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Energy Import Dependency in Lithuania and Greece During Decarbonization of Energy Sector

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ABSTRACT

Energy import dependency is an important indicator of energy security showing dependency of country on energy imports. This is especially important during current geopolitical situation in Europe. The study analyses the energy security issues during low carbon energy transition based on comprehensive literature review and presents empirical study on analysis of energy import dependency during low carbon transition of selected EU member states from different geographical regions, i.e. Lithuania and Greece. Based on this case study paper illustrates findings of literature review showing how fast penetration of renewables can mitigate increase of energy import dependency and enhance energy security of the countries

INTRODUCTION

The low-carbon energy transition and the fast penetration of renewables in the energy mix have a positive impact on reducing demand for fossil fuels. However, due to the high intermittency of renewable energy sources, storage capacities and reserve power plants are also necessary. Therefore, the problem of energy security is very important during the low-carbon energy transition. There is no agreement among scholars and policymakers on the best methods or indicators to measure energy security. Many indexes and integrated indicators have been developed by scholars; however, using these indicators for decision-making is highly complicated. The information provided by these indexes is often contradictory, and country rankings do not present justified results ((Narula and Reddy, 2015).

Many studies analyze energy security issues and challenges during the low-carbon energy transition (Jia et al., 2022; Sattich et al., 2022; Vatalis et al., 2022; Liu et al., 2023; Paine et al., 2023; Naheed et

al.,2024; Willis et al., 2024). However, there is limited scientific literature on the discussion of energy import dependency growth during this transition in specific EU member states with different local energy resources and renewable energy potentials. There is a lack of case studies analyzing, comparing and discussing the trends of energy security among countries by using reliable energy security indicators.

The paper aims to overcome these gaps and presents a case study on the analysis of energy import dependency trends in selected EU countries from different geographical regions during the process of low carbon energy transition. The rest of this study has been structured as follows: section 1 provides a literature review and background of the study; section 2 introduces methods and data; section 3 analyses energy import dependency indicator trends in selected EU countries; section 4 provides a discussion; and section 5 concludes.

1. LITERATURE REVIEW AND BACKGROUND

1.1 Energy decarbonization process

Among the most controversial issues of the decarbonization and the transition pathways from fossil fuels to green energy technologies, is the characterization of our era as globally climatic changed. Subsequently, great challenges of effective management parameters have been emerged to promote a just transition plan that is prone to minimize the effects on local communities and to maximize the long-term benefits for the enhancement of regional sustainable development (Vatalis et al., 2022). In this study the development of a conceptual model was employed to evaluate the crucial aspects of decarbonization projects, through a sampling survey from a coal dependent region. This methodology was based on the Structural Equation Modeling (SEM) in order to investigate a framework of ten hypotheses further exploring those possible relationships that have been built from this conceptual model (Vatalis et al., 2022). From a methodological perspective in the relevant literature, it has been conducted a quantitative modeling to develop a dynamic supply and demand system from freight transportation demand, renewable energy production, alternative new energy, renewable energy consumption and carbon dioxide emissions. This model was dedicated to assess the impact of demand-side and supply-side changes on energy decarbonization (Zhang, 2024). It was indicated that adjusting the freight volumes of railway and aviation, renewable energy electricity supply, as well as the use of alternative new energy sources, each one of these variables showed a varying degree of impacting on decarbonization in transportation. The proposed interventions on the demand side of freight volumes concluded that CO₂ emissions from transportation can decrease to levels below those before the intervention-induced fluctuations, whereas renewable energy consumption was increased to levels above those before the adjustment (Zhang, 2024).

In long-run energy- and globally- oriented studies it was proven that deep energy decarbonization cannot be achieved without high penetration of renewables. Among them, it can be noted that in attempting to gain higher renewable energy penetrations, the variability and the intermittent nature of solar photovoltaic (PV) electricity is susceptible for ramping issues with existing fossil fuel generation, being characterized by longer term energy storage to increase the reliability of grid operation (Haggi et al., 2022). This study was concentrated on the perspective of the distribution system operator that operates the distributed energy resources on a standard IEEE 33-node distribution network considering representative technical and physical constraints through minimizing total investment and operation cost. For this, a variety of case studies at very high PV penetrations have been literature conducted to disclose the challenges and the paths to net-zero emission energy production using hydrogen energy (Haggi et al., 2022). By employing an econometric analysis, it was concluded that sensitivity of utility PV costs and electrolyzer capital costs on hydrogen production at \$1/kg implying that the distribution network can achieve 100% renewable electricity production, while hydrogen production is estimated at a cost of \$1/kg by 2050 (this long-term timeplan complies with conservative cost estimates), or by 2030 (this short-term timeplan complies with accelerated costs' decline) (Haggi et al., 2022).

Global energy projects that offer realistic solutions of energy production from clean renewable sources has attracted a wide research and geographical interest in recent years. Among these studies it was investigated the decisive role of Ukraine, Moldova, Romania, and Azerbaijan in the competition for

primacy in scientific developments through green hydrogen. In this context the implementation of global projects for the production of green hydrogen was determined through main feasibility parameters covering a wide range of natural factors, including: geological structure, ecological and climatic characteristics, as well as the utmost challenging of 21st century natural factor of using significant volumes of fresh surface water without harmful environmental impact (Bahrii et al., 2023). The availability of a sufficient amount of water resources, solar and wind energy was spatially framed in countries of Ukraine and marine water areas of Moldova, Romania, Azerbaijan. Besides to obtain energy resources, it was estimated the saving of thousands of square kilometers of fertile agricultural land. The mostly identified areas of the water surface for energy and green hydrogen facilities were that of Danube-Peddrobrudzha zone (Ukraine, Moldova and Romania), the lower Dnipro the Chernobyl Exclusion Zone (Prypyat River), Transcarpathia (basins of the Latoritsa and Tisza rivers), Azerbaijan (basins the Kura, Arax Rivers, the seawater area of the Kyzylgat marine reserve) and their approximate areas (Bahrii et al., 2023).

Another geo-spatially important study that was focused on energy efficiency for the transition to energy decarbonization is that of Naheed et al. (2024). These authors were concentrated on the crucial role of renewable energy transition towards mitigating the ecological depletion, especially among the densely populated and fast emerging/developing Asian countries. These countries are struggling to meet the targeted levels of renewable energy adoption while simultaneously pursuing foreign support and funding aid for energy sector. In this context a follow-up study and 22 Asian developing countries for the period 2003-2022 was conducted to investigate if and to what extent the foreign aid can be offered on the energy decarbonization transition (Naheed et al., 2024). Besides, the study disclosed the roles and the challenges of promoting a wider renewable energy diffusion. The methodological background incorporated the two types of foreign aid, which were that of nonrenewable and renewable energy, through data provided by the OECD towards the support of developing economies having an unstable and weakly developed the energy sector. The research findings stressed out the significant contribution of energy aid towards the transition in achieving both energy decarbonization and financial support of these embracing renewable energy technologies to be scaled up and technically mature (Naheed et al., 2024).

From an industrial perspective, among heavy industries is the rapidly transitioning global steel industry towards energy decarbonization aiming at addressing the climate crisis (Kwon et al., 2024). Among the main sources of GHGs emissions from steel mills is sintering. Traditional sintering processes use straight inclined chutes to feed raw materials that are fed into the sinter machine. The technical constraint of this process is the insufficient horizontal momentum, resulting in poor segregation of the layered materials (Kwon et al., 2024). For this in the literature there are published studies that proposed an improved charging chute design profile to reduce coal consumption and to increase productivity. While deploying the (firstly modeled and simulated) charging chute using the cycloid curve authors reported that the actual field implementation in a sintering process achieved a 2.9% increase in operational productivity together with a 6% fuel consumption reduction. Besides to the proposition of the proper optimal chute design, it is also crucial the successful implementation at a full-scale steel mill that can realistically contribute to fuel consumption reduction as well as carbon reduction in steel mills (Kwon et al., 2024).

In a regional-spatial and operational literature coverage it is noteworthy that local energy decarbonization can be valued in alignment with Net Zero plans and designing since new disruptive technologies may not be ready at scale in the near term. In this respect there are researchers who investigated the role that electrifying local energy systems (LES) could play via coordination across local electricity, heating, transport, and buildings sectors in the case of Wales (Jing et al., 2022). These researchers developed a local energy emissions model to simulate whether an electrified LES could achieve the emission target. Then, a local energy optimization model was employed to address the induced significant increment of peak demand. It was shown that decarbonizing the local heating sector is proven as vital and challenging, considering the UK current initiatives while a greater effort to achieve at least 46% residence installing heat pumps is needed by 2035. Overall, through models' implementation, it was demonstrated that electrification can be valued as a feasible solution to achieve deep decarbonization, while flexibility is the key in electrification with huge cost-saving potential in upgrading electricity networks (Jing et al., 2022).

Another notable technology refers to those power systems that are changing towards a decarbonized one is that of industrial and tertiary sites as net-zero energy systems (NZESs). It is a fact that the integration into the grid of the power generated by RESs as well as the electrification of the heating, gas and transportation sectors is becoming an imperative challenge, thus NZESs planning could advance the solutions of fully integrating volatile RESs into the power system (Richter et al., 2021). This study underscored the importance of planning such large energy consumer sites as NZESs are offering a holistic modeling approach. Besides to a qualitative case study regarding the planning of a Net-Zero Energy Data Center located in Germany it was pointed out the necessity of new interdisciplinary (mainly, or at least involving, the social dimension) analysis methods (Richter et al., 2021). Such an analysis is prone to accelerate the decisionmaking process during the planning of RES-based on-site power generation systems. Subsequently computation and cooling systems should consider newly emerging technologies in the market (which (technologies) should be taken into account) (Richter et al., 2021).

Another important field of energy decarbonization is the technology involved at integrated passive heating and cooling systems. Indeed, passive heating and cooling systems are capable to significantly reduce space-heating and space-cooling loads in buildings, being also characterized by minimal embodied energy investment and extremely low operational energy demand. Optimum performance requires movable insulation, operable shading, operable vents, as well as other adjustable elements, but effective methods of operation control are in the early pace of development. A numerical optimization of interdependent passive heating and cooling parameters of load reductions and thermal comfort have sparsely examined, while the development of simplified control strategies has to be explored, yet (Rempel and Lim, 2019). In this study authors investigated specific designing and planning problems of the adaptive reuse of an historic brick office building in the Mediterranean climate of Berkeley, California. It was demonstrated the magnitude of the passive space-conditioning resource in this energy-intensive region and simultaneously valued the power of simple, effective operational strategies to realize substantial energy savings (Rempel and Lim, 2019).

At this point it can be also denoted that hybrid energy sources are better than producing energy from a single technology. The combination of renewable energy and fuel generators allowed users to cover seasonal fluctuations of resources and protected them from the unpredictability of fuel prices and supply. Nonetheless, the large-scale industrial demand is a real challenge due to its consistency throughout the day and the intermittent nature of renewable sources (Ismail et al., 2023). In relevant literature it was proposed a novel approach for optimal hybrid energy decarbonization for any demand type in general and industrial demand in particular. The proposed framework is developed by integrating the Hybrid Optimization of Multiple Energy Resources (HOMER) while the industrial oil and gas complex with high wind and solar resource availability was adopted as a study case of Abu Rudeis, Egypt There is a use of 11 Gas Turbine Generators (GTGs) to generate electricity, where the hybrid configurations include PV and wind systems. The proposed modelling considered a subtotal of 21 criteria of technical, environmental, economic, and socio-political interest revealing that the incorporation of a wind farm of nine 2 MW wind turbines, each one, with the GTGs is the Optimal Hybrid Configuration (OHC) (Ismail et al., 2023).

From political and designing perspectives both designing of energy and the climate policy are considered as inseparable “expert” domains of relying on techno-economic tools. Besides, policy requires the politics support and social acceptance through democratic process. Other directly affiliated policies of people's views, values and behaviours are that of reducing carbon emissions from homes and transport (Willis et al., 2024). It is thus necessary to supplement technical analysis with methods that allow an exploration of codesign, whereby groups of citizens work with policy analysts to develop strategies informed by the lived experience of citizens, as well as the specialist knowledge of analysts. While co-designing is a well-studied tool for a variety of public services, such as healthcare, there is a sparsely investigated literature production of co-designing public policy measures (Willis et al., 2024). In this study a Citizens’ Panel was composed by representative group of people working with specialists in order to create co-designed policy recommendations towards reduction of carbon emissions in the household sector. The proposed process was able to provide detailed and realistic proposals from the conducted policy co-designing emphasizing to the necessity of leadership motivations and the governmental support. In particular, the consistent information, the targeted regulation and the financial incentives can prioritize the wider potential role for policy co-designing for energy and climate issues (Willis et al., 2024).

From a socio-economics perspective the developing countries have to confront the energy decarbonization transition by overcoming significant financial constraints, which are impossible to manage without foreign aid that can support the prosperity of their energy sector. However, the identification of those mechanisms between energy aid and the energy decarbonization transition have to be empirically validated, accordingly (Liu et al., 2023). This study indicated that energy aid can effectively promote the transition to energy decarbonization, sustaining the most substantial positive impact especially on renewable energy generation, energy policy and energy distribution. Moreover, it was observed a managerial and operational asymmetry between energy aid and energy decarbonization transition. Subsequently, while energy aid is indirectly driving the energy decarbonization transition through human capital devotion, there is also a notable positive impact by other factors such as by balancing the governmental policies and clean fuels' demand (Liu et al., 2023).

1.2 Energy security and it's measures

The issue of energy security measures has historically and literature attracted the scientific interest at early 2000's. Among these earlier studies it can noted a study that discussed the India's policies and measures for economic efficiency, environment protection and energy security (3-E) (Venkaiah et al., 2007; Manante et al., 2023). Energy security is a term that is commonly invoked in public discourse and the policy domain to emphasize a link between energy issues and national security concerns and to frame arguments surrounding the need for a variety of energy policy prescriptions. Nevertheless, insufficient consensus has reported over the meaning, as well as misconception of the means to achieve the goal, of energy security (Dunham and Schlosser, 2016). The relevant literature production has been engaged with the evolution and implications of energy security, while regulatory and politics initiatives were undertaken to determine how energy security arguments are intertwined with legislative policy praxis (Dunham and Schlosser, 2016). This research revealed the historical terminology and evolution of addressing energy issues, security concerns, as well as environmental protection provisions. A broad conceptualization of environmental security can contribute to the contemporary debate over the effect of framing environmental issues as security concerns, extending these considerations to the sparsely (at the time of publication, almost one decade ago) of energy security (Dunham and Schlosser, 2016).

The most recognized measures of energy security that have been reported in the relevant literature are related to the energy security of the EU-27 countries (Rybak et al., 2023). Among them there is an exemplified study for Poland and the EU-27 average, where literature-extracted indicators examined energy security using the 4A concept as a basis for research on energy security (Rybak et al., 2023). The authors of this study expanded a predefined set of factors of energy security by adding the RES as an additional category. The setting research objectives included different types of impact, including the availability of energy raw materials on the level of energy security, as well as selected critical raw materials including rare earth elements. All these types of material are inseparable part of the wider RES technologies' development. A taxonomic method was conveyed while authors further proposed remedial measures that would make it possible to increase the level of energy security of the EU member states (Rybak et al., 2023). Another important issue of research value is the investigation of the effects of economic complexity and energy security risk on measures of energy efficiency, namely energy intensity and carbon intensity (Payne et al., 2023). At this study a panel of the top-25 energy use countries was developed and the empirical results from quantile regression analysis for the full panel of countries showed that while economic complexity increases it raises energy efficiency through lower energy intensity and carbon intensity. Besides increase in energy security risk causes a raise of energy intensity with the impact on carbon intensity varying across quantiles (Payne et al., 2023).

Concerns about climate and energy security are leading to increased government intervention in the energy sector, in particular as they relate to the choice of energy supply options. While many of these options will improve both energy and climate security, many measures will benefit one while harming the other. This raises an important question for governments and energy planners: how can conflicts between climate and energy security be resolved? Therefore, relevant studies have to be focused on barriers and problems raised whenever governments and companies attempt to simultaneously address climate and energy security concerns at various energy supply areas. Operationally, studies conclude by

arguing against choosing one objective over the other, and by outlining steps of action to resolve conflicts between the two agendas (Froggatt and Levi, 2009).

From an operational perspective it has been introduced a set of three different indices: 'Energy Sustainability Index', 'International Index of Energy Security Risk' and 'Energy Architecture Performance Index' together with their variants, in order to examine if and to what extent can be provided consistent results for various countries. A compare-and-contrast analysis revealed that the three indices are able to provide different and inconsistent to each other country rankings (Narula and Reddy, 2015).

From a spatio-geographical perspective it is worthy mentioning that the most influential factors affecting China's energy security can be accompanied by identification of effective strategic measures, such as the fuzzy AHP, to determine weights for ranking the importance of Chinese energy security factors and, then, to prioritize those strategic measures targeting to enhance those same factors (Ren and Sovacool, 2014). In this context it was observed that a low proportion of renewable energy penetration is valued as the most severe-threatening factor of China's energy security. It was also argued that future researches and technological maturity/full development of energy technologies are proven the most needful-advantageous strategic measures of improving energy efficiency (Ren and Sovacool, 2014). Similarly, in another spatio-geographical-based study it was referred that electricity utilization is not always a legal topic, but there is general information disclosing that criminal offences in electricity networks are widespread in the world. Subsequently, instability in the electricity market can be considered as a serious threat to energy supply security globally, which also detrimental to the economics, social and political welfare development (Šincans and Ivančiks, 2017). As preventive and precautionary actions that deserve further development are studying the experience of legal systems and case-law close to each time national level (in this case in Latvia), in alignment with the cases of criminal offences; also interested in those emerging problems and particularities of the situation raised, such as the peculiarities of electricity thefts, foreign practice and possible solutions that could improve the national energy security to be drawn (Šincans and Ivančiks, 2017).

1.3 Energy security and decarbonization

The energy security investigation coupling with the decarbonization issue has not been demonstrated as a priority issue in the literature, showing a sparsely developed scientific topic. Among these study it was stressed out that China targets at net-zero carbon emissions by 2060 and an emission peak before 2030. This target is able to reduce coal consumption for power generation and steelmaking. This environmental target is linked with national policies to improve energy security, primarily with expanded domestic coal production and transport infrastructure. All these are predominately coal-fed sectors, thus, challenging the analysis of the effects of internal pressures on Chinese coal imports (Gosens et al., 2022). These authors identified that a reducing rate of Chinese coal consumption can affect intensively seaborne imports, comparing to domestic supply. Moreover, recent (within the last five years of examination) expansions of rail and port capacities are able to also reduce the costs of getting domestic coal to southern coastal provinces, thus, further reducing the demand for seaborne thermal coal and amplifying the effect of decarbonization on coal imports. It is also noticeable that seaborne coking coal imports are prone to decline due to the expanded supply of cheap and high-quality coking coal from neighboring Mongolia (Gosens et al., 2022).

In another Asian-conducted study it was pointed out that Japan is among the countries that are deprived from sufficient fossil fuel resources. Subsequently, mid- to long- climate policies took into considerations and constraints of renewable energy sources and nuclear power and, subsequently, meeting the requirements for both the decarbonisation and for energy security (Oshiro et al., 2016). In this context an assessment of the feasibility of decarbonization pathways in Japan up to 2050 was developed focusing on energy security during the latest (the last decade of analysis) national energy and climate policies. This decarbonization by 2050 is prospected as feasible and realistic, even without nuclear power, but the following three preconditions: energy efficiency improvements, low-carbon electricity and electrification in end-use sectors (Oshiro et al., 2016). Besides, all long-term decarbonization pathways are able to accomplish enhanced energy security together with import dependency reduction to less than a half of the total primary energy and import bills for fossil fuels reduction by around 70% comparing to existing level (that was at the time of study publication, Oshiro et al., 2016, which is a decade ago). At this point it can

be also signified that renewable energy sources and technologies could play a protagonist role of setting requirements for both climate-environmental stability and energy security. In the mid-term timeplan of year 2030 a steady fuels' import dependency at today's levels had been noted (Oshiro et al., 2016).

In the European context Zwickl-Bernhard and Neumann (2024) examined the LNG trade in 2040, focusing on the role of Europe as an LNG importer. The disclosed complexities of Europe's strategy are simultaneously related to achieve decarbonization goals and to resolve energy security concerns regarding LNG (Zwickl-Bernhard and Neumann, 2024). The study proposes an optimization model to determine the optimal global LNG trade between exporters and importers. As an alternative to imports of Europe the potential role of domestic natural gas production equipped with carbon capture and storage was examined. In employing two scenarios, which were that of low and high LNG demand it was indicated that Europe plays a primary role in the global LNG market solely in the ambitious sustainable scenario, whereas its significance diminishes in the high-demand scenario (Zwickl-Bernhard and Neumann, 2024).

1.4 Energy security during decarbonization in Greece and Lithuania

Lithuanian electricity sector sustains a portion of 70% of consumed electricity being generated abroad. This dependency rate is among the highest rates in the EU's and is mainly attributed to the fact of dependency was on the Russian Federation until 2015. The absence of Lithuanian primary energy resources showed a progressive transition from a pro-nuclear to directly a national renewable energy strategy within the last decade of analysis. In the relevant literature energy security Sattich et al. (2022) focused their study on energy security in Lithuania showing that the relevant renewable energy policies can be perceived by potential energy security threats. Moreover, authors identified the achievement of a high degree of perceived energy security as the primary enabler of renewable energy. This study also demonstrated two distinct national energy strategies: 2009–2012 and 2013–2018 through developing political processes. This study revealed that the primary target of renewable energy installment is not the association of energy security concerns with high dependency rate, but the desecuritization of energy supply which, in turn, allowed a realistic and feasible renewables-based strategy (Sattich et al., 2022).

In earlier studies Lithuanian situation of safety and security of energy supply was described as quite complicated comparing to other European countries, since few countries supply primary energy sources, while there are not developed networks of gas, oil and electricity to Western Europe, thus, transmission network needs modernization (Augutis et al., 2008). The main research target of such early stages of the relevant literature production (15 years ago) was the design of the methodological scheme of energy safety and security of supply, which would be well reasoned by scientific methods and would let to these problems solution. The conducted methodology included the stages of analysis of scenarios of disturbances, economical modeling, reliability modeling of supply systems, and analysis of consequences (Augutis et al., 2008). Energy supply disturbances and evaluation of their appearance probabilities are also crucial. The model was based on 110 different energy disturbance scenarios which were selected and simulated according to Wilks statistics. Besides, these scenarios were evaluated by economical model, referring to assessment costs of energy system. Authors proposed that in the short run important decisions have to be undertaken in Lithuania, including construction of power plants, including nuclear power plant (NPP), valuing also the estimation of safety and security of energy supply (Augutis et al., 2008).

Lithuania's energy security is inseparable from the country's membership in the EU and NATO. Lithuania sustains little domestic resources and almost overly dependent on external suppliers, making it a very interested country in multilateral energy cooperation (Molis and Vaišnoras, 2014). Authors presented a chronological outline of the most important developments, distinguish the main goals, problems and possible solutions (Molis and Vaišnoras, 2014). Subsequently, authors explored Lithuania's interests and achievements in creating the EU Common Energy Policy and formulating a NATO energy strategy (period of reference is one decade from the publication date of this study, early 2014). The research focus was directed on Lithuania's achievements and failures during the EU Presidency, also on the importance of the NATO Energy Security Centre of Excellence and its possible impact on energy security (Molis and Vaišnoras, 2014). Despite the fact that energy security problems in Lithuania have been analyzed on a regular basis there is no comprehensive research on the very issue of the public perception of

energy security (Leonavičius et al., 2013). An empirical survey of public poll that took place in 2013 was used to explain the public perception of energy security and its main aspects, showing the existing difference of society opinion between different social groups in terms of gender, age, education, occupation, income and living area (Leonavičius et al., 2013). It can be argued that different aspects are taken into account in public perception on energy security from which the dominance of "The prices of energy resources" and "Reliability of energy supply services" was fixated throughout different social groups. The three most ambivalently ranked aspects were that of "Development of oil extraction", "Development of nuclear energy" and "Development of shale gas extraction" (Leonavičius et al., 2013).

Conclusively to the Lithuanian case it can be broadly referred that the issue of the energy security in social sciences is mostly prevalent in political sciences. The sociological research of the issues of energy is rather scarce. The reasons of the lack of concern about sociology of energy security could be related to the specific geopolitical context of post-Soviet states. The energy policy of new democratic post-Soviet states are pressed to reconstruct the entire energy system of former Soviet Union (Augutis et al., 2018). This issue does not found only on a technological or political basis, but it is a primary social issue directly related to the consumption of users of gas and electricity and their prices. The societies and different social groups become an important social actor in the stressful energy policy. In the Lithuanian case there is a lack of attention to social determinants of perception/public opinion of energy security. Therefore, a more comprehensive understanding of the Lithuanian public perception of energy security can be achieved on two aspects: (a) An analysis of public opinion on the most important aspects of energy security and the social factors influencing them. The hypothesis is that public perception of energy security is related to value orientations. (b) An analysis of how public opinion on energy policy executed by the government and confidence in the government are intertwined with the concept of energy security (Augutis et al., 2018).

Regarding the case of Greece an earlier study (Jones et al., 2017) stressed out that definitions of energy security have evolved to include qualitative dimensions, such as social acceptability. Alongside there are more classic issues such as the availability and affordability of energy supplies. Despite the importance of lay-public opinion in shaping energy and environmental policy, little was known (by the time of publication, 8 years ago) about the underlying nature of people's attitudes towards energy security. Jones et al. (2017) utilized an online survey to gather perceptions of energy security in samples from the two neighbouring countries Greece and Turkey with a historical reliance on energy imports, making a deeper analysis to understand the densely developed relationships between individuals' pro-environmental and pro-cultural orientations and their energy security concerns (Jones et al., 2017).

From a jointly spatio-geographical and industrial perspective Greek lignite reserves are mainly located in the northwestern part (Region of Western Macedonia) of Greece, reaching a total of 5 billion tons. Considering that Greece is planning to stop burning lignite for electricity production, the recovery of the trapped methane in lignite coalbed reservoirs can be a valuable alternative for power generation helping to the reduction of the direct emissions of methane during mining activities (Vasiliadou et al., 2024). Authors evaluated the Lephalale Coal Bed Methane (LCBM) in the Region of Western Macedonia (Ptolemaida basin, Greece). LCBM assessment is traceable including the collection of three samples in the area of active mine and were subjected to desorption experiments at different temperatures ranging at 25 °C up to 150 °C with grade/pace of 25 °C intervals. The experiments aiming at channeling high purity Ar gas at 1 atm of pressure. Moreover, a SWOT analysis was carried out disclosing the strengths and the opportunities (both are positively attributed internal factors), against the weaknesses (both are negatively attributed internal factors) and the threats of a potential LCBM exploitation in Greece, while also considered a plethora of social, economic, and environmental nexus (Vasiliadou et al., 2024).

2. DATA AND METHODS

Several indicator frameworks, ranging from integrated indexes to separate indicators, are used to measure energy security. In this study, the energy import dependency was selected as an indicator to measure energy security during the low-carbon energy transition in Lithuania and Greece. The data were obtained from the EUROSTAT dataset (EC, 2024).

The energy import dependency indicator shows the share of total energy needs of a country met by imports from other countries. The rate shows the proportion of energy that an economy must import. It is defined as net energy imports divided by gross available energy, expressed as a percentage. The indicator shows the share of total energy needs of a country met by imports from other countries. It is calculated as net imports divided by the gross available energy. Energy dependence = (imports – exports) / gross available energy. This indicator is measured in % of imports in total energy consumption of all products, solid fuels, hard coal, oil and petroleum products, and natural gas.

3. RESULTS

The trends of energy security indicators during the 2010-2022 period are compared in Figures 1-4 for Lithuania and Greece. In Figure 1, the dynamics of energy import dependency of all products during 2004-2022 is compared in Lithuania and Greece.

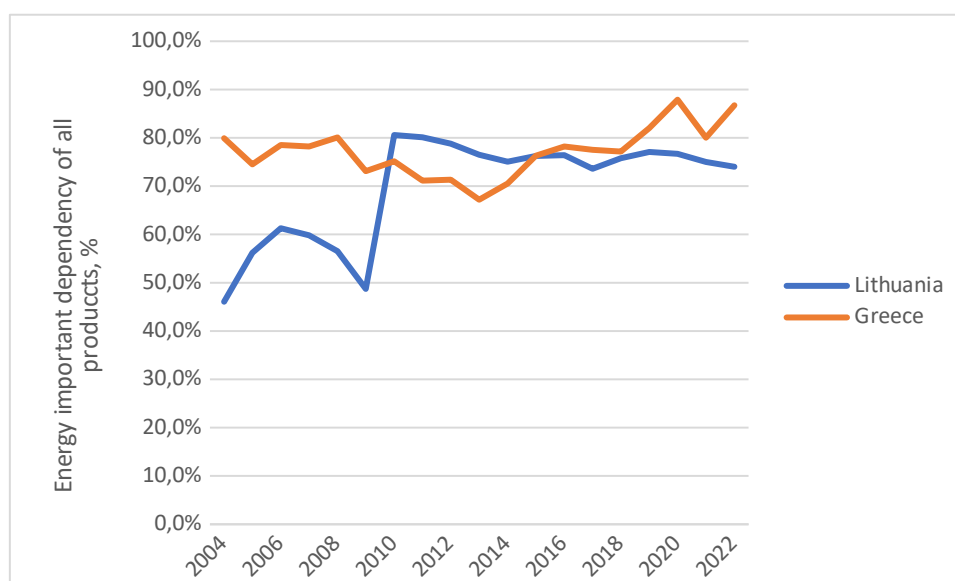


Figure 1. Energy import dependency dynamics in Lithuania and Greece

Source: own

As the information provided in Figure 1 shows, energy dependency has increased significantly in Greece during the low-carbon energy transition. At the same time, Lithuania has noticed a decrease in energy import dependency during the low-carbon transition process.

In Figure 2 energy import dependency of solid fuels in Lithuania and Greece was compared for 2004-2022 year period.

As one can notice from Figure 2 the energy import dependency of solid fuels in Lithuania was significantly higher during all investigated period and it has increase in 2022 year significantly. The energy import dependency on solid fuels in Greece was very low during all investigated period and in 2022 it was even negative showing that Greece has exported more solid fuels then imported.

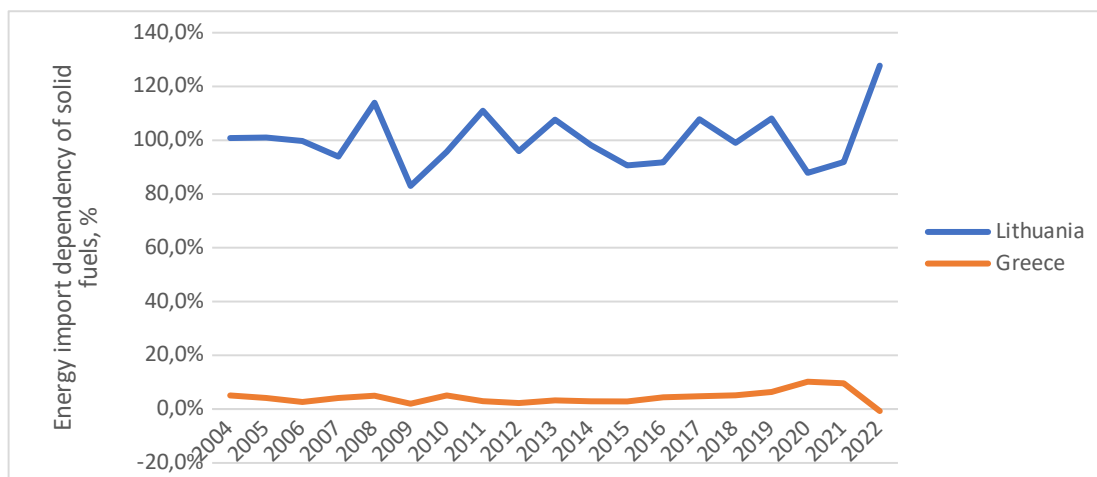


Figure 2. Energy import dependency of solid fuels in Lithuania and Greece

Source: own

In Figure 3 the energy import dependency of hard coal dynamics during 2004-2022 is provided for Lithuania and Greece.

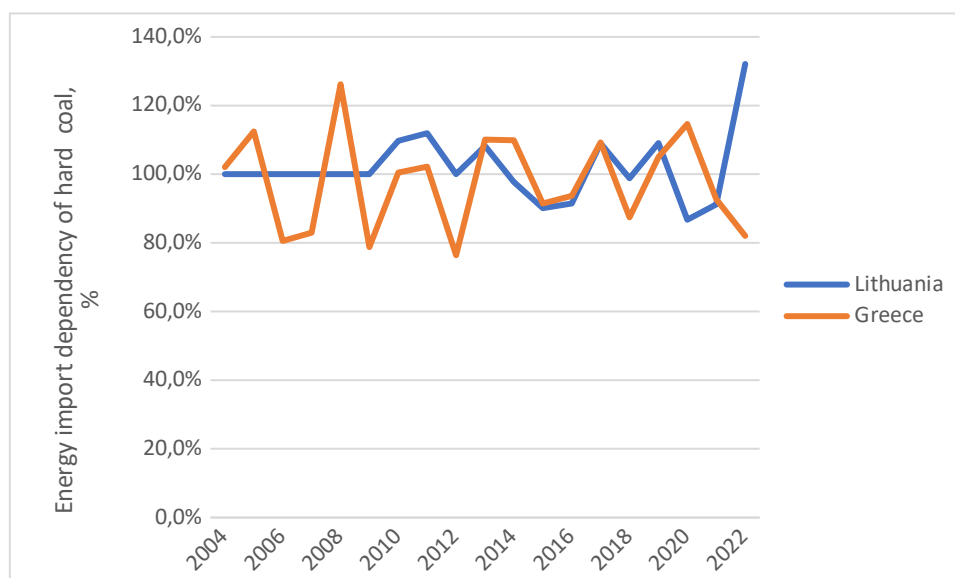


Figure 3. Energy import dependency of hard coal dynamics in Lithuania and Greece

Source: own

One can notice from Figure 3 that annual fluctuations can be noticed energy import dependency of hard coal in Greece. Though in Lithuania less fluctuations can be noticed in the trend of this indicator the energy import dependency on hard coal was higher in Lithuania during the recent years of low carbon energy transition.

In Figure 4 energy import dependency of oil and petroleum products in Lithuania and Greece during the 2004-2022 period is plotted. Information in Figure 4 shows that Greece's dependency on oil and petroleum products for energy imports was higher during all investigated periods. At the same time, Lithuania's trend of increasing dependency on energy imports can be noticed.

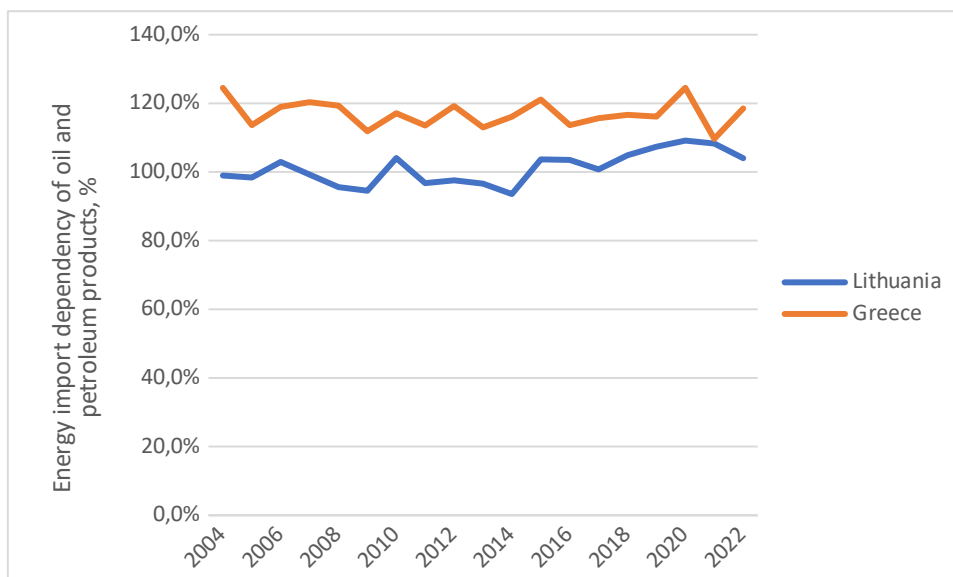


Figure 4. Energy import dependency of oil and petroleum products in Lithuania and Greece
Source: own

In Figure 5 the dynamics of energy import dependency on natural gas is provided for Lithuania and Greece.

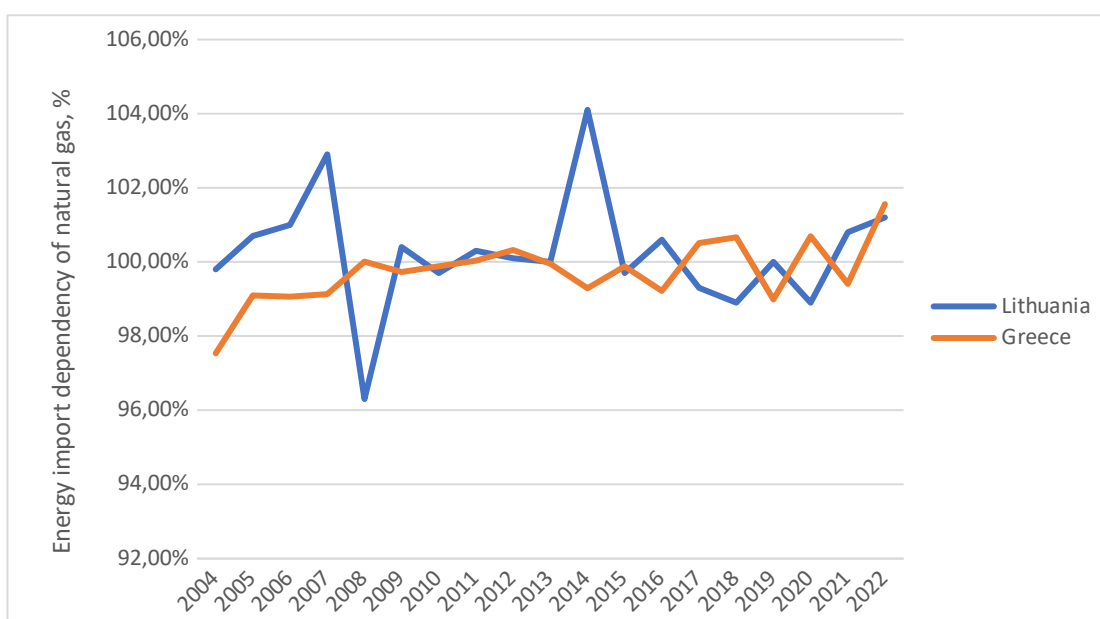


Figure 5. Energy import dependency of natural gas in Lithuania and Greece
Source: own

The trends in Figure 5 show that energy import dependency on natural gas in Lithuania and Greece is very high. In 2022, they were on the same level, though during the low-carbon energy transition process, the high fluctuation of this indicator was noticed in Greece.

Overall analysis of energy import dependency during 2004-2022 in two EU member states shows the increase in energy import dependency during low carbon energy transition, though Greece had quite a high energy import dependency even in 2004- 80% compared to Lithuania's -46.1%. In Lithuania, the closure of the Ignalina nuclear power plant had the main impact on the increase in energy import dependency. Before 2004, the country was a net energy exporter. The fast penetration of renewables during

the low-carbon energy transition process allowed to mitigate energy import dependency growth, which peaked at more than 80% in 2010.

In Figure 6 the pace of penetration of renewable energy sources in Lithuania and Greece are given for the 2004-2022 year period.

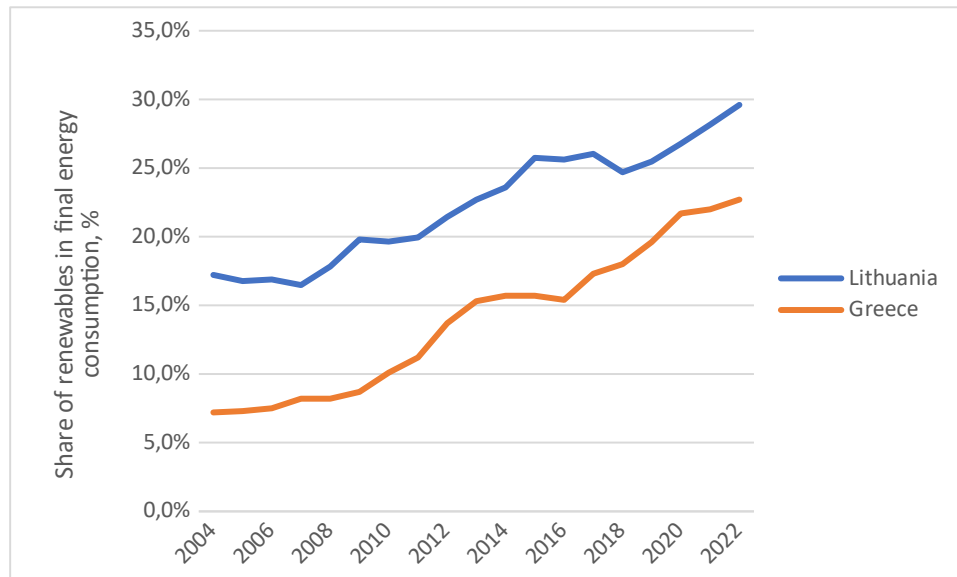


Figure 6. Share of renewable energy in final energy consumption in Lithuania and Greece

Source: own

The increase in the share of renewable energy in final energy consumption in Lithuania during the low-carbon energy transition was more significant compared to Greece. This had an impact on lower energy import dependency of Lithuania in 2022-74%, compared to Greece -87%. In Lithuania, the share of renewables in final energy consumption reached 30% in 2022 and 23% in Greece.

4. DISCUSSION

From a methodological perspective, relevant studies stressed out that although surveyed respondents agree with the need for a change in the current fossil fuel resources' management system, they do not regard that the decarbonization will eventually have a positive effect on the sustainability of the coal-dependent region. Besides, respondents who support such changes they do not believe that the climate change has seriously impacting on humanity and natural ecosystems (Vatalis et al., 2022) while other studies proved contracting, to the aforementioned, results and argumentations (Kyriakopoulos et al., 2023; Tsepi et al., 2024).

Another important issue of discussion refers to the role of RES technologies in energy storage and energy demand designing/schedule. Indeed, if new RES-based on-site technologies are well designed, then, they can contribute to significantly decrease the whole energy demand of data centers. Besides, the optimal sizing of electric- and thermal- energy storage systems together with an expedient choice of performance indicators of evaluating those available technology options, are identified as key-aspects of decreasing the external energy demand of tertiary sites, such as data centers (Kyriakopoulos, 2021; Richter et al., 2021).

National governments are often introducing policies which modify energy markets in order to achieve multifaceted social and political goals that are better serving their (national) energy needs and energy security. Even though these policies have historically created with the best of intentions, often they have unintended consequences (Diaz et al., 2013). Therefore, the energy security has been recognized as a critical issue of measuring heat energy poverty following various public policies to: a) define the concept

of heat poverty in households on the basis of a review of international literature, b) discuss the phenomenon of heat poverty of households in national level and present the research methodology through determining/suitable indicators and measures of heat poverty of households, c) determine what are the most noticeable imperfections in shaping the energy security strategy (at a national basis) (Swierszcz, 2020). While the “measures” is primary conceptualized as a “quantitative” research problem while there are also theoretical and empirical dimensions to be conveyed. For this, the most suitable methods that can be utilized are that of: analytical and synthetic, inference, together with the aforementioned quantitative and qualitative (Swierszcz, 2020). From an socio-economics perspective of energy security interest it can be argued that the disaggregation of results between high-income and middle-income countries revealed clear differences in the impact of economic complexity and energy security risk on both energy intensity and carbon intensity, making necessary policymakers of energy management to come to recommendations of wider, than that of national borders, interest, such as those provided in the context of the United Nations sustainable development goals (SDGs) (Payne et al., 2023).

Regarding the interrelation between energy security and decarbonization among the most critical factors is the availability of renewable energy sources. Therefore, in cases (countries) of limited potential for renewable energy sources in the mid-term there is a re-designing framework of other pluralistic field applicability, as that of nuclear power, which are negatively impacting on carbon intensity and energy security. In these countries there are promotion policies that enhance fossil fuels’ security, as well as provision of fuel sources diversification in alignment with supply routes for the foreseeable future. Taking into consideration that indigenous fossil fuel resources are scarce and finite, as well as the uncontrollable availability of nuclear power, renewable energy sources can play a decisive role to replace unabated fossil fuels (Oshiro et al., 2016).

CONCLUSIONS

Based on the conducted analysis of decarbonization-referred interest, it was highlighted that a just low carbon transition cannot be an easy process, and it might cause disruptions to the societies. A just transition plan should be a result of effective public dialogue with the active participation of all stakeholder groups, which are directly or indirectly affected by the major changes of decarbonization. It can be stressed that there is a need for multi-sectoral collaboration between the energy sectors to deliver cost-optimal energy decarbonization at the national scale.

The literature on energy decarbonization and renewable energy sources revealed the need to conduct comprehensive analyses underscoring those intricate interactions between energy aid and energy decarbonization transition. These research orientations also convey crucial policy implications for international organizations and governments aiming to foster sustainable energy transitions among developing countries and to enhance the effectiveness of energy aid.

The case study, which analyzed energy import dependency trends during the low-carbon energy transition of selected EU member states from different regions, showed that the fast penetration of renewable energy sources allows for the mitigation of energy import dependency. Lithuania is distinguished by the high pace of renewable energy penetration, having an impact on the mitigation of energy import dependency growth, which is very important for Lithuania after the decommissioning of the Ignalina nuclear power plant at the end of 2009.

In Greece, the energy import dependency was higher in 2022 compared to Lithuania, though in 2010, Lithuania had higher energy import dependency. Greece has a significantly lower energy import dependency on solid fuels compared to Lithuania due to abundant lignite resources; however, low carbon energy transition requires a reduction of usage of high carbon content fuels, especially lignite and hard coal. Therefore, the fast penetration of renewable energy sources can have a positive impact on energy import dependency reduction in Greece.

Finally, critical and noteworthy literature-emerging issues are the following:

Future studies can be directed to investigate the mediating impact of human capital and financial development as well as the moderating effect of institutional quality and demand for clean fuel. energy poverty is increasingly understood as a multi-dimensional issue caused by the low-carbon energy trans-

ition. Another crucial factor of future promising research has focused the human capital and financial development with the imperative investigation of the contentious nature of energy poverty at the regional and international levels of analysis. Such a humanitarian-oriented domain can offer a comprehensive understanding of energy poverty sources that are foremost understood in the household sector, but also play a protagonist role in the energy decarbonization transition and the wider/technologically mature development of renewable energy technologies (Streimikiene and Kyriakopoulos, 2023).

Why developing measures of energy security at the national level, countries that rank at the top of the list of different indices are insensitive to differences in the construction of the index, and it can be inferred that they have robust energy systems, which partly resolves the conflict. In the long run, it is vital for researchers to examine the energy security and low-carbon energy transition of a country with other relevant tools. Indeed, while at the country level, the assessment of a country's performance may be correct for the country ranking through individual indices, the each-time score obtained at a specific study may not be an accurate or credible indicator for generalized applications to be drawn.

Whenever renewable energy potentials are insufficient to eliminate the requirement for fossil fuels in mid-term, then, the unavailability of alternative sources of energy production, as that of nuclear power, would severely affect energy security. Therefore, suitable mid-term policies profoundly keep requiring the enhancement of energy security of fossil fuels, coupling with alleviation of the impacts of price volatility.

Whenever perceived energy security is conceptually linked with the European energy landscape, EU member states (such as in the case of Lithuania) find it permissible to base their national energy strategy on renewable energy sources. In the light of renewables and energy security at EU, considering also the (de)securitization that has been intensified by the East-West in EU, it can be underscored that the current geopolitical crisis in Eastern Europe is promoting geographical disputes that could be proven as detrimental to the transition towards the renewable energy sources and technologies.

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