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Eliciting knowledge from stakeholders to identify critical issues of the transition to climate neutrality in Greece, the Nordic Region, and the European Union

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ABSTRACT

There are considerable differences in the pace and underlying motivations of the energy transition in the different geographical contexts across Europe. The European Union's commitment to climate neutrality by 2050 requires a better understanding of the energy transition in different contexts and scales to improve cooperation of involved actors. In this article, we identify critical issues and challenges of the European energy transition as perceived by stakeholders and investigate how these perceptions vary across geographical contexts. To do so, we couple a policy document analysis with research based on stakeholder engagement activities in three different scales, national (Greece), regional (Nordic Region) and continental scale (European Union). Our findings show that stakeholder perspectives on the energy transition depend on contextual factors underlying the need for policies sensitive to the different transition issues and challenges in European regions. They also reveal cross-cutting issues and challenges among the three case studies, which could lead to further improvement of the cross-country collaboration to foster the European energy transition.

1. Introduction

The European Green Deal lays the foundation for the European Union's (EU) aim for climate neutrality by 2050 [1]. While the goal is clear, the pathway to climate neutrality is not. EU policies call for a "unification" of energy systems at the continental level, such as the common European electricity market, which will require Europe-wide investments in energy infrastructure and production [2]. In fact, the EU needs a significant shift of the energy system away from its existing reliance on fossil fuels, enabled by an increase in energy efficiency and renewable energy sources (RES) [3,4] as well as associated infrastructures, such as electricity transmission lines and electric vehicle chargers [5]. Furthermore, reducing greenhouse gas (GHG) emissions in accordance with mid- and long-term targets will require broader social changes and a comprehensive approach that includes new regulatory frameworks, norms, and behaviours [6]. In this effort, many different actors will need to contribute to make the implementation of a sustainable future possible [7].

Despite the Europeanisation of energy policy [8,9], energy systems across Europe vary significantly. The Science Advice for Policy by European Academies consortium suggests that a systemic approach is required to accelerate and facilitate the European energy transition in order to reflect on the differences that exist between the energy systems across Europe and to build on the current state of knowledge about potential transition pathways [10]. Although the EU has a common energy and climate policy framework, national strategies, options, and geopolitical history differ greatly [11,12]. For example, some countries hold abundant natural resources, while others depend entirely on imported fossil fuels [13]. This divergence illuminates the considerable differences in the motivation, the speed, and the level of decarbonisation

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with which the energy transition has been pursued in energy systems across European countries and regions thus far [14].

In this context, countries will require different pathways to climate neutrality. A lack of reflection over these differences carries the risk that Europe will be decarbonised and transformed into a “two-speed” way, thus providing most of the gains of clean energy investments to Western European “climate leaders” [15]. Such an effect can exacerbate spatial unevenness and inequality across Europe [16]. In that sense, a better understanding of what is known, what is partially known, and what is currently unknown with respect to the different energy systems across Europe is required [17]. As a result, it is critical to draw on lessons learnt by Member States and understand the different context-specific challenges and issues of the energy transition to advance collaboration and accelerate climate efforts globally [18].

Previous studies in the literature have identified a variety of challenges to achieving a low-carbon energy transition in Europe at the regional [14,19] and national [20–22] levels using a variety of methodologies, such as expert interviews, critical literature reviews, policy document analysis, or adopting a political economy perspective. Nevertheless, the academic literature on critical issues of the energy transition is fairly limited with reference to the goal of Europe to reach climate neutrality by 2050. For example, Tomaszewski [23] was among the first to examine the challenges and threats to the Polish energy sector in the context of the EU Green Deal. Furthermore, studies that consider the perspectives of a large sample of stakeholders on a European-wide scale after the recent EU commitment to become climate neutral by 2050 are lacking.

In this article, we investigate what experts, representing different European countries and stakeholder groups, namely policy, energy industry, science, and civil society, perceive as critical issues and challenges of the European energy transition to climate neutrality by 2050 and how these perspectives are influenced by differences in geographical context. To this end, we apply a multi-method approach combining a policy document analysis with multitudinous stakeholder engagement and cross-case comparisons in three case studies with different geographical and socioeconomic contexts and scales. We seek to expand the domain knowledge about differences in context-specific issues and challenges as well as cross-cutting themes, and discuss how these should be overcome to reach the specific energy and climate objectives of different energy systems. This enables us to draw conclusions for better-informed decision-making and joint planning at national, regional, and supranational/EU levels.

2. Research design

Our research design is based on qualitative research that provides an in-depth examination of three case studies and their cross-case comparison. We combined different techniques of data collection (desktop research, semi-structured interviews, focus groups, and workshops [24]), which were embedded within the concept of the “three types of knowledge framework” [25,26]. We chose this approach due to its straightforward structure and usefulness with regards to developing research questions in a way that they meet stakeholder knowledge demands [27]. The application of the “three types of knowledge tool” provided a high-level framework through which we analysed the collected data, while considering the nature and the spatial variation of the case studies [28]. For our desktop research, we selected policy documents, since, at the time of conducting this research, they constituted the most updated source of the climate and energy “status quo” (i.e., scenarios and targets) in the investigated geographical contexts. An additional advantage of this approach is that it allowed us to avoid potential bias from stakeholder opinions.

As regards the case studies, we combined diverse cases to illuminate the full range of differences and demonstrate cross-cutting themes. The spatial variation across contexts emphasises cross-case differences of political, social, cultural, economic, demographic, and technological particularities of energy systems. We investigated the critical issues and challenges to reach climate neutrality for three case studies to explore how stakeholder perspectives differ and to achieve greater generalisability of our findings [29]. We believe that the geographical dimension adds an important value in identifying critical issues and challenges of the energy transition and better understanding the several important implications of geographies for the EU energy policy landscape.

2.1. Case study selection

We empirically investigated stakeholder perspectives in three European cases: Greece, the Nordic Region (Denmark, Finland, Iceland, Norway, and Sweden), and the EU as a whole. We selected these cases as representatives of different spatial scales of the European energy transition and geographical contexts with different demographic, economic, energy and climate characteristics, and governance levels. Considering that all the EU’s national energy systems will need to be coordinated in the future to make Europe climate neutral by 2050, we also consider the level of the integration potential. In this sense, Greece (Southern Europe, national scale) is a relevant case because it is considered to have a relatively isolated energy system, while, in contrast, the Nordic countries (Northern Europe, regional scale) deregulated their electricity markets in the early 1990s and integrated them into a common Nordic market [30]. Electricity in the Nordics is already more than 90 % carbon-free and is expected to be fully decarbonised by the end of the 2020s [13]. Finally, the EU’s energy system encompasses a diversity of geographical contexts under one umbrella.

2.2. Analytical framework

The “three types of knowledge” framework is built around three main guiding questions that emphasise different types of required knowledge. First, knowledge about what is (“system knowledge”), i.e., analytical and descriptive knowledge about the current system or problem situation. Second, knowledge about what should be (“target knowledge”), namely knowledge about the desired future and goals as well as the values that indicate which direction to take. Third, knowledge about how we get from where we are to where we should be (“transformation knowledge”), which includes questions about technical, social, cultural, and other possible means of acting that aim to transform existing practices and introduce desired ones [31].

There are different ways of distinguishing between the three forms of knowledge, especially in relation to research on sustainable development (for example, see Becker [32] and Becker et al. [33]), while similar groups of questions can be found in Grunwald [34]. In the context of our work, the first of the guiding questions addresses the current state of the specific areas of the energy system, while the two following questions address targets and the transformation pathways required to achieve these targets. For each case, we explored all the three types of knowledge, as presented in Fig. 1. Our key objective was to identify and better understand the critical issues and challenges of the European transition to climate neutrality; thus, stakeholder interactions mainly aimed at extracting “transformation knowledge”, since this is the most understudied topic in the scientific literature, while “system knowledge” and “target knowledge” are well-documented in existing policy documents.

2.3. Research approach

To explore the different types of knowledge and collect relevant data, we applied a multi-method approach, including analysis of the latest available policy documents that contain targets and scenarios for the selected cases and stakeholder engagement activities (Fig. 2). Our research process was structured based on the “three types of knowledge” framework and its guiding questions. This work was implemented during the period October 2019–February 2021 in the context of the EU-funded Horizon 2020 project “Sustainable Energy Transitions

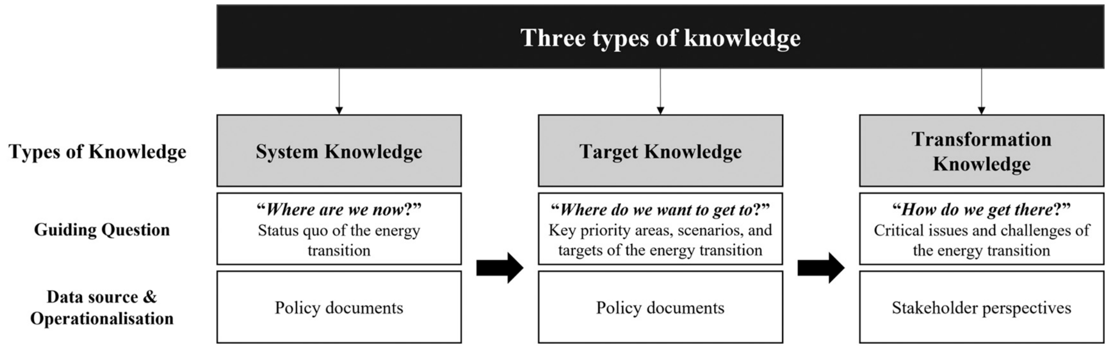

Fig. 1. The "three types of knowledge" framework and its implementation for each of the three cases under study. Adapted from [26].

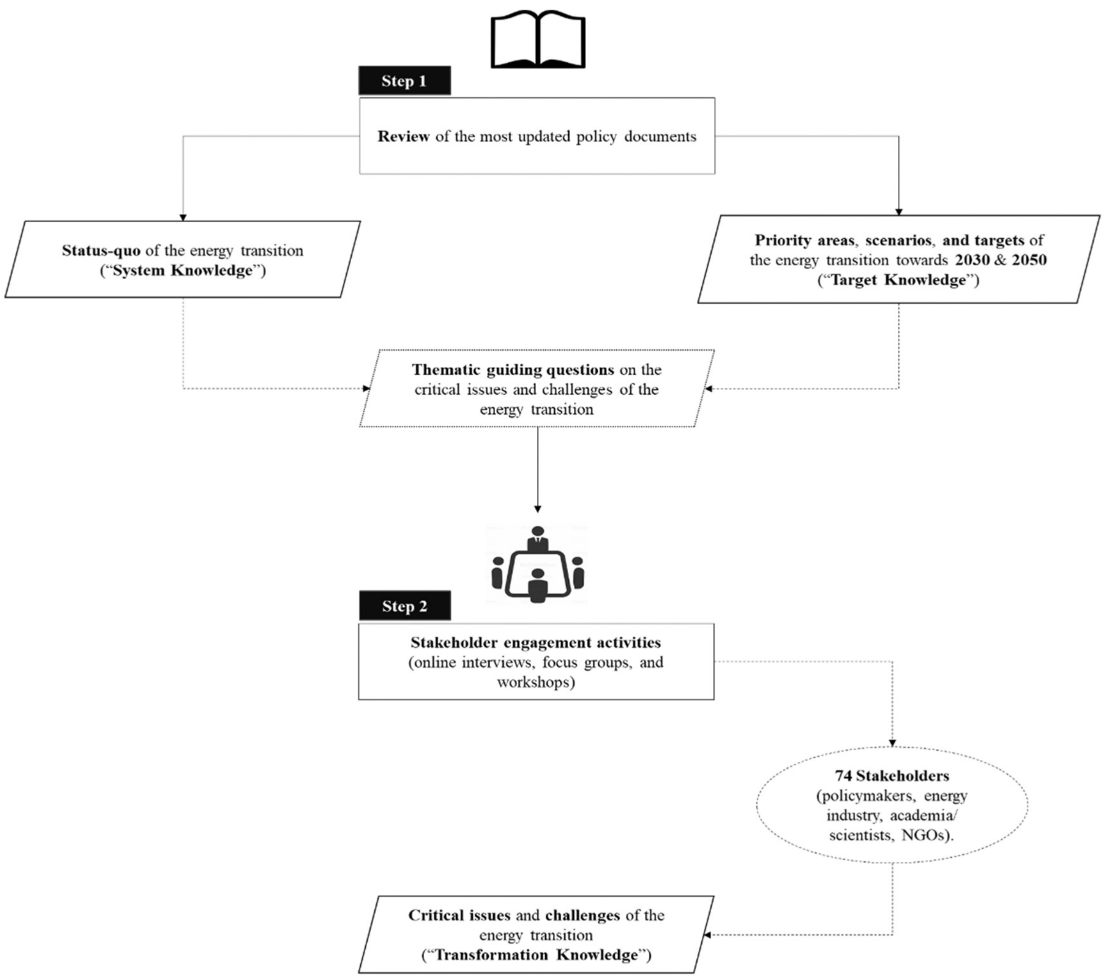

Fig. 2. A multi-method approach to identify stakeholder perspectives on the key critical issues and challenges of the energy transition to climate neutrality by 2050 in the three cases under study.

Laboratory (SENTINEL)[1]" [35].

2.3.1. Step 1: policy document analysis

The policy document analysis took place from October 2019 until June 2020. First, we reviewed the most recent policy strategies, including Nationally Determined Contributions under the Paris Agreement as well as National Energy and Climate Plans (NECPs) and Long-Term Strategies for 2050, especially for the national case study. For the regional and continental cases, we studied strategies and plans primarily at an aggregated level, including officially acknowledged energy strategies published by the Nordic Energy Research Council (i.e., Nordic Energy Technology Perspectives [36] as well as the reports analysing the progress of the Nordic countries towards carbon neutrality [37,38]) and the European Commission (i.e., the EU Reference Scenario 2016 and the European Green Deal). Where necessary, we also advised individual national policy strategies, for example, the Nordic countries' NECPs. At the time of implementing our research, the "Nordic Clean Energy Scenarios" [39] and the EU Reference Scenario 2020 [40] had not been published yet. In this article, we acknowledge the update of the policy

[1] https://sentinel.energy/.

scenarios and targets for both the Nordic and the EU cases and thus include them in our results. Through the policy document review, we identified the "status-quo" of the energy transition in the three cases, namely at which point each context was regarding the energy transition ("system knowledge"), along with the key priority areas, scenarios, and targets of the energy transition towards 2030 and 2050 ("target knowledge"). "System knowledge" and "target knowledge", as collected from the policy document analysis, allowed us to create thematic guiding questions with reference to the critical issues and challenges of the energy transition in the different geographical contexts under study, to be discussed with stakeholders.

2.3.2. Step 2: stakeholder engagement activities

From July 2020 until February 2021, we involved in the research process experts from the energy and climate community to extract their various perspectives on potential future developments in the Greek, the Nordic, and the EU energy systems. Stakeholders represented all parts of the quadruple helix model of innovation, which recognises four major actors in the innovation system: science, policy, industry, and society [41]. In the quadruple helix setting, actors are involved in multi-layered, dynamic, bi-directional interactions rather than unidirectional push-pull relationships [42]. In our research approach, we did not use this setting to identify differences based on the stakeholders' areas of expertise, but to synthesise multiple perspectives on the critical issues and challenges of the European energy transition, thus avoiding participant bias. Table 1 presents the number of engaged stakeholders from policy, energy industry, science (i.e., academia, research, and consulting) as well as civil society (i.e., citizen groups and non-governmental organisations (NGOs)). Fig. 3 shows the percentage shares of the countries where stakeholders' institutions were based across case studies. Table 2 includes the different disciplines of the engaged stakeholders for each case study. The involvement of stakeholders was structured around the thematic guiding questions belonging to thematic research priority areas identified through the policy document analysis. The main goal of these interactions was to dive into the specifics of the energy transition in each geographical context (i.e., "status quo", priority areas, scenarios, and targets) and identify different critical issues and challenges of the energy transition to achieving climate neutrality. The collected input was processed and summarised to fully reflect the "transformation knowledge" of each case study.

Table 1
Number of stakeholders engaged for each group of the quadruple helix model of innovation.

Stakeholder groups	Greece	Nordic Region	EU-27
Policy	3	3	5
Energy industry	15	1	4
Science	11	11	10
Civil society	4	0	7

Table 2
Disciplines of involved stakeholders per case study.

Case study	Stakeholder disciplines
Greece	Electricity Distribution & Transmission Network; Energy & Climate Modelling; Energy Communities; Energy Efficiency in Buildings; Energy Management & Trading; Energy Planning; Energy Policy Analysis; Energy Storage & Curtailment; Oil & Gas; Regional energy planning; RES & Energy Efficiency Policy; Social Acceptance & Environmental Constraints of RES; Wind Energy
Nordic Region	Biofuels, Electricity & Hydrogen in Transport; Decentralised/ Remote energy systems; Gas Transmission Network; Electricity Distribution & Transmission Network; Energy & Climate Modelling; Energy Markets & Economics; Energy Policy Analysis; Heating in Residential Buildings; Hydrogen, Power-to-X & Carbon Capture and Storage; Oil & Gas; RES & Energy Efficiency Policy; Sector coupling; Thermal Storage & Hydropower
European Union	Biofuels, Electricity & Hydrogen in Transport; Biomass in Industry; Building Demand Forecasting; Charging Infrastructure for Electric Vehicles; Circular Economy; Demand-Side Flexibility; Electricity Storage & Hydropower; Energy Efficiency in Buildings & Industry; Energy Management & Trading; Energy Markets & Economics; Energy Policy Analysis; Green Hydrogen & Power-to-X; Heating & Cooling; Life Cycle Assessment; Regional energy planning; RES & Energy Efficiency Policy; Smart Grids

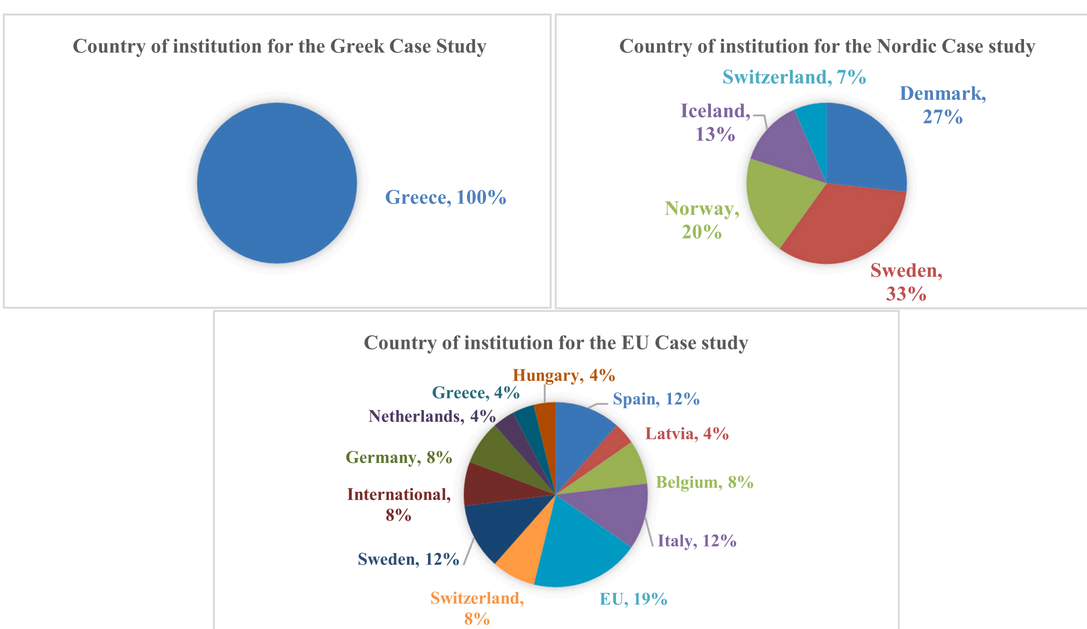

Fig. 3. Distribution (%) of stakeholders' country of institution for each case study.

Table 3
Overview of the research activities implemented in the three case studies.

Case study	Policy document analysis	Stakeholder engagement activities
Greece	National Energy and Climate Plan (2019) Long-Term Strategy 2050 (2019)	15 online interviews and focus groups with a total of 33 stakeholders
Nordic Region	Nordic Energy Technology Perspectives (2016) Nordic Clean Energy Progress (2020)	1 online workshop with a total of 15 stakeholders from all the Nordic countries
European Union	EU Reference Scenario 2016. Energy, transport and GHG emissions. Trends to 2050 (2016) The European Green Deal (2019)	1 online workshop with a total of 26 stakeholders from different Member States

As our work coincided with the COVID-19 pandemic, all stakeholder engagement activities were implemented in an online format, which was the common practice among the EU energy research community at the time [43]. We conducted online interviews and focus groups that followed a semi-structured interview design and two online open-discussion thematic workshops with a larger sample of field experts. For the national case, we conducted online interviews and focus groups, in which stakeholders involved in the preparation of the updated plans and strategies also participated (for more details see: [44]). For the regional case, we conducted an online workshop with experts from the entire Nordic Region [45]. Another online workshop was held for the EU case with stakeholders from multiple Member States [46]. All stakeholder engagement activities were designed to operate around the guiding questions from the applied "three types of knowledge" framework, according to the identified thematic research priority areas for the energy transition in each case study, and aimed at illuminating specialised and contextualised knowledge, while considering the ethical and inclusivity requirements of the European Commission. A summary of the research process is presented in Table 3. Even though COVID-related constraints resulted in different levels of participation and formats for the stakeholder engagement activities across case studies, we managed to engage with experts representing different stakeholder groups across case studies. We asked questions with similar scope for each geographical context in order to make the comparability of the data acquired from the consultations feasible. We recorded and transcribed the feedback received from the interviews, the focus groups, and the workshops. The main feedback was collected via online participatory tools, such as Kialo[2] and Miro[3], and summarised in notes by the workshop facilitators. All research concerning the national case was conducted in Greek, while the Nordic and EU case studies were conducted in English. The presented findings for the "transformation knowledge" in the three cases were further analysed and synthesised by the authors; therefore, they do not contain any quotations, and are presented serially and in accordance with the identified thematic research priority areas for the energy transition in each case study.

3. Results

3.1. National scale (Greece)

3.1.1. System and target knowledge

Domestic lignite has played a significant role in the Greek electricity generation and subsequent policymaking processes up until early 2019, despite the active promotion of RES in the policy agenda thus far [47]. However, in the second half of 2019, a governmental decision to fully phase out lignite by 2028 was taken [48], which requested for further analysis of the effects that the lignite phase-out would have on the future development of the country's energy system [49]. This resulted in the development of the revised NECP outlining the energy and climate objectives, policy priorities, and targets of the country until 2030 [50], and the development of the Long-Term Strategy for 2050, which presents the different viable options and energy transition scenarios in accordance with the long-term European vision for climate neutrality [51]. In 2021, the chief executive officer of PPC announced that the lignite phase-out could be completed by 2025 [52], whereas both the NECP and the Long-Term Strategy have been under revision to account for the effects of the COVID-19 pandemic [53]. For the transition to the post-lignite era, the government has devoted special focus on the regions where the power plants exist to alleviate effects from the loss of employment and analyse consequences in the whole supply chain [54].

Fig. 4 presents the main targets regarding GHG emissions, final energy consumption, and RES shares in electricity generation as specified in the different scenarios of the NECP and Long-Term Strategy. All scenarios of the Long-Term Strategy document assume the achievement of the NECP targets by 2030 and incorporate goals, priorities, and policy measures for the post-2030 period. In particular, the "NECP-2030" scenario foresees the continuation of the current NECP policies post 2030, while the "NECP-2050" scenario, which aims at significant GHG emission reduction by 2050, foresees the reinforcement of the NECP policies with larger intensity after 2030 compared to the 2020–2030 period. In addition, the Long-Term Strategy includes four more ambitious scenarios: (i). the "Energy efficiency and electrification for 2 °C (EE2)" scenario, (ii). the "New energy carriers for 2 °C (NC2)" scenario, (iii). the "Energy efficiency and electrification for 1.5 °C (EE1.5)" scenario, and (iv). the "New energy carriers for 1.5 °C (NC1.5)" scenario.

The "EE2/1.5" scenarios consider that it is economically and technologically uncertain to develop new climate-neutral energy carriers that will replace fossil fuels and strongly promote the electrification of energy uses in all sectors and the improvement of energy efficiency. They also include the large-scale development of biofuels and biogas to replace fossil fuels in areas where full electrification of the energy system is not possible. To achieve climate neutrality, electricity generation must have a zero-carbon footprint and is based on the development of large-scale RES projects.

On the other hand, the "NC2/1.5" scenarios assume that appropriate policies at the EU level account for gradual maturation of technologies, enabling climate-neutral hydrogen, biogas and synthetic methane production via electricity. In this context, ambitious policies focus on improving energy efficiency and electrifying transport and heating, since, otherwise, the volume of electricity generation from RES would increase to unattainable levels. Energy efficiency and electrification targets in the "NC2/1.5" scenarios are slightly lower than those in the "EE2/1.5" scenarios. Emissions from fuel use in the "NC2/1.5" scenarios are reduced using zero or low-carbon footprint gases and hydrocarbons, while in the "EE2/1.5" scenarios, emissions are avoided due to the improvement of energy efficiency, electrification, and the increased use of biomass.

Based on the abovementioned targets and scenarios, Table 4 summarises the main thematic research priority areas based on the policy documents analysed, coupled with the respective guiding questions that were created for each thematic area to structure the stakeholder discussion on the critical issues and challenges of the energy transition in Greece.

3.1.2. Transformation knowledge

Stakeholders from industry were sceptical about the high amount of variable renewable energy (VRE) that is foreseen by 2030 and 2050, noticing that a RES penetration of more than 60 % in the short term is unduly ambitious. On the other hand, stakeholders were also optimistic about the potential of RES in the power sector, mentioning that within a few years, VRE facilities will be operating in the same way that the conventional power plants have done so far, and that large wind turbines are already able to provide similar services to conventional plants.

[2] https://www.kialo.com/.
[3] https://miro.com.

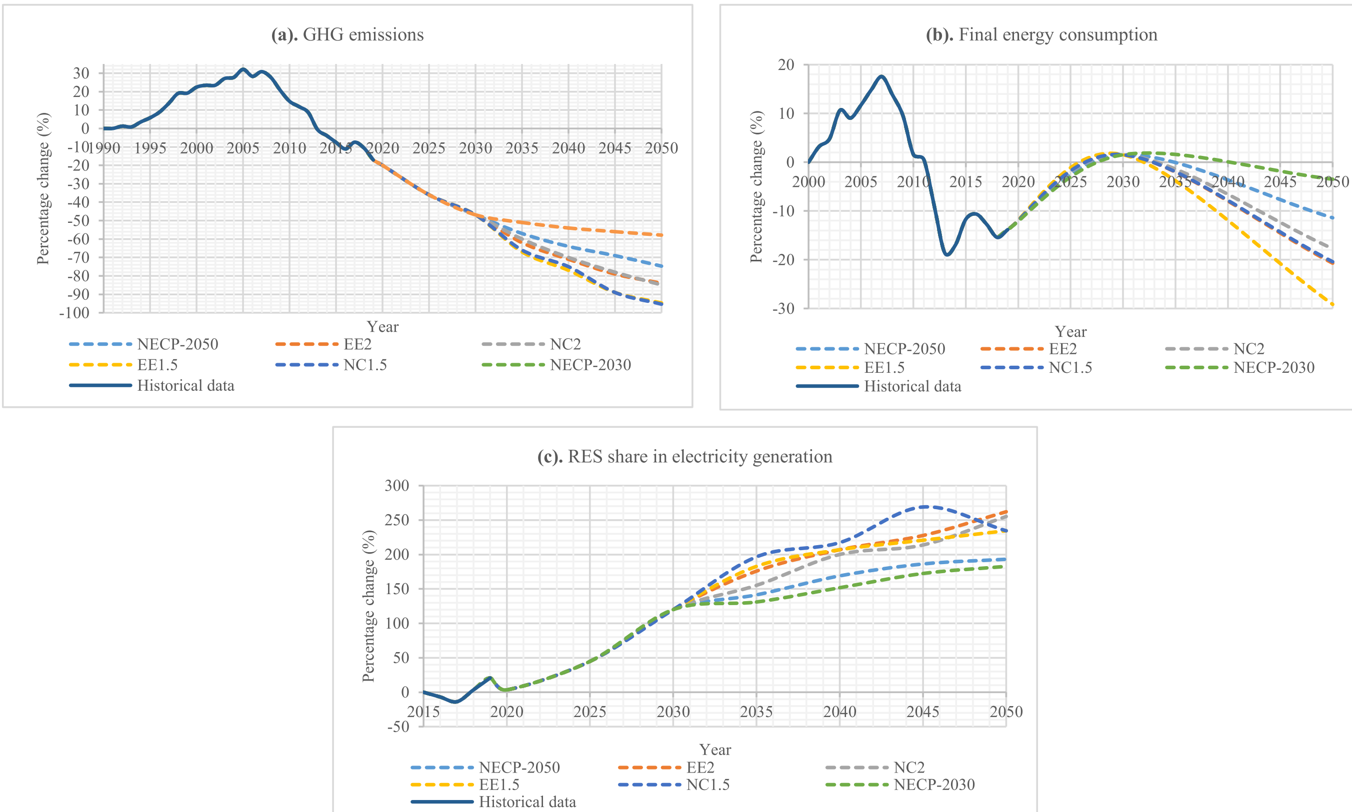

Fig. 4. Main targets of the energy transition towards 2030 and 2050 in Greece according to the different scenario specifications for (a). GHG emissions [50,51,55], (b). final energy consumption [50,51,56], (c). RES share in electricity generation [50,51,57]. Targets expressed as percentage change relative to 1990 (GHG emissions), 2000 (final energy consumption), 2015 (RES share in electricity generation).

Table 4
Thematic research priority areas for the energy transition in Greece and thematic guiding questions.

Power sector transformation & security of supply	• What could be the role of fossil fuels in the electricity mix in view of the lignite phase-out? • How could issues of capacity adequacy and security of supply be addressed in the short- and long-term transition, also considering particularities of the non-interconnected systems?
Sector coupling & decarbonisation of end-use sectors	• What could be the key options towards the decarbonisation of the different end-use sectors? • To what extent could hydrogen replace direct electrification in the different end-use sectors?
Energy efficiency, demand-flexibility & digitalisation	• What options and funding mechanisms could lead to the achievement of the energy saving targets? • What demand-flexibility measures could be implemented and what should be the necessary digital infrastructure?
Environmental concerns	• What would be the environmental concerns of decarbonisation, also considering the technological configurations required?
Socioeconomic implications	• What would be the socioeconomic implications of the lignite phase-out?

Some stakeholders were critical about the swift shutdown of the lignite power plants, with many of them pointing out that this decision seems to favour natural gas. In particular, one interviewee from industry mentioned that despite the ambitious target to phase out lignite, it does not seem like there is much process regarding decarbonisation as a whole and that by replacing lignite almost exclusively with natural gas in power generation and heating, Greece just invests in new fossil fuel infrastructure. In this context, stakeholders also expressed the risk that investing in natural gas power plants could lead to stranded assets in the next 10–15 years and stated that, although natural gas was considered as the cheap transition fuel ten years ago, it has been lately criticised as a key culprit to the energy price crisis. As a result, investing in natural gas today could potentially lead to greater costs in the long term than investing in RES and energy efficiency.

Experts highlighted that the interconnections of the Greek system with neighbouring countries should be further increased, and, to this end, some domestic network upgrades will also be necessary. With regards to interconnections with neighbouring countries, stakeholders were concerned about how electricity markets will cooperate under the Target Model, wondering whether power producers will prefer to sell electricity to countries with higher electricity prices. Stakeholders highlighted the importance of electricity storage and mentioned that options in the short term should include both pumped and battery systems. They reflected on the difficulty to reach high VRE penetration without using storage options and further expanding their technological capacities. Industry experts highlighted that in isolated or non-interconnected electricity systems, hydrogen may be a more attractive storage option than batteries, utilising available natural gas networks for its distribution after 2030. Especially in cases of large VRE penetration, energy conversion to hydrogen could have more significant value, as hydrogen generation could become a possible alternative to expanding the electricity grid. Furthermore, stakeholders suggested that hydrogen could also substitute natural gas in the industrial sector and could have a complementary role in transport, particularly for vessels. Regarding the electrification of different end-uses in transport, experts perceived various impediments to electric mobility, such as high investment costs of electric vehicles and the lack of charging infrastructure. On the other hand, in the heating sector, stakeholders mentioned the high investment cost of heat pumps and the lack of expertise in designing and installing them as critical challenges.

With reference to the demand side and implementing energy efficiency projects, stakeholders stated that the energy service company market remains negligible and reflected on the need for establishing financing schemes, like loans, possibly under the European Investment Bank activities, which could support the creation of energy service companies and provide incentives to consumers and other companies. They also pointed out the requisite for increasing the amount of money available for the refurbishment of residential buildings, highlighting that it is essential to have at least two more programmes similar to the "Exoikonomo-Aftonomo" programme (a financial programme targeting refurbishments in residential buildings [58]) on an annual basis in order to reach the energy saving targets of 2030. In addition, some stakeholders argued that the required peak shaving, namely the proactive management of overall demand to eliminate short-term demand spikes, during the operation of the system can be achieved via demand-response with smart meters and that it would be critical for the wide deployment of smart meters if part of their costs was funded. Stakeholders suggested that utilities should create financial incentives, like time-of-use tariffs or even more adaptive tariff schemes, to maximise the benefits of combining smart meters with demand-response solutions.

From an environmental perspective, the main concern raised by stakeholders was about the treatment of waste batteries after the end of their lifetime, pointing out that it is more difficult to use, reuse and recycle batteries than to simply dispose them. They emphasised that materials of novel technologies, like battery storage systems and wind turbines, should be recycled and that decisions on RES investments should also consider their environmental impact. In addition, stakeholders stated that people who live near RES installations typically react negatively and do not understand the advantages of such technologies. Moreover, it was mentioned that lobbying against RES has been quite effective so far. A representative from an NGO stated that powerful actors and lobbies have excessive power today, which leads to deadlocks in energy policy planning and implementation. As an analogy, the stakeholder linked the current issues to an example of the tobacco industry, noticing that the fossil-fuel lobby has come out relatively successful in a decades-long fight to delay decisions on climate change and energy transition, much like the tobacco industry effectively delayed for decades the diffusion of scientific knowledge to the public and the corresponding policy implementation. Stakeholders mentioned that changing people's minds about RES technologies is challenging and that initiatives to raise public awareness are most effective if they are continuous and spread out across time. According to stakeholders, such activities should also be linked to different types of incentives, highlighting the lack of public incentives and information towards sustainability.

Finally, stakeholders from NGOs and academia mentioned that many people will lose their jobs due to the lignite phase-out and wondered how those currently employed in lignite power plants and mines will be involved in the transition, stating that new vulnerable social groups could emerge. In this regard, energy policy should account for aspects such as energy democracy and justice. These concepts are associated with the equitable distribution of costs and benefits from social and economic participation in the energy system, and with alleviating the social, economic and health burdens of those who are disproportionately harmed by the energy system [59,60]. At the same time, experts referred to the need for identifying social innovations that could alleviate energy poverty. In this context, some stakeholders stated that it would be desirable to conceptualise and explore alternative (not only technological) pathways that are less bounded by cost-effectiveness considerations and embody aspects of social inclusion, justice, and energy sufficiency. One interesting proposal for the redevelopment of the affected areas was to convert the municipalities close to the lignite mines into showcase energy communities, utilising available financing mechanisms like the "Just Transition Fund".

3.2. Regional scale (Nordic Region)

3.2.1. System and target knowledge

The Nordic Region (Denmark, Finland, Iceland, Norway, and Sweden) has a relatively advanced power sector due to large hydropower resources [61] and the integration of electricity markets across multiple countries [62]. Moreover, Nordic countries are leaders in terms of prioritising electrification by integrating electricity and heat generation in buildings, industry, and transport [19]. The institutional cooperation between the Nordic countries regarding energy and climate policy has significantly sped up after 2015, when the Nordic Council of Ministers chose to fortify cooperation and determined relevant strategic directions [63]. In 2016, the "Nordic Energy Technology Perspectives" report was released, delving into long-term, low-carbon, and cost-efficient technology pathways, which could lead to a carbon-neutral energy system in compliance with the Paris Agreement [36]. This report included the "Carbon Neutral Scenario (CNS)".

In early 2019, the Nordic prime ministers signed the "Declaration on Nordic Carbon Neutrality", signalling the new vision for a more carbon-neutral region [64]. Afterwards, the Nordic Energy Research Council published reports that follow the Nordic commitment to a carbon-free society by 2050, underlining the necessary cutting-edge technological options [37,38]. Finally, in autumn 2021, the updated "Nordic Clean Energy Scenarios" were published, showcasing different technological and societal pathways as well as illustrating how political choices might shape the future of the Nordic energy system towards carbon neutrality [39].

Fig. 5 presents the main targets concerning CO_2 emissions, final energy consumption, and RES shares in electricity generation as specified in the "CNS" scenario and the "Nordic Clean Energy Scenarios". The "CNS" scenario assumes that Nordic energy-related CO_2 emissions will be reduced by at least 85 % by 2050 and outlines specific strategic actions that would be critical in achieving the 2050 climate targets. The "Nordic Clean Energy Scenarios" try to balance research and development, industry strategic decisions, and public acceptance levels that will affect outcomes regarding the Nordic future energy system. They consist of three individual scenarios: (i). the "Carbon Neutral Nordic (CNN)" scenario, (ii). the "Climate Neutral Behaviour (CNB)" scenario and (iii). the "Nordic Powerhouse (NPH)" scenario. It should be noted that the "Nordic Clean Energy Scenarios" do not reach full decarbonisation, as a small amount of CO_2 is emitted from the industrial, power and heat and upstream sectors. Even though most of the CO_2 emissions are captured with the use of Carbon Capture and Storage (CCS) technologies, the amount of CO_2 captured is not enough to achieve a 100 % CO_2 emission reduction.

The "CNN" scenario seeks the least-cost pathway under current national plans. In this scenario, the Nordics expand electricity exports to Central Europe, but only slightly over present predictions, as the electrification of the heating, transport and industry sectors necessitates a substantial supply of electricity. To maintain the sustainability of bioenergy use, biomass imports from beyond the Nordics are limited to present or slightly higher levels. Bioenergy with Carbon Capture and Storage (BECCS) is used to offset the cost of some of the most expensive CO_2 emission reduction alternatives. Furthermore, due to social acceptance and land use constraints, onshore wind is limited below its technical potential.

On the other hand, the "CNB" scenario is driven by a high level of political and citizen engagement, assuming that politicians and citizens employ additional energy and material efficiency measures across sectors, resulting in lower energy consumption. Decentralised generation solutions are becoming increasingly widespread, reducing the amount of energy distributed through grids. Because of more efficient use of transportation modes and fewer but more efficient heavy transport, energy demand is expected to drop.

Finally, the "NPH" scenario explores the possibility that the Nordics play a larger role in the European energy transition by providing low-

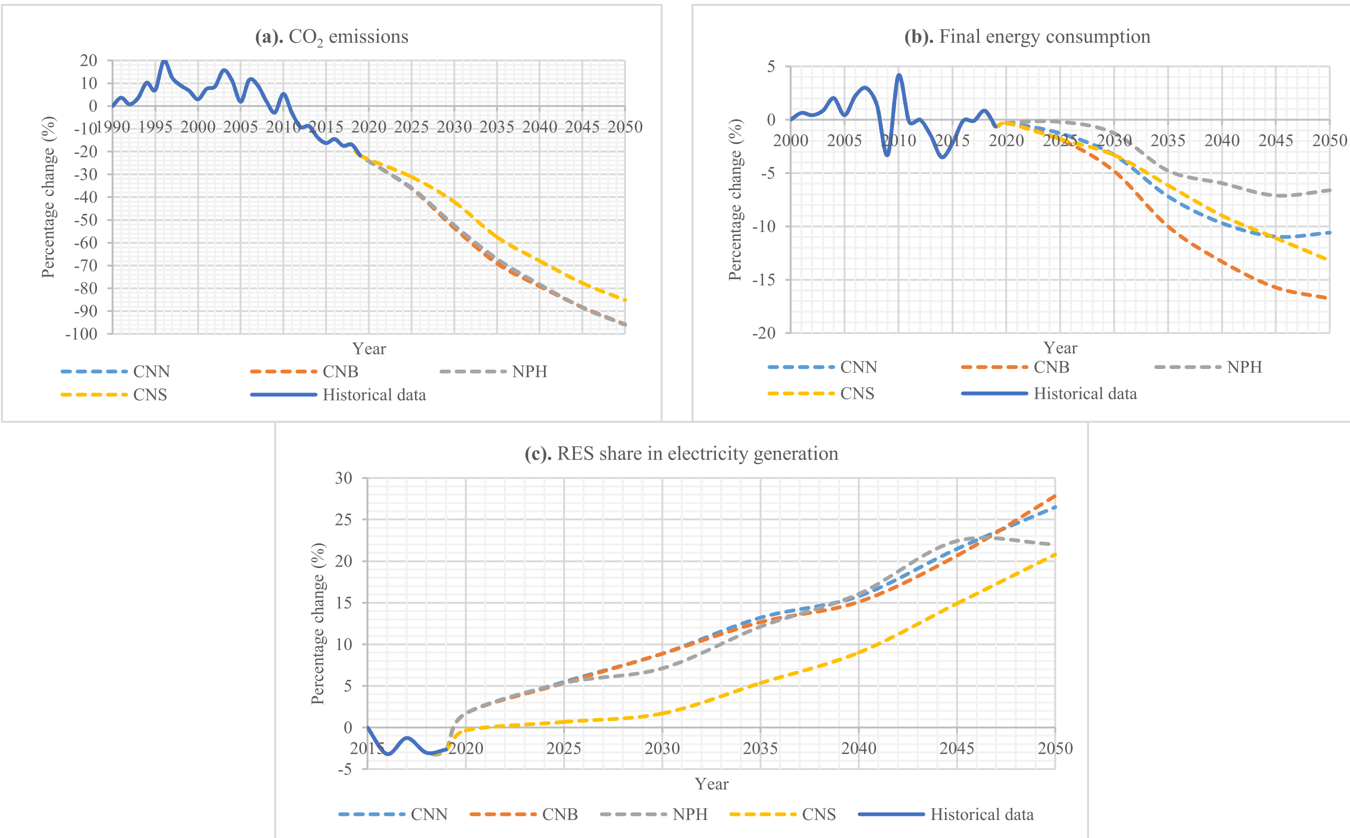

Fig. 5. Main targets of the energy transition towards 2030 and 2050 in the Nordic Region according to the different scenario specifications for: (a). CO_2 emissions [36,39,55], (b). final energy consumption [36,39,56], (c). RES share in electricity generation [36,39,57]. Targets expressed as percentage change relative to 1990 (CO_2 emissions), 2000 (final energy consumption), 2015 (RES share in electricity generation).

cost clean energy and by hosting low-carbon services and industries (e.g., carbon-free steel and aluminium). All these activities raise the demand for electricity and other energy products. There is also more excess heat from industry and services that may be utilised for district heating. Greater power transmission capacity between the Nordics, and from the Nordics to Central Europe, is assumed as well as increased power-to-X fuel production.

Based on the abovementioned targets and scenarios, Table 5 summarises the main thematic research priority areas based on the policy documents analysed, along with the respective guiding questions that were created for each area to structure the discussion with stakeholders on the critical issues and challenges of the energy transition in the Nordics.

3.2.2. *Transformation knowledge*

According to stakeholders, further utilisation of the vast availability of land area could contribute to developing more onshore wind power capacity. In combination with a large amount of available bioenergy, this could increase electricity generation from RES and potentially strengthen the Nordics' position as exporter of electricity to other European countries, like Germany (see also Sovacool et al. [19]). Stakeholders expressed the prevalent concern that increasing the deployment of solar power might lead to stranded assets across other technologies. They noticed that, even though nuclear power is economically unfavourable, it still plays an important role in the Nordics (like, for example, in the case of Finland, where it has been recently decided to commission new nuclear power plants) and cannot be assumed to be out of the picture, since there is no set deadline for its ending. With regards to hydrogen storage, stakeholders argued that it will be necessary to increase system flexibility but at the same time, installing new hydrogen pipes, which could be less expensive than installing new overhead power lines, might be difficult. In addition to the potential of the Nordics to become an electricity hub for Europe, their hydro reservoirs could also play a significant role in balancing European VRE. Experts stressed the need for better collaboration between the Nordics, which, despite the Declaration on Nordic Carbon Neutrality, still seems to be insufficient.

Table 5
Thematic research priority areas for the energy transition in the Nordic Region and thematic guiding questions.

Power sector transformation & security of supply	• What balancing options could facilitate high shares of RES under a common electricity market? • What would be the contribution of power generation coming from non-renewable sources?
Sector coupling & decarbonisation of end-use sectors	• What could be the key options that could allow for reduction of industrial GHG emissions? • What could be the key alternatives to replace direct electrification in the transport sector? • What could be the key options for decarbonisation in the heating sector?
Energy efficiency, demand-flexibility & digitalisation	• What options would be necessary to improve energy efficiency and reduce energy consumption in the building sector? • What should be the role of smart systems in facilitating the flexible operation of the power system?
Environmental concerns	• What would be the environmental concerns considering the potential of regional resources?
Socioeconomic implications	• What would be the socioeconomic implications of the short-term transition to a decarbonised energy system?

The workshop's participants noticed that decommissioning thermal generation units in favour of wind turbines will require the reinforcement of power transmission lines; otherwise, there will be risk that the Nordics may be unable to share increased levels of wind power generation.

Furthermore, the invited experts argued that the Nordics have a competitive advantage to further develop hydrogen projects, due to their well-developed oil and gas industry and a high potential for VRE production. In the case of blue hydrogen, more investments in CCS technologies are perceived to be needed to decarbonise its production and the Norwegian CCS business model could be replicated across Europe. Nordic stakeholders underlined that besides CCS and hydrogen, there is potential for waste-to-energy technologies, but this path is heavily influenced by the European legislation on negative emissions and pollution caps from small and medium waste-fuelled combustion facilities. Experts also voiced concerns over range and total tonnage constraints with battery usage. In this regard, passenger transportation could depend on biofuels in the short-term, which should be substituted by electricity in the long run. Heavy-duty vehicles and maritime transport could rely on power-to-X technologies, like hydrogen or synthetic fuels, rather than being totally electrified, serving as replacements to current fuels. Nevertheless, stakeholders referred to biofuels not only as an alternative fuel for transportation, but also for power plant supply and industry, arguing that this can pose a challenge of resource constraints in the biomass supply.

As regards heating, stakeholders focused on the need for changing district heating systems by implementing heat recovery and thermal storage to balance high shares of VRE production. According to them, this could provide the heating sector with additional cost-efficient flexibility and facilitate the exploitation of the advantages of smart energy systems. Experts also reflected on the potential of heat pumps as an effective heating option in areas where district heating is not available, especially where less efficient technologies, like direct electric heating, are still in use. Given the population increase expected in the Nordic cities, stakeholders acknowledged that buildings should be refurbished at a faster rate. They argued that even though new energy efficiency policies in the Nordics are climate compliant, energy consumption remains high because existing buildings tend to lack high efficiency standards that are suitable to northern climate zones. Additionally, in countries with low electricity prices, like Sweden, current incentives targeting the reduction of consumption are inadequate. They also made the link to cultural habits such as overheating the houses in the winter. In that sense, behavioural measures and practices, which can save a significant amount of energy (e.g., heat pumps, lifestyle changes) should be prioritised. Experts also discussed the potential synergies between smart buildings and smart grids to facilitate the flexible operation of power systems.

In addition, the experts mentioned that the increasing demand for batteries will lead to a reliance on mineral resources. Moreover, the decision to recycle batteries rather than dispose them after their life cycle will be dictated by the dominant types of batteries, similarly to RES technologies. In this context, potential raw material supply constraints were perceived as the biggest risk to the adoption of batteries. Stakeholders also discussed key challenges for exploiting the potential of bioenergy in the Nordics, focusing on the lower heating value of biomass compared to other fuels and the higher environmental footprint that it has compared to other types of RES. Furthermore, the use of and access to bioenergy varies among the Nordics. Experts highlighted that not all Nordic countries are eager to sacrifice biodiversity to create more bioenergy, while some of them heavily rely on biomass imports that could potentially cause transboundary problems.

From a social perspective, stakeholders mentioned that there have been increasing protests against new RES infrastructures and demands for nature protection in Iceland and Norway. They also noted that, so far, it has been easy for the Nordics to reach their energy and climate targets; however, this is expected to change. For instance, to reduce emissions in the Swedish transport sector by 70 % by 2030 will require not only technological change, but also a substantial change in lifestyle habits to achieve the last 5–10 % of emission reductions. In this respect, the application of specific instruments, like consumption-based targets, which might cause additional high costs for people, could be introduced, but may be less accepted by the society. In this regard, stakeholders emphasised the role of communication and education to increase awareness for the need of climate policies among the public. Additionally, it will be a challenge to find ways to cover future incomes in Nordic industries that have so far been largely covered by fossil fuel-related economic activities (e.g., Norway's oil and gas sector). Stakeholders expressed concern about the lack of clarity regarding distributional effects and pointed out that there is no evidence for job creation. They also stressed the need for fair policy packages across different governance levels, which could be difficult due to the different ideologies of decision-makers at the national and municipal levels.

3.3. *Continental scale (European Union)*

3.3.1. *System and target knowledge*

Over the last two decades, the EU has been a global leader in combating climate change [65]. Following the Paris Agreement in 2016, the EU adopted the "Clean Energy for all Europeans" strategy [66], followed by the "Clean Planet for all" strategy in 2018, which outlined the economic and societal changes required to attain net-zero GHG emissions by 2050 [67]. Both strategies highlighted the need for high-level decarbonisation [68]. At the end of 2019, the EU presented the European Green Deal as a set of policy initiatives with the overarching aim of making Europe the first climate neutral continent by 2050 [1]. In 2020, a recovery plan for Europe was established to enable European countries to deploy multiple financing instruments to repair the damage caused by the COVID-19 pandemic at the economic and social level [69]. To align current laws with the 2030 and 2050 ambitions, the EU worked on the revision of its climate and energy legislation under the "Fit for 55" package [70], which is a bundle of proposals to review the existing EU legislation and to implement new initiatives aiming at aligning EU policies with the climate goals agreed.

The EU Reference Scenario, published in 2016, focused on the EU energy system, transport and GHG emission patterns, with specific sections on non-energy emission trends and the different policy interactions between these sectors [71]. It covered all the EU-28 member states at the time and had a timeframe up to 2050. This scenario has served as a benchmark for policy and market trends, and it has been used so far to inform policy debates and decision-making. After the announcement of the European Green Deal, the 2030 Climate Target Plan proposed more ambitious decarbonisation goals by 2030 (at least 55 % of GHG emission reduction compared to 1990) [72], which was a significant increase of at least 40 % compared to the previous target that was set in the 2030 climate and energy framework [73].

The new EU Reference Scenario 2020 [40] projects the impact of macroeconomic, fuel price and technology trends and policies on the growth of the EU energy system. Its projections apply to the EU-27 member states individually and collectively. This scenario is a consistent and policy-relevant estimate of future changes in the EU and serves as a baseline for new policy efforts. It represents trends that policymakers can use as a starting point for developing policies to close the gap between, where the EU's energy and climate policy is now and where it wants to be in the medium and long term. Fig. 6 presents the main targets regarding GHG emissions, final energy consumption and RES shares in electricity generation, as specified in the two scenarios. For GHG emissions we also plot the commitment to climate neutrality according to the European Green Deal.

Based on the abovementioned targets and scenarios, Table 6 summarises the main thematic research priority areas based on the policy documents analysed, along with the respective guiding questions that were created for each area to structure the discussion with stakeholders

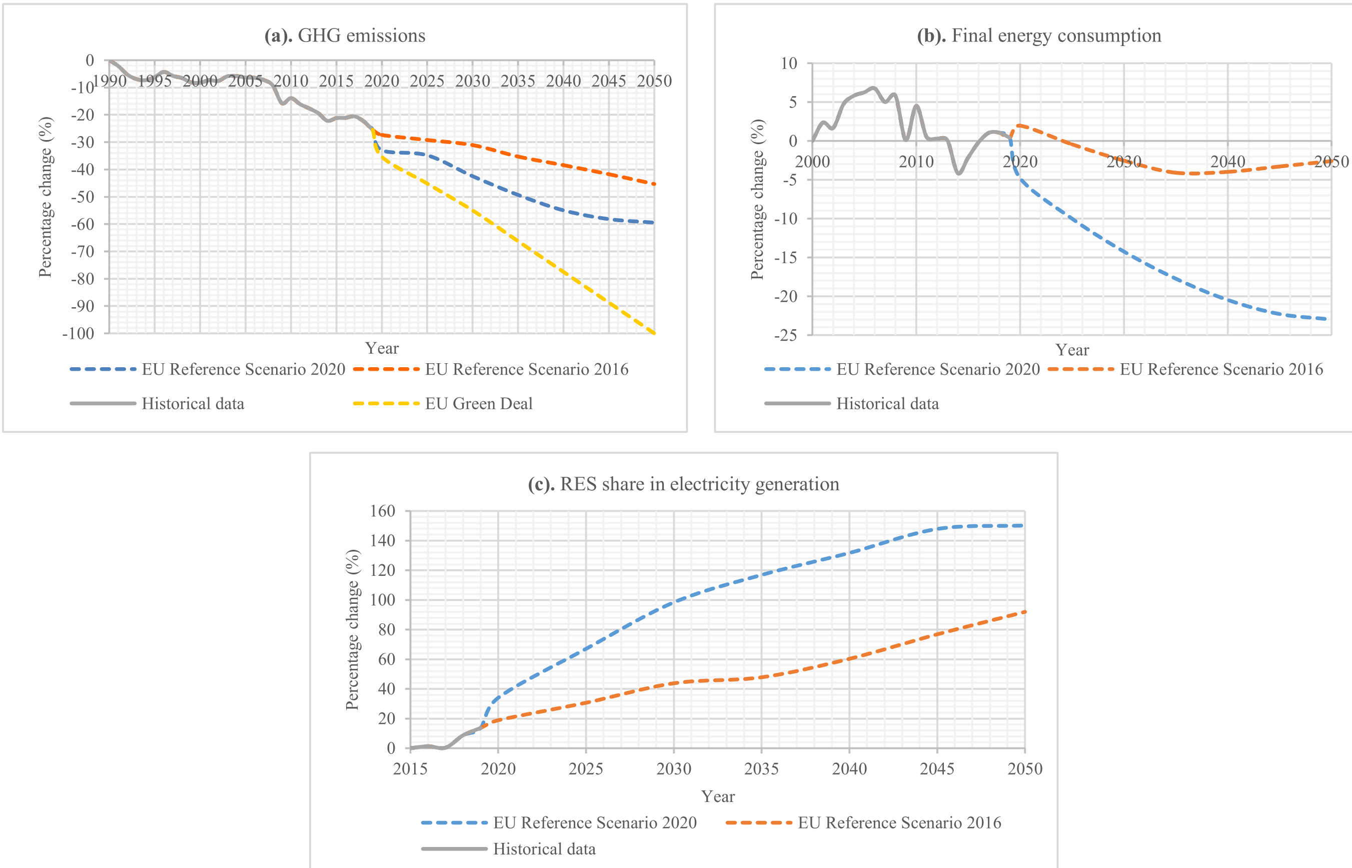

Fig. 6. Main targets of the energy transition towards 2030 and 2050 in the EU according to the different scenario specifications for (a). GHG emissions [40,55,71,72], (b). final energy consumption [40,56,71], (c). RES share in electricity generation [40,57,71]. Targets expressed as percentage change relative to 1990 (GHG emissions), 2000 (final energy consumption), 2015 (RES share in electricity generation).

Table 6
Thematic research priority areas for the energy transition in the EU and thematic guiding questions.

Power sector transformation & security of supply	• What would be the key options in the power sector under a unified energy market towards climate neutrality? • How could issues of capacity adequacy and security of supply be addressed in the short- and long-term transition, also considering interconnections between European countries?
Sector coupling & decarbonisation of end-use sectors	• What would be the key options for the decarbonisation of the different industrial subsectors across Europe? • What could be viable alternatives to replace direct electrification in the transport sector? • What could be the key options for decarbonisation in the heating sector?
Energy efficiency, demand-flexibility & digitalisation	• What options and funding mechanisms could facilitate the achievement of energy efficiency targets in the building sector? • What would be the role of demand-flexibility and digitalisation towards climate neutrality?
Environmental concerns	• What would be the environmental concerns considering the potential of resources across European countries?
Socioeconomic implications	• What would be the socioeconomic implications of the short-term transition to a European decarbonised energy system, also considering provisions of the recovery packages?

on the critical issues and challenges of the energy transition in the EU.

3.3.2. *Transformation knowledge*

Stakeholders discussed the expected time needed for the European power system to be capable of handling a large share of RES. They noted that RES could provide more than 70 % of Europe's energy by 2040, albeit with a few stipulations, such as overcoming problems related to their intermittency and the uncertainties surrounding the availability of materials for batteries. According to stakeholders, an open question remains regarding how nuclear energy can contribute to decarbonisation efforts. For example, in Belgium the decision about the nuclear phase-out was made in 2003 but its implementation has been insufficient, while in the Netherlands, some actors advocate building new nuclear power plants by 2030. Stakeholders shared various opinions for potential power sector flexibility mechanisms. Among different options, experts referred mostly to energy storage, especially in reference to 2030, which could be implemented with various options (e.g., pumped hydro). They suggested that emphasis in the long term should be placed on hydrogen, which could potentially be imported from Africa and the Middle East, since it could be more cost-effective to store energy in the form of heat, liquids, or gaseous fuels in comparison to electricity. Stakeholders also expressed the need for RES systems that are smart and integrated to avoid solely focusing on power grids. Moreover, they mentioned that having Europe-wide targets brings differentiated consequences to countries, including additional interconnections between countries.

With reference to heavy industries (e.g., steel, cement), stakeholders pointed out that hydrogen and electrification can facilitate transitioning away from pet coke and coal feedstock. In their view, the decarbonisation of industry will require the use of biomass as a feedstock to produce biofuels and biogas, leveraging both mechanical and feedstock recycling of current plastics as well as CCS. As stakeholders explained, there are certain risks associated with CCS (e.g., concerns about public health consequences, risk of a drop in real estate values) and some countries are hesitant to invest in it, although they expect that this technology will become commercially viable. From their perspective, CCS could be used to produce blue hydrogen contributing to industry decarbonisation. Stakeholders mentioned that the anticipated rise in hydrogen production can generate a conflict between the means of its utilisation, as hydrogen could either be utilised for power generation or be used as a replacement for natural gas in industry.

Concerning sustainable mobility, stakeholders indicated that passenger transportation could become fully electrified in 2050. They pointed out that electrifying heavy-duty transport with batteries is a viable solution to cover short distances and in case direct electrification is not possible, synthetic fuels could be another alternative. Stakeholders noted that some heavy-duty vehicles are primarily used for short distances, enabling easier use of batteries compared to those used for long distances. On the other hand, the feasibility of hydrogen passenger cars might be a steppingstone to hydrogen-powered heavy-duty transport. Heavy-duty vehicles rely on hydrogen cars to become a widespread solution, which is not the case right now, with stakeholders arguing that there is not currently a certain solution for long-distance trucking.

Moreover, stakeholders emphasised the need for better balancing of energy demand as a prerequisite for decarbonisation. They referred to various region-specific elements that influence energy demand in the EU, such as climatic variances and their effects on adopting heating and cooling solutions, architecture of buildings, electrification patterns, population and urbanisation trends, and behavioural characteristics. Experts mentioned that market influences, as in real estate, would significantly affect the uptake of energy efficiency measures and their success. In that context, they highlighted the importance of business models that encourage people to invest in the relevant technological infrastructure. Stakeholders mirrored that digitalisation will be pivotal for the decarbonisation of European buildings as it increases both energy efficiency and consumer awareness. They also stated that the first step to progress with digitalisation should be the widespread implementation of smart meters as well as monitoring their impacts on consumer awareness and behaviour. According to their views, digitalisation should synergise with EV charging-discharging patterns in order for electric vehicles to serve as electric storage facilities across Europe.

Regarding environmental aspects, stakeholders stated that manufacturing of new energy technologies will result in increased resource extraction. They noted that there are considerable differences in environmental impacts when installing batteries behind, or in front of the meter, considering factors like system efficiency and type of technologies avoided as a result of the usage of storage. It was underlined that installing batteries behind the meter is more difficult for the distribution system operator to control, hence, connecting rooftop photovoltaics to the grid is preferable to using battery storage. Workshop participants reflected on the environmental effects of centralised and decentralised energy systems. Related to that, they also emphasised the strong interrelation between environmental and energy systems, highlighting that increased biomass production and expansion of solar photovoltaics and wind farms may lead to environmental consequences due to the violation of land-use constraints. They referred to the multiple uses of biomass for the production of various goods (e.g., fuels, chemicals, fertilisers, food) and the competition for its utilisation across diverse sectors, with certain industries remaining heavily reliant on bioenergy.

Finally, stakeholders argued that, while regionally balanced electricity supply is desirable, it may result in conflicts between local and continental interests. These were illustrated by examples of environmental implications of small hydro generating units, local wind opposition motivated by the “not in my back yard” mindset, or concerns about bioenergy exploitation. At the same time, experts expressed optimism about the creation of new green jobs and innovative services (e.g., demand-side management, hydrogen, RES technologies, smart grids) after the implementation of the European Green Deal. Nevertheless, they put attention to challenges, such as the phase-out of coal, consequently leading to the unemployment of many coal workers and the reliance of timely reskilling to reintegrate into economic activities. Stakeholders indicated that this could have significant impacts on the income of local and regional economies and suggested that both positive and negative effects for consumers should be considered. This is relevant in the context of recent discussions on just transition, considering citizen participation within the transition.

4. Discussion

Our study shows that stakeholder perspectives on critical issues and challenges of the European energy transition to climate neutrality depend on geographical context (Table 7). We observe differences particularly regarding views on the flexibility of the energy system, carbon capture and negative emission technologies, the role of nuclear energy and natural gas and considerations of societal challenges. We also observe similarities in terms of the interconnectedness of the energy system, the role of hydrogen for decarbonising the industry and transport sectors, energy efficient renovations and digitalisation, technology demand for raw materials and social acceptance and distributional effects of the transition. The similarities provide important starting points for multi-level and cross-scale cooperation, while differences indicate that policies need to be adaptive to context-specific issues and challenges.

4.1. Differences in perspectives on energy transition issues and challenges

An important difference between stakeholder perspectives lies in the capacity of electricity systems to handle high VRE penetration levels. On the one hand, stakeholders at the national level were more sceptical about the integration of high levels of RES penetration as it requires plenty of energy storage capacity for sufficient uptake of electricity from VRE plants. Stakeholders saw the setup of state-of-the-art RES plants combined with storage technologies as a central priority with some suggesting that hydrogen storage could be an efficient alternative for remote systems. On the other hand, stakeholders felt that the Nordics have a strong starting point for the integration of VRE sources, compared to most of the other European countries, especially due to the large hydro reservoirs and the potential in wind power. This potential in hydro could facilitate balancing increased penetration of VRE in neighbouring countries. In this way, Nordic countries can both provide electricity exports to Central European countries and produce power-to-X fuels to serve domestic and export demand from continental Europe.

Another notable difference concerns the potential of adopting carbon capture and negative emission technologies, like CCS and BECCS, which could further support achieving the target of climate neutrality. Stakeholders in the Nordic Region are fond of the use of CCS for the decarbonisation of industry in applications such as blue hydrogen production. According to them, the Nordics are considered well-suited to develop and apply CCS and BECCS as plenty of carbon storage options are available as well as relevant research institutions and companies [39]. Furthermore, long experience with such technologies, coupled with offshore energy industries and large storage potentials, make Norway an emerging frontrunner. Additionally, the large presence of bio-based sectors, such as pulp and paper, and bioenergy in district heating, offers opportunities to achieve negative emissions through BECCS. In contrast to the Nordics, Greek and European stakeholders were sceptical about investing in CCS and BECCS due to issues of economic viability, regulatory challenges, and public acceptance. The requirement to be close to biomass resources and the lack of CCS infrastructure constitute important barriers to the establishment of BECCS [74].

Table 7
Stakeholder perspectives on the critical issues and challenges of the European transition to climate neutrality in different geographical contexts.

Priority areas	Greece	Nordic Region	European Union
Power sector transformation & security of supply	- Criticism for investing in fossil fuel infrastructure. - Need for reinforced national and regional interconnections. Concerns about market operation under the Target Model. - Need for electricity storage and attractiveness of hydrogen storage for remote energy systems.	- Belief that nuclear power cannot be ruled out. - Call for better regional collaboration and becoming electricity generation exporter to Central Europe. - Suggestion for becoming an electricity hub for Europe by balancing European VRE with hydro reservoirs.	- Scepticism about the future role of nuclear energy. - Need for expansion of interconnections and improved collaboration between the Member States. - Uncertainty about the prioritisation of storage options in the short term and suggestion for hydrogen storage in the long term.
Sector coupling & decarbonisation of end-use sectors	- Key barriers in heating: high heat pump investment costs and lack of expertise in their implementation. - Industry: suggestion for heat recovery and hydrogen to replace natural gas. - Key barriers in transport: high electric vehicle investment costs and lack of charging infrastructure.	- Heating: suggestion for heat recovery and thermal storage and heat pumps in areas without district heating. - Industry: suggestion for waste-to-energy technologies and blue hydrogen. - Key barriers in transport: range and total tonnage constraints of electric vehicles. - Passenger transport: suggestion for biofuels (short-term) and electricity (long-term). - Heavy-duty transport: suggestion for power-to-X technologies.	- Heating: need for better balancing of energy demand in buildings by considering multiple influencing factors. - Industry: suggestion for blue hydrogen and electrification to replace fossil fuels in heavy industries. Need for BECCS. - Passenger transport: suggestion for full electrification (long-term). - Heavy-duty transport: suggestion for electrification and synthetic fuels as alternative.
Energy efficiency & digitalisation	- Scaling up energy efficiency projects with public programmes, incentives and financing instruments. - Need for financial incentives for smart meters.	- Increasing the renovation rate of buildings with economic instruments and incentives targeting consumption reduction. - Combining smart buildings and smart grids for flexible system operation.	- Facilitating energy efficiency investments with new business models. - Digitalisation using smart meters.
Environmental concerns	- Need for careful management of raw materials for RES and batteries.	- Risk of raw material supply constraints. - Trade-offs between biodiversity and bioenergy.	- Need for careful management of raw materials for RES and batteries. - Trade-offs between biodiversity and bioenergy.
Socioeconomic implications	- Concerns about social acceptance of RES projects. - Concerns about job losses and new vulnerable groups. - Inclusion of energy democracy and justice in energy policy.	- Concerns about social acceptance of RES projects. - Concerns about the replacement of lost fossil fuel sector jobs. - Need for fair policy packages across different governance levels.	- Concerns about conflicts of interest for RES projects. - Concerns over the reskilling of coal workers. - Emphasis in just transition considerations.

Furthermore, we find regionally specific path dependencies on existing energy sources. This finding is aligned with Sovacool [75], stating that in most cases energy transition in the EU member states has been path dependent rather than revolutionary, as niches will rarely evolve to completely dominate a landscape due to complexity, timing, and causality. Both Greek and Nordic experts stressed that there is a risk that new natural gas and nuclear plants could become stranded assets. According to some stakeholders, nuclear energy will continue to play a role in the Swedish and Finnish power sectors mainly due to the limited domestic hydro capacity and the ever-increasing electricity demand [76], while others highlighted that the future role of nuclear energy at the EU level remains questionable. Stakeholders expected that Greece will increase its dependence on gas because of the decision to phase out lignite by 2028, instead of accelerating the transition to a 100 % RES system. This is attributed to national planning political decisions that have prioritised natural gas as the main energy source that could economically replace lignite at a large scale in the short and medium terms [77]. These decisions have been criticised by Zervas et al. [78], stating that natural gas price can be significantly affected by geopolitics, since geopolitical events directly affect energy markets. The latter has been validated by recent developments, especially when observing the implications of the invasion of Ukraine by Russia.

Lastly, we find differences in the relevance and types of social aspects important to the stakeholders. Given the very ambitious short-term emission reduction targets in the Nordics, behavioural measures were stated to play an important role to achieve full decarbonisation. Unsurprisingly, Greek stakeholders were more concerned over the socio-economic implications of decommissioning lignite power plants, such as increased unemployment, resulting from power plant and mine closures in areas where economic activity is heavily reliant on lignite [79], social injustice, as local understandings and needs tend to be ignored by top-down decision-making approaches [80], and energy poverty in the affected regions and municipalities, i.e., region of Western Macedonia and municipality of Megalopolis [81].

4.2. Similarities in perspectives on energy transition issues and challenges

The need for interconnectedness of power systems is a notable cross-cutting issue that emerged in all three case studies. Grid interconnection with neighbouring regions is an important strategy for integrating renewables and existing interconnections are weaker in Greece than in the Nordics and in Central Europe. The Greek electricity system is largely isolated from the rest of Europe and even within Greece the interconnection between islands and the mainland has always been a challenge; thus, a lot of islands remain not interconnected. Conversely, the Nordics are among the countries that have fulfilled the 2020 interconnection target [82]. Despite their concerns about market operation under the Target Model, Greek stakeholders asked for reinforced national and regional interconnections. Furthermore, stakeholders believed that the institutional cooperation between the Nordics on climate and energy actions, which was enhanced with the signing of the Declaration of Nordic Carbon Neutrality, should be maintained. They even asked for a stronger cross-country collaboration and strengthening of the Nordics' role in the European energy transition. European stakeholders also stood for increasing cross-border and regional cooperation between countries in line with the goal of creating an "Energy Union" as proposed by the EU [83].

We also find that stakeholders focused on the potential of hydrogen storage across all cases. Hydrogen can contribute as storage in the power sector, an energy carrier option used in heating, transport, and industry, and, finally, as a feedstock for industry [84]. Stakeholders also perceived hydrogen and power-to-X technologies to take a prominent role when it comes to the decarbonisation of industry and heavy transport. In Greece, there was interest in hydrogen storage applications, in the context of which the interconnection of electricity and gas networks is also investigated, whereas stakeholders in the Nordics showed interest in hydrogen to help break the dependence on fossil fuels, especially where electrification is disadvantageous. In addition, at the EU scale, an aggressive hydrogen strategy has been pursued and industry projects that could dramatically increase demand for hydrogen are already in planning.

We observe a cross-case need for increasing the implementation rate of energy efficiency projects. In Greece, the need to renovate the existing, old building stock is indisputable as this will result in cost savings for citizens and will improve comfort, safety, and health conditions [85]. Stakeholders in the Nordics also acknowledged that without energy efficiency improvements it will be more costly and harder to reach climate neutrality. Furthermore, stakeholders at the continental scale applauded the European Commission's efforts to lift national regulatory barriers that inhibit energy efficiency investments in rented and multi-ownership buildings, by also paying attention to energy poor households. We also observed that across the three cases, and in accordance with the directions set by the European Green Deal, stakeholders acknowledged the importance of innovative digitalisation solutions as means to enable the flexible operation of power systems.

An important aspect that appeared in all three cases is the lifecycle management of raw material demand for low-carbon technologies, which is relevant to the EU's vision for the transition to a circular economy as set out in the recent Circular Economy Action Plan, which makes the technology reuse and recycling a cross-cutting issue [86]. Another cross-cutting challenge is social acceptance of RES projects. According to experts, efforts to raise public awareness on energy and climate policies targeting RES technologies should be initiated at the local level, where people tend to become more sensitive to the effects of the climate crisis and oppositions towards RES projects unfold. This is also acknowledged by scientific literature, indicating that to foster acceptance of RES projects, public trust in local governments and developers must be built through a transparent process that spans the entire chain from planning to development and plant operation [87]. Stakeholders also highlighted aspects of social justice, balancing of associated benefits and disturbances, and increasing community engagement as important channels to improve acceptance of RES projects. Increasing inclusiveness, transparency, and public participation in the energy system can significantly improve energy policymaking [88]. Finally, the societal implications of fossil-fuel phase-outs were raised by stakeholders in all three cases. Coal- and carbon-intensive regions have different levels of potential to induce structural change because of the different levels of dependency on incumbent industries, which may exacerbate the socioeconomic implications of a paradigm shift [89].

4.3. Limitations and outlook

Although our findings can further inform the domain knowledge about the focal challenges to climate neutrality, thus contributing to better-informed policy design at different administrative levels, we acknowledge specific limitations stemming from our research design. First, we did not request "system knowledge" and "target knowledge" from stakeholders, thus no triangulation for these knowledge types could be provided. Second, our research took place before the outbreak of the energy crisis stemming from the invasion of Ukraine by Russia. Thus, it does not account for the strategic EU decisions regarding the faster reduction of the dependence on fossil fuels, and especially Russian oil and gas, as well as further boosting energy efficiency gains and the share of renewables across all sectors [90].

Further research is needed to better understand the diversity of the different issues and challenges of the European, regional and national pathways to climate neutrality by 2050, by specifically accounting for emerging geopolitical developments that can affect strategic decisions. Future research should also dive deeper into the specific reasons for the observed differences (why) and the interactions between the scales (governance perspectives). Such an approach would enable to investigate and explore stakeholder visions on how the European energy systems' elements should be integrated and managed in the future, either from a participatory/multi-level governance perspective, or a cost-benefit point of view. That would contribute to enlarging scientific literature on the visions of energy transitions [91]. For example, considering that stakeholders prioritised hydrogen and power-to-X technologies when it comes to the decarbonisation of the industry and the heavy transport sectors, a pertinent research question is where and how hydrogen will be produced in Europe and whether this will be limited to green hydrogen, or also blue hydrogen from carbon capture and storage, a system dilemma also stated by Damman et al. [92]. Additionally, we observe a need for further studies exploring the trade-offs between supply and demand of raw material resources to see whether an equilibrium among them can be reached. More research addressing the reuse and recycling of technologies is needed, as the European Green Deal aims at moving towards a circular economy, as well as research that seeks to find the trade-offs between environmental sustainability and social justice (see also: [93]).

Finally, with increasing complexity of policymaking, model-based climate and energy policy advice is expected to gain more importance over time [94]. Our work contributes towards more policy-relevant model-based analysis by informing the energy system modelling community on the most updated critical issues and challenges with which stakeholders and decision-makers will be faced in the future. Applying energy system models to a range of user applications is a vital step to ensure that energy system models are becoming better at including relevant critical issues and challenges of the energy transition [95,96]. To this end, we call for existing and future consortiums to use different modelling suites to respond to the critical issues and challenges that we have identified for the three cases to enable better-informed decision-making.

5. Conclusions

In this paper, we synthesise stakeholder perspectives from three diverse case studies, i.e., Greece, the Nordic Region and the EU, to better understand the critical issues and challenges of the European energy transition. We identify cross-cutting trends that could serve as strategic recommendations for the energy transition in different European contexts. Specifically, the multiple benefits of hydrogen, mainstreaming energy efficiency projects, balancing the demand for raw materials, social acceptance of RES projects and energy justice are topics that should be at the core of the energy policymaking in the EU. We also find that better cross-border and regional cooperation between countries is necessary to achieve climate neutrality. This is especially important for isolated energy systems since they may be influenced at a higher level by energy crises than geographical contexts with stronger cross-country collaboration. As such, speeding up grid interconnection projects with neighbouring regions could allow the higher integration of renewable electricity and improve security of supply. Furthermore, many European countries are facing the challenge of phasing out highly polluting fossil fuels from their energy mix. In the process of decarbonisation, we observe path dependencies on less polluting fossil fuels, or "clean" but risky technologies, namely natural gas and nuclear energy, respectively. These dependencies should be further considered to avoid potential future lock-ins to technologies that are now deemed as "intermediate" options; however, in the medium-term, a lot of effort may be required to get rid of them.

This knowledge should be integrated during the policy design process, since decision-makers tend to mimic best practices in terms of policies and strategies for transition planning from other countries, or regions [97]. However, diverse contexts require different energy and climate policies that take into account the "status quo" of the energy transition. For example, climate and energy policies designed at the EU level meet different realities at the national level, and, thus, tailored transpositions into national law are needed, also accounting for the "context" factor. Nevertheless, synergies between countries with similar context should be further explored as decision-making in a given geographical context could be guided by similar issues and challenges in different contexts, and vice versa.

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

The data that has been used is confidential.

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