How Independent is the Energy Sector in the EU?

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ABSTRACT

The current geopolitical situation and the Russian invasion in Ukraine have urgently increased the role of energy independence in national energy security. Nevertheless, the European Union, is still very dependent on imports of fossil fuels such as oil and natural gas, which are mainly sourced from neighboring Russia. Now more than ever, to accelerate Europe's energy independence and transition to carbon neutrality, it is critical to restructure national energy infrastructures and promote the rapid development of local renewable energy resources. To understand whether the EU are ready to accelerate the decarbonization of their energy system by abandoning energy imports from Russia, it is necessary to assess what progress has been made so far in reducing net energy imports. In this study, Log-Mean Divisia Index (LMDI) decomposition analysis is used to examine the changes in net energy imports in the EU-27 during the period from 1995 to 2020. The change in net energy imports is measured by four main factors: changes in energy dependence, changes in energy intensity, changes in economic growth, and population. The results show that not only has no progress been made in reducing the EU's energy import dependency, but the situation has actually worsened and become more unstable over the past five years.

Keywords: energy independence; LMDI; decomposition analysis; net energy imports

NONMENCLATURE

Symbols	
NI	Net energy imports
EN	Gross available energy
GDP	Gross domestic product
POP	Population
DEP	Energy import dependency
EE	Energy efficiency
EC	Economic growth

1. INTRODUCTION

Current geopolitical situation shows that energy is no longer perceived as just a necessary commodity but as an asset that can be weaponized. In light of the changing political environment and the increasing impact of climate change, energy security is becoming an essential component of a country's economic, environmental, and social stability [1]. Following the Russian invasion of Ukraine, the EU expressed concern about increasing the EU's energy independence and therefore launched REPowerEU in May 2020: Joint European Action for More Affordable, Secure and Sustainable Energy. It is a plan to increase Europe's energy independence and end fossil energy imports from Russia before 2030. This plan aims to promote the implementation of energy efficiency measures, diversify current energy suppliers, and accelerate the use of RES by exploiting the maximum potential of local RES to compensate for Russian energy imports and support Europe's energy independence [2].

Energy independence becomes an important driver and predictor of a country's economic development, as energy is used in all major sectors of the economy and energy costs impact all the main supply chains of the economy [3]. Energy security is also addressed in the United Nations Sustainable Development Goals, where net energy import dependency is used as an indicator of countries' level of national energy security [4]. Energy import dependency is also one of the main parameters that is used to explain the overall energy system infrastructure of the country [5]. Increasing energy import dependency means that the energy system is more dependent on external resources than on its own, making it more vulnerable to geopolitical threats that can cause significant disruptions to energy supplies [6].

Literature shows that there are studies that examine the degree of energy independence in each country, but there are fewer articles that look at progress in reducing national energy imports and increasing energy self-sufficiency. Moreover, there is no generally accepted method for studying changes in the level of energy security and net energy imports. A study by [7] uses

decomposition analysis to show how energy efficiency improvements positively affect energy independence. However, another study by [8] evaluates the impact of renewable energy development on regional energy independence using the GIS method. A study by [9] uses econometric methods to show the role of interdependencies among countries in providing energy imports to ensure uninterrupted energy supply and their implications for future energy security.

This study applies Log-Mean Divisia index (LMDI) decomposition analysis to examine the changes in net energy imports in the EU-27 during the period from 1995 to 2020. The analysis allows to identify the main drivers of change in net energy imports and to understand what progress has been made in reducing the EU's energy import dependency. Assessing progress is important for policymakers to avoid making expensive mistakes and develop more effective sustainability strategies for the future based on historical experience [10].

2. METHODOLOGY

Index decomposition analysis (IDA) is a comprehensive mechanism that allows to identify the main drivers of change in environmental performance indicators [11]. The conceptual framework of IDA is based on the decomposition of the study phenomenon, breaking down the element of the research study into several factors to examine their influence on the outcome [12]. Two main IDA frameworks can be distinguished - the Divisia index decomposition and the Laspeyres index decomposition. The difference between the two methods lies in the residuals obtained during the decomposition, where the Laspeyres index produces residual terms, while the Divisia index produces a perfect decomposition with no residuals [13]. This study applies Divisia index method due to its advantageous property of perfect decomposition. Furthermore, Divisia index method can take two forms – arithmetic mean or logarithmic mean, as well as integrate two main calculation approaches - additive or multiplicative [14]. This study uses logarithmic mean Divisia index (LMDI) with additive approach in order to study changes in absolute values of net energy imports. LMDI method is one of the most frequently used IDA methods to study energy efficiency [15], [16], sustainability [17], greenhouse gas emissions [18], and other green transformation challenges.

This study applies the LMDI decomposition analysis method to study changes in net energy imports of European Union countries. According to LMDI, changes in net energy imports are determined by four main factors – changes in energy dependency, changes in

energy efficiency, changes in economic growth, and changes in population, as indicated in Eq. (1). Net energy imports are expressed as energy imports minus energy exports. Table 1 summarizes all the factors used in the decomposition analysis.

$$NI = \sum_i NI_i = \sum_i \frac{NI}{EN} \frac{EN}{GDP} \frac{GDP}{POP} POP = \sum_i DEP_i\, EE_i EC_i POP_i \quad (1)$$

where *NI* is net energy imports, *EN* is gross available energy, *GDP* is gross domestic product, *POP* is population, *DEP* is energy import dependency, *EE* is energy efficiency, *EC* is economic growth, *i* denotes a particular country.

Table 1
Description of LMDI decomposition analysis factors

Factor	Indicator	Description
Energy dependency effect (*DEP*)	Net imports (imports-exports) per gross available energy (NI_i/EN_i)	Measures changes in energy import dependency and reliance on energy resources abroad. Positive value shows greater energy import dependency and negative value shows reduced energy import dependency.
Energy efficiency effect (*EE*)	Gross available energy per gross domestic product (EN_i/GDP_i)	Measures improvements in energy efficiency by reduced energy intensity of economy. Positive value shows negative trend and decrease in energy efficiency, negative value shows significant improvements in energy efficiency by more efficient use of energy resources.
Economic growth effect (*EC*)	Total gross domestic product per number of inhabitants (GDP_i/POP_i)	Measures changes in economic growth and development which directly impact the amount of energy resources used in the economy. Positive value shows increase in economic growth and its impact on energy demand increase, negative value shows decrease in economic output which in turn decreases overall demand for energy.
Population growth effect (*POP*)	Total number of inhabitants (POP_i)	Measures changes in total number of inhabitants in a country. Positive value shows growth in population which pushed energy demand to increase, negative value shows decline in population which requires less energy resources to meet the needs of inhabitants.

Furthermore, the equation is derived in Eq. (2) that measures changes in net energy imports from future year *T* to initial year *0*.

$$\Delta NI = NI^T - NI^0 = \Delta NI_{DEP} + \Delta NI_{EE} + \Delta NI_{EC} + \Delta NI_{POP} \quad (2)$$

Changes in each decomposition factor from Eq. (2) is calculated according to Eq. (3)-(6):

$$\Delta NI_{DEP} = \sum_i \frac{NI^T - NI^0}{lnNI^T - lnNI^0} ln \frac{DEP_1^T}{DEP_1^0} \quad (3)$$

$$\Delta NI_{EE} = \sum_i \frac{NI^T - NI^0}{lnNI^T - lnNI^0} ln \frac{EE_1^T}{EE_1^0} \quad (4)$$

$$\Delta NI_{EC} = \sum_i \frac{NI^T - NI^0}{lnNI^T - lnNI^0} ln \frac{EC_1^T}{EC_1^0} \quad (5)$$

$$\Delta NI_{POP} = \sum_i \frac{NI^T - NI^0}{lnNI^T - lnNI^0} ln \frac{POP_1^T}{POP_1^0} \quad (6)$$

where NI^T is net energy imports in the future year; NI^0 is net energy imports in the initial year.

All the data used for this study is collected from the Eurostat database. Data on net energy imports and gross available energy are collected from complete energy balances [nrg_bal_c] data set. Data on gross domestic product is collected from GDP and main components [nama_10_gdp]data set. Data on number of inhabitants are collected from population on 1 January [demo_pjan] data set. Data set on energy import dependency [sdg_07_50] and share of renewable energy in gross final energy consumption by sector [sdg_07_40] was used to validate the results obtained in the LMDI decomposition analysis of this study. Data were collected for all 27 EU member states for the period from 1995 to 2020 which was the latest available year for all the selected LMDI indicators [19]–[23].

3. RESULTS

The LMDI decomposition analysis is applied to measure the changes in net energy imports in EU-27 over the period from 1995 to 2020 divided into five groups of five-year periods. More detailed analysis is performed for the period of the last five years (2015-2020) for all 27 EU countries to examine the recent situation in accelerating energy independence at the EU level. The results show different energy structures and energy import tendencies for the countries.

Figure 1 illustrates the results of the LMDI decomposition analysis for the EU-27 for the period 1995 to 2020. The results show that economic growth and population growth are the main drivers of total energy demand growth, which in turn increases the need for net energy imports in the EU. The EU's energy import dependency has fluctuated over the periods. In the first two periods (1995-2000 and 2000-2005), there was an upward trend in energy import dependence, which was reflected in annual increases and greater EU exposure to energy trade. In the third period (2005-2010), the EU's overall energy import dependency showed slightly, decreasing trend which was mainly due to the global financial crisis, which reduced energy demand in all EU countries. In the fourth period (2010 - 2015), the EU's

dependence on energy imports increased only minimally compared to growth in 1995-2005 due to implemented climate action plans, which put pressure on EU countries to increase the share of renewable energy in total energy consumption.
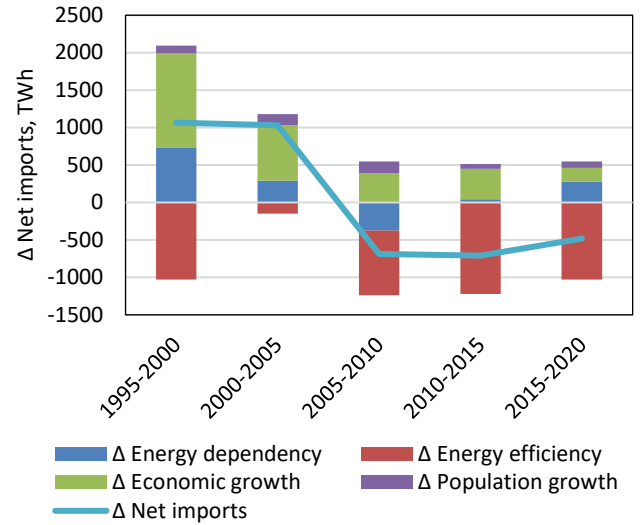

Fig. 1 LMDI decomposition analysis results for EU-27

In the fifth, the most recent period (2015-2020), the EU show rising energy import dependency that have reached the highest value compared to other periods. The growing dependence on energy imports is explained by the stable energy demand in the EU, where the growing economy and population demand fossil fuels, which are mainly consumed in transport, industry, households and agriculture. However, due to the EU's strategic climate change policies, the EU has significantly reduced its domestically generated fossil energy during 2015-2020. Therefore, to balance the energy demand, the required fossil energy was imported from abroad, mainly from Russia [24]. This has in turn pushed net energy imports during 2015-2020 to increase.

The importance of energy efficiency measures is also highlighted in the results of the LMDI decomposition analysis, as energy efficiency was the most important counter-response factor that decreased the need for net energy imports in all periods studied. The greatest impact of energy efficiency improvements was in the period from 2010 to 2015.

Figure 2 illustrates the contribution of the LMDI decomposition analysis factors to the changes in EU-27 net energy imports for the fifth study period (2015-2010), as well as the percentage change in total net energy imports over this period. Moreover, Table 2 summarizes the results for each country.
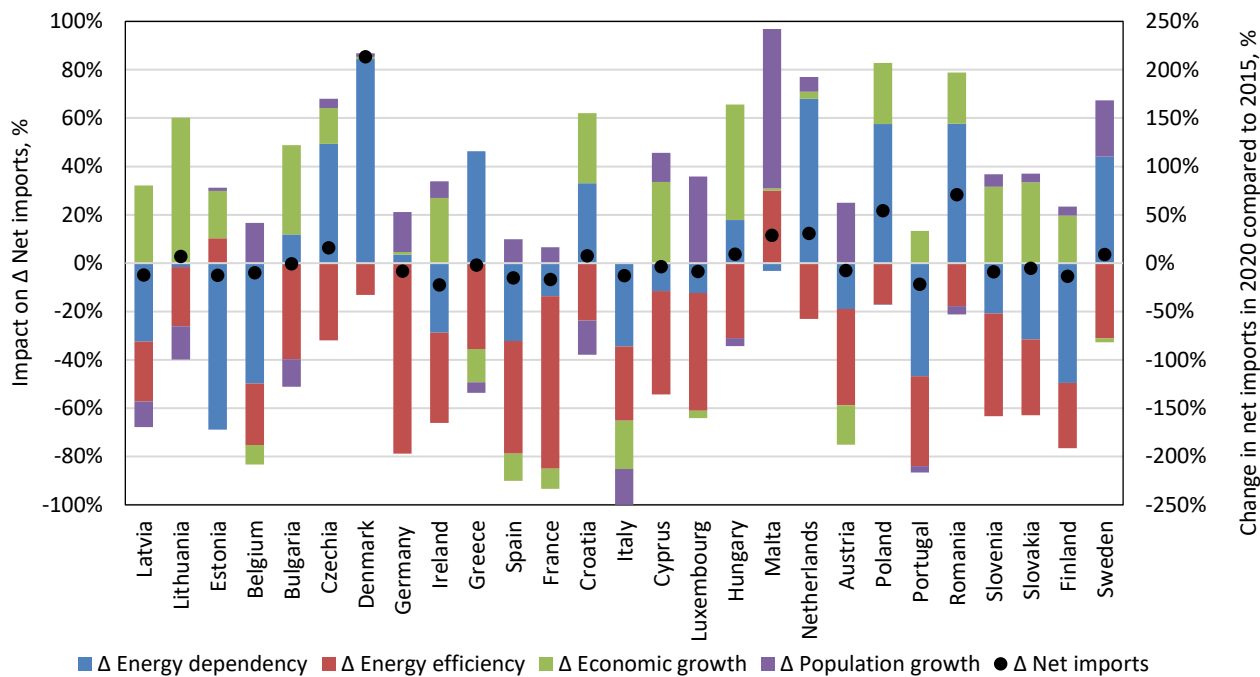
Fig. 2 Contribution of LMDI decomposition analysis factors to ΔNet imports for EU-27 in the period from 2015 to 2010

Table 2
LMDI decomposition analysis results from 2015 to 2020 for EU-27 (GWh)

Country code	Δ Energy dependency	Δ Energy efficiency	Δ Economic growth	Δ Population growth	Δ Net imports
LV	-3118	-2364	3083	-1021	-12.4%
LT	-361	-5281	12969	-2954	6.9%
EE	-1528	227	435	29	-12.5%
BE	-42974	-21831	-7039	14352	-9.9%
BG	3039	-10179	9478	-2927	-0.7%
CZ	34172	-22102	10179	2722	15.9%
DK	66920	-10445	786	1138	213.3%
DE	11952	-268706	3621	56584	-8.5%
IE	-30082	-39021	28206	7211	-22.7%
EL	29602	-22685	-8873	-2792	-2.2%
ES	-68306	-98778	-24019	20981	-15.4%
FR	-37083	-194658	-22623	17988	-16.9%
HR	4944	-3555	4358	-2126	7.5%
IT	-62686	-55787	-36252	-26973	-12.9%
CY	-1379	-5130	4015	1451	-3.6%
LU	-1749	-6908	-435	5088	-8.6%
HU	8183	-14197	21899	-1560	9.1%
MT	-252	2392	81	5253	28.8%
NL	196205	-66484	8525	17231	30.6%
AT	-6903	-14540	-5926	9094	-7.7%
PL	157877	-46741	69516	-502	54.0%
PT	-30285	-24141	8663	-1696	-22.1%
RO	43875	-13515	16048	-2565	70.8%
SI	-2615	-5338	3979	634	-8.9%
SK	-7254	-7196	7668	836	-5.2%
FI	-23580	-12829	9388	1739	-13.8%
SE	19555	-13858	-682	10370	9.0%
EU-27	**256172**	**-983649**	**117047**	**127589**	**-5.0%**

The results show that the majority of EU-27 countries managed to reduce their net energy imports in the period from 2015 to 2020, with the exception of 9 countries that showed the opposite. The highest increases were recorded by Denmark (213.3%), Romania (70.8%), Poland (54.0%), the Netherlands (30.6%) and Malta (28.8%). Other countries such as the Czech Republic (15.9%), Hungary (9.1%), Sweden (9.0%), Croatia (7.5%) and Lithuania (6.9%) recorded lower increases in net energy imports during this period. All of these countries, with the exception of Malta and Lithuania, also showed significantly increased energy import dependency.

On the other hand, some countries have succeeded in significantly reducing their dependence on imported energy in the period from 2015 to 2020. These countries include Latvia, Estonia, Belgium, Spain, France, Italy, Cyprus, Luxembourg, Austria, Portugal, Slovenia, Slovakia and Finland.

In absolute terms, the countries with the highest net energy imports are Germany, Italy, France, Spain, the Netherlands, Poland, and Belgium, so changes in energy import dependency in these countries strongly influence the overall degree of energy independence of the EU.

The supply of natural gas and petroleum products is the main cornerstone for strengthening energy independence in almost all countries of the European Union [1]. In 2020, natural gas accounted for almost a quarter (23.7%) of gross available energy in the EU, with an import dependence of 83.6%. In the EU, natural gas is

mainly used for district heating and electricity generation. In 2020, Russia was the EU's main natural gas trading partner, and over the past decade, the EU's dependence on natural gas imports has increased from 71.6% in 2011 to 83.6% in 2020 [25], [26]. In countries with a high share of natural gas in the total energy mix, such as Italy (40%), the Netherlands (38%), Hungary (34%), Ireland (33%), Croatia (30%), Germany (26%), and Lithuania (25%), where the share of natural gas in total gross available energy in 2020 is higher than the EU average of 24%, serious restructuring of the energy system is needed [27].

A study by [28] estimates that it is possible to reduce dependence on imported natural gas by implementing energy efficiency measures, especially in the non-profit consumer and heat generation sectors. More importantly, increasing energy self-sufficiency can be achieved not only through energy efficiency measures, but also by building the necessary infrastructure and enabling environment for domestic energy production. In addition, the study shows empirical results that demonstrate historical periods in which a reduction in natural gas consumption was achieved despite increasing economic growth [28]. Therefore, more serious measures should be taken in all EU member states to phase out natural gas use in all sectors of the economy.

Energy independence can be accelerated by increasing the use of renewable energy (RES), which enables the generation of clean energy based on local resources, even in countries without available conventional energy sources [29]. Therefore, the development of sufficient infrastructure to exploit the maximum potential of renewable energy, which includes RES production, distribution and accumulation technologies, is extremely important for all EU countries [29]. RES contributes to the EU's two main strategic development priorities. First, RES is the key element for the decarbonization of the energy system and contributes to the achievement of climate change mitigation goals. Second, it strengthens national energy security by making it possible to become less dependent on external energy resources sourced through massive energy imports [29]. The greatest advantage of RES is that it is not limited to one energy carrier that is a depleting resource, but offers a wide variety of energy sources such as wind, solar, biomass, geothermal, and hydro. Therefore, depending on the geographical and climatic conditions, it is possible for each country to develop RES infrastructure for the higher production of a specific type of RES [29].

In order to show the positions of each EU-27 country in terms of level of energy import dependency and the share of renewable energy sources in total energy consumption, a correlation analysis is performed. Figure 3 illustrates the relationship between the share of renewables in gross final energy consumption and energy import dependency in 2020 for all EU-27 countries. The results show that for a number of countries that have a high energy import dependency, the share of renewable energy resources is also lower compared to other countries. This group of countries is particularly vulnerable to both the geopolitical situation and the consequences of climate change. The group of countries with high vulnerability includes Belgium, Greece, Lithuania, Italy, Ireland, the Netherlands, Spain, Germany, Malta, Cyprus and Luxembourg. However, Sweden shows the most competitive positions in terms of decarbonization of the energy system and national energy security.
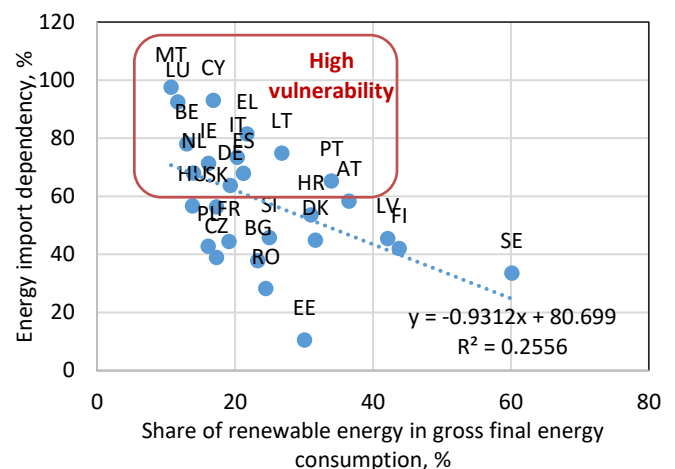

Fig. 3 Relationship between share of renewable energy in gross final energy consumption and energy import dependency in 2020 for EU-27 countries

4. CONCLUSIONS

Although EU energy import dependency was raised as an important issue back in 2015, when negotiations on the EU Energy and Climate Strategy 2030 began in response to Russia's escalating aggression in Ukraine [30], the results of this study reveal alarming findings. Not only has no progress been made in reducing the EU's dependence on imported energy, but the situation has actually worsened and become more unstable over the past five years.

The results show that at the EU level in the past five years (2015-2020) energy import dependency have increased significantly. Current improvements in energy efficiency have not been able to compensate for energy demand influenced by population and economic growth in the EU. Growth in net energy imports and import

dependency is explained by the reduction in domestically generated fossil energy in EU-27 which was driven by stringent climate action plans [24]. Therefore, to compensate the demand, the necessary fossil fuels were imported. The EU has relied not only on oil imports, but also on natural gas, as natural gas is still considered a transitional source on the road to carbon neutrality [31]. In most countries, there is still lack of serious action towards more rapid replacement of natural gas in energy systems.

The results of this study suggest that, in addition to energy efficiency measures, a rapid switch to local renewable energy sources is key to phasing out imported fossil fuels, strengthening national energy security, and promoting the EU's transition to climate neutrality [32], [33]. In addition, accumulation technologies that compensate for the disruption of variable energy play a crucial role in the more rapid deployment of renewable energy resources [34].

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