duration is usually around ten years. There is a secondary market for used FSRUs, and they can be shipped to other places after the lease ends, which will avoid stranding the terminals on German shores.

In contrast, fixed onshore LNG terminals in Germany are controversially discussed [48,49,50]. An additional 40 billion cubic meters of annual capacity is planned at fixed terminal facilities on land, all in the same locations as some FSRU terminals. As of May 2023, final investment decisions had not been made for any onshore terminal. The earliest possible completion of the onshore terminals would be in 2026, most likely later. However, there might be an overlap with the leases of the floating terminals so that total LNG import capacity might temporarily rise to more than 80 bcm per year, i.e., almost 100% of German consumption and well above pre-war imports from Russia, which were on the order of 55 bcm per year [49,51].

These permanent fixed onshore terminals will likely become stranded assets, impeding energy transitions through infrastructure lock-ins. Considering Germany's remaining emission budget [39], fossil natural gas needs to be phased out during the 2030s. Using LNG terminals until 2043 would be a serious economic and energy transition risk. More concretely, asset stranding is a serious risk for the fixed onshore terminals [50]. These stranded energy assets would affect privately-owned businesses, as there is no public investment in fixed onshore terminals to date. After natural gas prices have returned to pre-crisis levels and supplies during the winter of 2022/23 could be secured without LNG imports via onshore terminals, the business case for onshore LNG terminals has visibly vanished (again). There are enough FSRU LNG import capacities for the temporary need for LNG imports until the early 2030s before natural gas consumption will substantially decrease.

If private investors were to make an investment decision in onshore terminals, they would need a strategy to mitigate the stranded asset risk. Two risk mitigation strategies are possible, but both have uncertain realization perspectives. First, terminal owners could plan for conversion from importing LNG (i.e., natural gas) to importing hydrogen or hydrogen derivatives such as ammonia ("green gases"). This strategy is announced for all terminal projects, but the conversion will be associated with high shares of new-build requirements and, therefore, high costs [52]. Second, terminal owners could plan to receive public compensation for stranding their assets in a few years, e.g., based on the argumentation that they provided energy security. Such payments could be similar to the compensation payments to the German nuclear power plants or coal-fired power plants that were closed before the end of their economic lifetime. This would be a strategy that involves costs for the public budget. However, in contrast to the nuclear phase-out and coal phase-out, the closing decision would not be unforeseen at the time of the investment decision. Rather, the climate commitments and the ensuing natural gas phase-out by the mid-2040s are well-known framework conditions. Therefore, public compensation payments will be very controversial. Given that both risk mitigation strategies for onshore LNG terminal investments come with high uncertainties for private terminal owners, energy policy might decide to subsidize the investments, despite the risk of fostering fossil lock-ins.

Yet, the German government has also used the momentum of the geopolitical crisis of 2022 to accelerate the energy transition. It modified the regulatory framework to speed up renewables' expansion and improve building efficiency. Other policies, such as the decarbonization of heat supply, are also under discussion.

4.3. Channel 3: transmission from climate and energy risks to financial instability and green investments

Transmission channel 3 is one of two channels that highlight the impact of a crisis on a potentially fragile situation. More concretely, transmission channel 3 focuses on the role of financial instability in reducing the availability of green finance. As long as there are no safeguards in the financial that guarantee a continued service to the green transition and also in a crisis, any crisis in the financial and banking sector will reinforce the problems discussed in relation to transmission channel 1.

Yet, in 2023, Germany and Europe are on the verge of a bank crisis that risks finance to energy transition projects. The bank crisis was induced by a relatively steep increase of interest rates by the European Central Bank since mid-2022 that was supposed to counter the high inflation rates. High inflation rates were, among other factors, caused by high energy prices. High-interest rates lead to a rising share of failing loan paybacks, e.g., on mortgages, and, overall, a trust crisis with some banks. In March 2023, Crédit Suisse was the first large European bank to face serious problems in this bank crisis. An immediate contagion to other banks was avoided by rapid state intervention, but other banks may follow.

High-interest rates make loans more expensive and this, of course, also affects credit-financed renewable energy projects. While there is no reason to call the situation with a 3.5% interest rate (as of March 2023) a true "credit crunch," further interest rate rises are likely, which might render financing more difficult.

Moreover, the geopolitical crisis in 2022 had visible impacts on public finances. Here, we only focus on increased public spending related to the energy sector. Still, other sectors also saw increasing public expenditures (e.g., military expenditures), thus reducing Germany's fiscal space further. Related to energy, first, the almost bankruptcy of the German energy company Uniper impacted public finances. Uniper was the largest importer of Russian natural gas, next to the large chemical company BASF, and has an intermediary role as the main supplier to German utilities that were deemed "systemic" by German policymakers. Using the same jargon as during the 2008 financial crisis, when large banks were nationalized, Uniper's bankruptcy was prevented by nationalization. The Uniper nationalization involved public funds on the order of 25 billion euros.

Second, the German government spent large sums on public compensation packages to households and businesses in response to the temporary, but spectacular, rise in energy prices in 2022. For instance, natural gas prices in the European benchmark TTF in August 2022 reached more than 300 Euro per MWh compared to around 20–25 Euro per MWh in the previous years. High energy prices affect the production and consumer sector and, in 2022, were feared to cause social conflicts. Therefore, the German government spent almost € 30 billion in 2022 on cheaper public transport tickets and so-called "energy money" to support households.

4.4. Channel 4: spillover risks on the economy and net-zero transition

Mutually reinforcing effects between the climate crisis, the energy transition, financial stability, and the geopolitical energy crisis highlight the importance of considering the whole picture. The last transmission channel, which describes the spillover effects from the previous channels on the overall economy, takes these interactions explicitly into account. Climate goals and the energy transition may be jeopardized if policies focused on restoring financial stability and mitigating the negative economic repercussions of the geopolitical crisis outweigh previously established climate policies. As a result, regulations and policies that postpone climate change mitigation will not promote financial stability and energy transitions. Climate mitigation and the energy transition are critical for resolving financial instability, climate change, and geopolitical crises. Risks resulting from non-Paris aligned financial policies (channel 1) and fossil-based energy security policies (channel 2) contribute to financial instability and energy transition risks (channel 3) which, in turn, has spillover effects on the whole economy and net-zero transition. Financial instability and energy transition risks contribute, for example, to worsening the green finance gap and creating fossil lock-ins that might delay the net-zero transition.

At the sector level, constructing large LNG import capacities risks creating a fossil lock-in effect. This risk goes beyond the energy sector and could affect other sectors of the economy. There are several drivers for the fossil lock-in risk. First, the industrial transformation away from fossil natural gas can be delayed due to the perception of continued long-term availability of natural gas thanks to the large import capacities and new long-term import contracts. Ample future supplies potentially come at relatively low prices, which creates a further incentive for the natural gas-consuming industry to consolidate their fossil business models. For example, industrial processes that require high temperatures, e.g., in the glass industry, might not be converted to decarbonized technologies, such as heat pumps or renewable fuels, because future natural gas availability has been rendered certain for the decades to come by the emergency response policies during the 2022 energy crisis. This effect at the company level represents a lock-in risk in fossil-based industry strategies.

Second, we expect a spillover effect from the energy security policies on the green infrastructure transformation, which risks being delayed. In particular, the main pillar of the emergency response policies, i.e., the massive build-up of LNG import capacities along the German sea shores, risks binding administrative capacities that are, in turn, not available for the green infrastructure transformation. Public administration capacities in Germany, e.g., licensing and monitoring, are limited. Organizing the massive LNG terminals build-up at so-called "Germany speed" (dubbed by the German chancellor Olaf Scholz) binds large administrative capacities in the coastal regions that would otherwise deal with renewable energy, e.g., offshore wind investments and related infrastructure. On the sector level of the energy transition, this spillover effect results in "German sleep" for expanding renewable infrastructure and contributes to infrastructure lock-ins.

Third, this delaying effect comes in addition to a green finance gap risk, i.e., the reduced availability of public and private funds for the net-zero and the energy transition financial instability in a situation of stressed public funds by the energy crisis, financial instability, and high-interest rates. Money invested in LNG terminals cannot be invested in renewable energy, related infrastructure, and, thus, the energy and net-zero transformation. With regard to private funding, the financial regulator BaFin has postponed the planned policy for sustainable investment funds in response to the volatile regulatory, energy, and geopolitical environment following the conflict in Ukraine [53]. This decision further reinforced climate-related financial risks for financial institutes. In turn, this nourishes financial instability and the green finance gap, creating investment lock-ins both at the company level of financial institutes and the economy.

Lastly, delaying the energy transition and widening the green finance gap slows progress toward achieving net-zero emissions. Especially hard-to-abate sectors, such as the steel and cement industries, are affected. As CO_2 prices continue to rise, so does the urgency for a rapid transformation of energy-intensive industries. Steel producers, e.g., who transform their business strategies, are affected by the green finance gap and the delay of the energy transition since large green investments and high amounts of renewable energy and hydrogen are needed. The transformation is impeded due to the lack of assurance regarding future H_2 infrastructure and sufficient renewable energy sources, such as wind energy near industrial clusters, for producing green hydrogen through electrolysis.

5. Discussion

5.1. Key findings and recommendations to inform policymakers

This section marks the final step of our analysis, discussing the study's results and implications at policy and research levels (see Fig. 1). The case study revealed that crises can catalyse the net-zero and energy transition. The pivotal factor whether crises reinforce positive or negative developments depends on the nature of the crisis response policies.

Our case study analysis of the transmission channels reveals the following key findings: First, disregarding climate risks, especially energy transition risks, might result in serious risks for the financial and energy sectors. Second, if energy security policies in response to a (geopolitical) crisis are not aligned with climate goals, they could hinder the progress of the energy transition. Third, risks to the financial and energy sectors contribute to financial instability and a delay of the energy transition. Fourth, the interactions can have a cascading effect on the economy and the net-zero transition due to fossil lock-ins and lack of green finance. Fifth, adopting a meta-perspective reveals that policies aimed at achieving financial stability and providing emergency relief in a crisis jeopardize climate mitigation and energy transition if not aligned with climate goals. Particularly the last finding shows that our framework offers a novel understanding of systemic risks amidst concurrent crises. This depth of understanding remains elusive if approached from an isolated sectoral – or crisis – perspective. Drawing from the key findings, we distill the following recommendations for decision-makers that are applicable beyond national borders and are underscored by examples and measures tailored to the German context:

First, short-term emergency policies that delay climate mitigation cannot safeguard financial stability, reduce transition risks, or accelerate the energy transition. When designing emergency policies in response to one specific crisis, considering the big picture of multiple crises and interconnected dynamics is essential. This precaution can prevent ineffective policies tailored to a specific crisis while overlooking interdependencies with other events. Fossil-based energy security policies, such as new LNG terminals, create fossil lock-ins and delay the energy transition. While short-term energy policies address the geopolitical energy crisis, they should not hinder long-term energy transition objectives. Helpful measures involve carefully assessing the energy-economic necessity, avoiding fixed LNG terminals in the German case, and establishing a definitive end date for LNG terminals in alignment with climate goals.

Second, strengthening climate-related energy and financial policies is crucial to increase resilience in anticipation of future crises. By reinforcing these policies, a robust system with financial stability is built, ensuring the necessary financial means and personnel capacities to address potential future disruptions while advancing energy transition goals. Currently, financial policies in Germany are insufficient for addressing climate risks due to their focus on "soft" measures. These policies, including Basel III regulations, are primarily tailored for short-term risks, inadequately reflecting climate risks' long-term. Especially further effort is needed to align the financial sector with the goals of the Paris Agreement, in both the micro- and macro-prudential frameworks, necessitating mandatory, internationally consistent disclosure requirements.

Third, by prioritizing renewable-based policies, policymakers can generate synergies that reduce energy transition and financial risks, aiding in achieving climate goals. Renewable-based policies accelerate the energy transition and therefore help decarbonize the economy, which is necessary to achieve the climate goals. Despite the substantive expansion of renewables and efforts to foster the energy transition in recent decades, the GHG emission reduction in Germany is slower than required [54–56]. Acknowledging the remaining national emissions budget [39], a faster phase-out of fossil energy, such as a rapid coal phase-out are efficient measures.

Fourth, climate-related asset stranding is a key risk in current crises and should be integrated into financial and energy decision-making and risk management. Exposure to emission-intensive assets concentrated within economic sectors poses a risk of fossil asset stranding to the financial system [55]. The example of the new LNG terminals in Germany shows that energy assets are particularly affected. For financial players, it is crucial to incorporate specific climate-related risks into risk-adjusted returns, market prices, and share values. Clear political decisions for a natural gas exit would be helpful to decrease uncertainty and risks associated with stranding assets.

5.2. Future research directions

The framework offers various applications for future research, inviting to new initiatives for evaluation and refining initial hypotheses. Adapting the study context allows to study crisis response policies from other countries or sectors, enabling comparative analyses between countries. Additionally, key developments, like the climate crisis, may be expanded to include planetary boundaries or the biodiversity crisis, while geopolitical energy crisis could be replaced with emerging crises.

Besides these adaptation options, a further research direction involves empirically investigating specific cases. The conceptual components serve as a foundation for developing a modeling approach for quantitative assessment, offering inspiration for integrating additional modeling components. These could involve, e.g., agent-based modeling approaches [57,58], the identification of main drivers used in scenario analysis [see, e.g., 59], or updating assumptions in energy system modeling [see, e.g., 24]. The framework aids in interpreting model outcomes by enhancing the researchers' understanding of the impacts of multiple crises and the potential policy responses.

Research directions also include further development of the framework. to tackle compounded risks and crises. It involves a systematic process of several essential steps, starting with Integrating established models and theories from related disciplines, such as economics and environmental impact assessment. Next, identifying variables and indicators for quantification, such as social metrics, and environmental measurements, becomes crucial. Subsequently, collecting pertinent data aligned with the predetermined variables and indicators can allow to validate and test relationships within the framework and can enable to develop qualitative and quantitative scenarios. The process remains dynamic with further refinement and iteration of the framework. Empirical discoveries and expert insights inform necessary adjustments. Ultimately, the framework can serve asa communication tool, elucidating the complexities and making research findings accessible to a broader audience.

6. Conclusions

A fundamental step toward comprehending and fostering the transition toward a zero-emission and just future is understanding how contemporary crises impact the energy transition and climate goals, as well as financial stability. The geopolitical energy crisis caused by the Russian invasion in Ukraine is such an important example of a crisis. It led to negative consequences in the energy sector with spillover effects for the whole economy and transition. In times of multiple crises – thinking about the Covid-19 pandemic or the escalating geopolitical Middle East conflict – designing and implementing adequate crisis response policies has become increasingly important, but also complex.

To address the complexities and lack of approaches considering the broader scope of interacting crises, the paper offers a novel conceptual framework in the form of a detailed, step-by-step guide. This framework is designed to be applicable to different contexts, crises, and policies. By applying the framework to the case of German energy and financial emergency policies, we enhanced the understanding of the dynamics and risk channels between (1) the climate crisis, (2) financial (in)stability, (3) the geopolitical energy crisis, and (4) the energy transitions.

We conclude that short-term emergency policies - such as the expansion of fossil LNG or weak macroprudential financial regulations - that outweigh climate goals in the long run cannot safeguard financial stability, foster the energy transition, or decrease transition risks.

CRediT authorship contribution statement

Franziska M Hoffart: Conceptualization, Investigation, Writing – Original draft, Writing – review & editing, Visualization, Project coordination. **Paola D'Orazio:** Investigation, Writing – Original draft, Writing – review & editing. **Franziska Holz:** Investigation, Writing – Original draft, Writing – review & editing, Visualisation. **Claudia Kemfert:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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