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From Targets to Action: Analyzing the Viability of REPowerEU in Achieving Energy Sustainability

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Abstract. EU's energy sector is facing turbulent times as it strives to strengthen energy independence without losing sight of providing affordable and sustainable energy to all. The European Commission's REPowerEU plan to accelerate the EU's energy transition places additional pressure on each member state's path to energy sustainability. To reach this objective, policymakers must assess the present energy sustainability levels of each member state, identify areas for development, and monitor the county's progress over time. The purpose of this article is to analyze and compare the energy sustainability levels of the EU member states using a variety of indicators and to identify key cornerstones for advancing their energy transition. This study develops an energy sustainability composite index (ESCI) in order to unravel and compare the multiple lawyers of energy sustainability, including energy security, primary energy intensity, share of renewable energy resources, energy efficiency, CO_2 emission intensity, and energy poverty. Log-Mean Divisia Index (LMDI) decomposition analysis is utilized to track the progress of energy policy in achieving reductions in energy-related CO_2 emissions from 2015 to 2019. Changes in CO2 emissions were decomposed using Kaya identity factors to determine which of the following factors contributed the most to the changes: changes in emission intensity, energy intensity, economic or population growth. The results indicate that all EU member states have untapped potential for improving energy sustainability.

1 Introduction

Growing global concerns about energy security and climate change have pushed national policymakers to assess the current state of energy sustainability and shifted the energy sector toward the adoption of new solutions for how energy is produced, supplied, consumed, and accumulated [1]. To strengthen energy self-sufficiency while achieving a sustainable green energy transition, the European Commission launched REPowerEU Plan in 2022: Joint European action for more affordable, secure and sustainable energy [2]. The REPowerEU plan is intended to address all aspects of the energy trilemma that determines national energy systems in order to ensure that sufficient efforts are placed on decreasing fossil energy import dependence from Russia while delivering energy at an affordable price to end-consumers. This can be accomplished by taking a more active role in implementing sufficient energy efficiency measures and deploying a higher proportion of renewable energy resources [3].

Effective energy policy should incorporate an optimal trade-off between economic affordability and environmental sustainability; however, the current energy crisis caused mainly by the Russian war in Ukraine has increased the importance of enhancing energy independence rapidly, which may place additional pressure on the current green energy transition targets [4]. Even though the European Commission is responsible for establishing the overall strategy and vision for the European Union, national climate policies, their effectiveness, and the priorities of national governments have a significant impact on the efforts of each member state to increase energy sustainability [5].

To assess the EU's ability to meet the European Commission's ambitious REPowerEU targets, it is necessary to examine the progress made so far and the ranking of EU member states in relation to these interconnected goals in energy sustainability. The purpose of this study is to determine each EU member state's current level of energy sustainability and how it has historically contributed to the EU's transition towards a sustainable, affordable, and secure energy system. The development of a comprehensive and effective energy policy relies heavily on the use of reliable data and rigorous evaluation methods [6]. To this end, this research employs a combination of two data-based mathematical approaches to provide a comprehensive assessment of the sustainability of the European Union's energy policies. The findings of this study have the potential to significantly inform the development of more robust energy policies.

The structure of the paper is as follows: Section 2 describes the integrated assessment approach utilized in this study, Section 3 describes the attained results from composite index and LMDI decomposition analysis, and Section 4 provides the study's primary conclusion.

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2 Methodology

In this study, an integrated assessment approach combining both composite index and decomposition analysis methods is used. The combination of both methods makes it possible to examine the current state of energy sustainability in individual EU countries as well as to assess progress in the transition to green energy, thus providing a comprehensive analysis and unlocking multiple aspects of energy sustainability. Using both methods allow to identify the key factors affecting national energy sustainability and the drivers of change in the green transition. At first composite index is calculated to evaluate the existing situation in energy sustainability levels, then decomposition analysis is applied to measure and monitor progress in energy policy of each EU's member state.

2.1. Composite index

The composite index method is used to construct energy sustainability composite index (ESCI). The main advantage of this method is that it allows combining numerous different indicators with different units of measurement to obtain a single metric - the composite index [7]. In addition, the results are easy to interpret because the ESCI results are scaled in an interval from 0 to 1, where 1 is the maximum value and 0 is the minimum value [8]. A higher ESCI score means higher energy sustainability compared to other EU countries and vice versa.

After defining the conceptual idea and the main objective of the composite index to be created, the construction of the composite index consists of five main steps - selection of indicators, impact assessment, normalization, weighting and aggregation. Table 1 provides an overview of the selected indicators of energy sustainability composite index, the databases used for data selection, and the assessed impacts of each indicator. Indicators were selected based on the literature review of factors affecting energy sustainability and data availability. Data were taken from publicly available databases - Eurostat and Odysee Mure. Data was selected for 2019 as this was the latest available data for all selected indicators for all EU-27 countries.

After data selection, each indicator was divided into two groups according to its impact on ESCI - positive and negative impact. If indicators with increasing value potentially have a positive impact on energy sustainability, such as increasing the share of renewable energy sources, then the indicator has a positive impact. If indicators with increasing value have a negative impact on energy sustainability, such as an increase in emission intensity, then the indicator has a negative impact [9].

The indicators are further normalized accordingly. The min-max normalization technique is used to normalize all indicators on a scale of 0 to 1. Positive impact indicators are normalized using Eq. (1) and negative impact indicators are normalized using Eq. (2), as retrieved from [10], [11].

$$I_N^+ = \frac{I_{act} - I_{min}}{I_{max} - I_{min}} \quad (1)$$

$$I_N^- = 1 - \frac{I_{act} - I_{min}}{I_{max} - I_{min}}\ , \quad (2)$$

where I_N^+ is normalized indicator of positive impact, I_N^- is normalized indicator of negative impact, I_{act} is the actual value of an indicator for the respective country, I_{max} is the maximum value of an indicator across all countries, I_{min} is the minimum value of an indicator across all countries.

After normalizing the indicators, a weighting is applied. Following the sustainability framework which assumes that all aspects of sustainability are equally important to sustainability, the technique of equal weighting is used in this study. Finally, the ESCI is calculated using Eq. (3), aggregating all indicators into a single composite index, as retrieved from [11].

$$\mathrm{ESCI} = \sum w \times I_N^+ + \sum w \times I_N^-\ ,\ w = \frac{1}{n_I}\ , \quad (3)$$

where ESCI is the energy sustainability composite index, w is the value of determined weight of a specific indicator, I_N^+ and I_N^- are normalized indicators, n_I is the total number of indicators.

Table 1. Selected indicators of energy sustainability composite index (ESCI).

Indicator	Description	Impact	Data source
Energy import dependency	Net energy imports divided by the gross available energy, %	-	Eurostat [12]
Share of renewable energy sources	Share of renewable energy in gross final energy consumption, %	+	Eurostat [13]
Primary energy intensity	Primary energy intensity at purchasing power parities (ppp) with climatic corrections, koe/EUR2015p	-	Odysee Mure [14]
Energy efficiency	Total energy consumption per number of inhabitants, Mtoe/population	-	Odysee Mure [15], [16]
CO_2 emission intensity	Total CO_2 emissions from fuel combustion activities per total final energy consumption (with climatic corrections), $MtCO_2$/Mtoe	-	Odysee Mure [17], Eurostat [15]
Energy poverty	Share of population unable to keep home adequately warm, %	-	Eurostat [18]

2.2 LMDI decomposition analysis

The decomposition analysis method is used to analyze how CO_2 emissions from fuel combustion have changed from 2015 to 2019. To provide the framework for decomposition analysis in this study, the Kaya identity approach is applied. Kaya identity is a mathematical identity used to explain changes in total emissions by determining four main factors-emission intensity, energy intensity, economic growth, and population growth-according to Eq (4), as retrieved from [19]. The advantage of the Kaya identity method is that it allows for the quantification of total CO_2 emissions by accounting for important determinants of emission changes. This technique is extensively employed to consider both energy and economic factors [20].

$$CO2_t = \frac{CO2_t}{En_t} \cdot \frac{En_t}{GDP_t} \cdot \frac{GDP_t}{Pop_t} \cdot Pop_t \qquad (4)$$

where $CO2_t$ are CO_2 emissions in a given period, En_t is energy consumption in period, GDP_t is gross domestic product in the period, Pop_t is population in the period. Data for the decomposition analysis using Kaya identity approach were obtained from Eurostat and Odysee Mure databases; the data sources used are summarized in Table 2.

Table 2. LMDI decomposition analysis impact factors.

Factor	Expression	Data source
Δ Emission intensity	Total CO_2 emissions from fuel combustion/ Total inland energy consumption	Odysee Mure [17], Eurostat [21]
Δ Energy intensity	Total inland energy consumption/ GDP (2015 chain linked volumes)	Eurostat [21], [22]
Δ GDP growth	GDP (2015 chain linked volumes)/ Total Population	Eurostat [16], [22]
Δ Population growth	Total population	Eurostat [16]

The Log-Mean-Divisia Index (LMDI) additive approach is used to decompose energy-related CO_2 emissions for each country, with changes in CO_2 emissions determined by changes in each separate decomposition indicator - emissions intensity, energy intensity, GDP growth, population growth - as shown in Eq. (5).

$$\begin{aligned}&\Delta(CO2)t = \Delta(Emission\ intensity)t\ + \\ &\Delta(Energy\ intensity)t\ + \Delta(GDP\ growth)t\ + \\ &\Delta(Population\ growth)t = \\ &\Delta\left(\frac{CO2_t}{E_t}\right)t \cdot \Delta\left(\frac{E_t}{GDP_t}\right)t \cdot \Delta\left(\frac{GDP_t}{P_t}\right)t \cdot \Delta P_t \qquad (5)\end{aligned}$$

According to the LDMI I additive decomposition technique, the change in each decomposition factor of CO_2 emissions is determined using Eq. (6) - Eq. (9), as retrieved from [23] and [24].

$$\Delta\, CEI = \sum_i \frac{CO2^T - CO2^0}{lnCO2^T - lnCO2^0} ln \frac{CEI^T}{CEI^0} \qquad (6)$$

$$\Delta\, EI = \sum_i \frac{CO2^T - CO2^0}{lnCO2^T - lnCO2^0} ln \frac{EI^T}{EI^0} \qquad (7)$$

$$\Delta\, GDP = \sum_i \frac{CO2^T - CO2^0}{lnCO2^T - lnCO2^0} ln \frac{GDP^T}{GDP^0} \qquad (8)$$

$$\Delta\, POP = \sum_i \frac{CO2^T - CO2^0}{lnCO2^T - lnCO2^0} ln \frac{POP^T}{POP^0} \qquad (9)$$

where CO_2 is CO_2 emissions from fuel combustion, CEI is CO_2 emission intensity, EI is energy intensity, GDP is economic growth, POP is population. Subscript 0 indicates the values of the base year, whereas subscript T indicates future values. The same notation is applicable to all variables.

3 Results

3.1. Composite index results

The goal of the Energy Sustainability Composite Index (ESCI) is to characterize the existing situation of energy sustainability based on data from 2019. The ESCI allows for cross-country comparison and identification of the main energy sustainability profiles of each country. Figure 1 depicts the energy sustainability composite index (ESCI) results. ESCI results are categorized into three primary groups: Group I consist of countries that have achieved ESCI results above the average, Group II is comprised of countries whose average ESCI score is equivalent to the EU average, and Group III is comprised of countries that significantly lag behind in energy sustainability and have achieved ESCI results below the average of 0.54.

With a score of 0.79, Sweden achieved the highest result among all countries. This is due to the high values obtained for all indicators except primary energy intensity, which indicates that Sweden has a slightly higher primary energy intensity than other EU member states. Denmark attained the second highest ESCI score, 0.74, and displayed consistently favorable results across all indicators.

The Group I category encompasses countries such as Latvia (0.69), Romania (0.66), Croatia (0.63), Austria (0.63), France (0.60), Estonia (0.59), and Finland (0.59). Nevertheless, this cluster of countries exhibits distinct patterns of strengths and weaknesses in their energy sustainability. Estonia's energy self-sufficiency is among the highest in the European Union, as evidenced by its energy import dependency score. However, the country's renewable energy resource share is notably lower and its primary energy intensity is higher, both of which have a detrimental impact on its energy sustainability. France's national energy sustainability is characterized by weaknesses in the share of renewable energy resources and primary energy intensity, while strengths are observed in lower energy poverty and CO_2 emission intensity. In comparison to other countries, Finland's energy sustainability is comparatively weaker due to its higher energy consumption per capita, as indicated by its energy efficiency indicator. However, Finland's energy poverty rate is relatively lower, which is its strongest aspect in terms of energy sustainability.

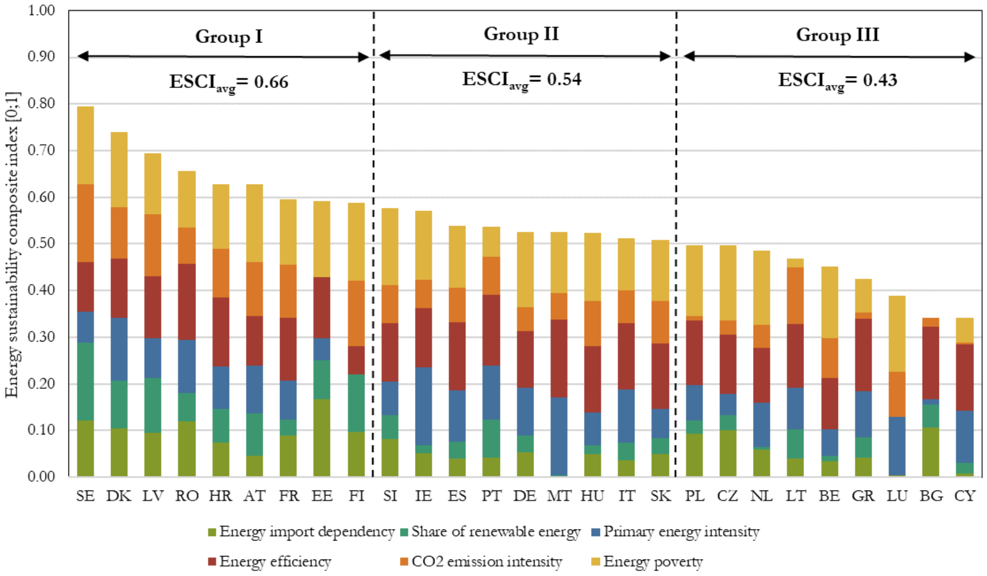

Fig. 1. Energy sustainability composite index (ESCI) results for EU-27 countries.

Group II countries overall show significantly higher energy import dependency compared to Group I countries which negatively affected their overall ESCI score. Significantly lower results were also reported for share of renewable energy sources compared to leading countries in Group I. Group III countries had the weakest indicators of energy poverty, share of renewable energy resources, and CO_2 emission intensity, which negatively impacted their ESCI score overall. The countries with the lowest total ESCI scores were Bulgaria and Cyprus, which both received 0.34.

Overall, it can be observed that there is potential for enhancing the energy sustainability of all countries, as none of them attained the maximum score of 1 and the average ESCI score was 0.54. ESCI methodology enables the identification of primary strengths and weaknesses of individual countries, as well as the tracking of advancements towards attaining energy sustainability.

3.2. LMDI decomposition analysis results

The main objective of the LMDI analysis is to examine what progress has been made in energy decarbonization over the 5-year period. Figure 2 shows the results of the LMDI decomposition analysis for all EU-27 countries. The results show the progress made by the EU Member States in reducing CO_2 emissions from fuel combustion in the period from 2015 to 2019 and the main factors influencing these changes.

The results show that the majority of EU countries have succeeded in reducing CO_2 emissions from fuel combustion, moving closer to overall decarbonization targets for the economy. However, eight countries showed the opposite trend, as they experienced a slight increase in energy-related CO_2 emissions. Countries that reported an increase in CO_2 emissions from fuel combustion over the 5-year period from 2015 to 2019 are Cyprus (7.27%), Lithuania (5.87%), Hungary (4.98%), Austria (3.94%), Luxembourg (3.94%), Latvia (3.90%), Slovakia (2.13%), and Poland (1.89%). Table 3 provides an overview of the development of CO_2 emissions in these countries over the period studied, broken down by the main economic sectors - transport, households, industry, services and agriculture. The results of the LMDI analysis show that the large increase in CO_2 emissions in Cyprus is due to the large increase in economic and population growth, which has significantly increased the total demand for energy. Although a reduction in energy and emissions intensity was achieved, it was not significant enough to compensate for the increase in the overall economy. An increase in CO_2 emissions was seen in almost all sectors except industry, with the transport and services sectors being the most critical.

For Lithuania, the economic growth factor was the main reason for the sharp increase in CO_2 emissions during this period. Improvements in energy efficiency, decarbonization of energy supply, and population decline contributed slightly to offset the overall increase in CO_2 emissions, but not completely. Although Lithuania experienced significant CO_2 emission reductions in the commercial, industrial, and residential sectors during the five-year period, overall energy-related CO_2 emissions increased due to emission increases in transport and agriculture sectors.

In Hungary, economic growth was also the main cause of the increase in CO_2 emissions. Although significant improvements in energy efficiency in Hungary have helped offset some of the potential CO_2 emissions, progress in switching from fossil fuels to renewables has been extremely slow. Transport, manufacturing, and agriculture are the most critical sectors in Hungary, as they experienced a sharp increase in CO_2 emissions over the period.

In Austria, strong population growth and economic growth have increased overall CO_2 emissions. Most importantly, Austria is the only country that experienced

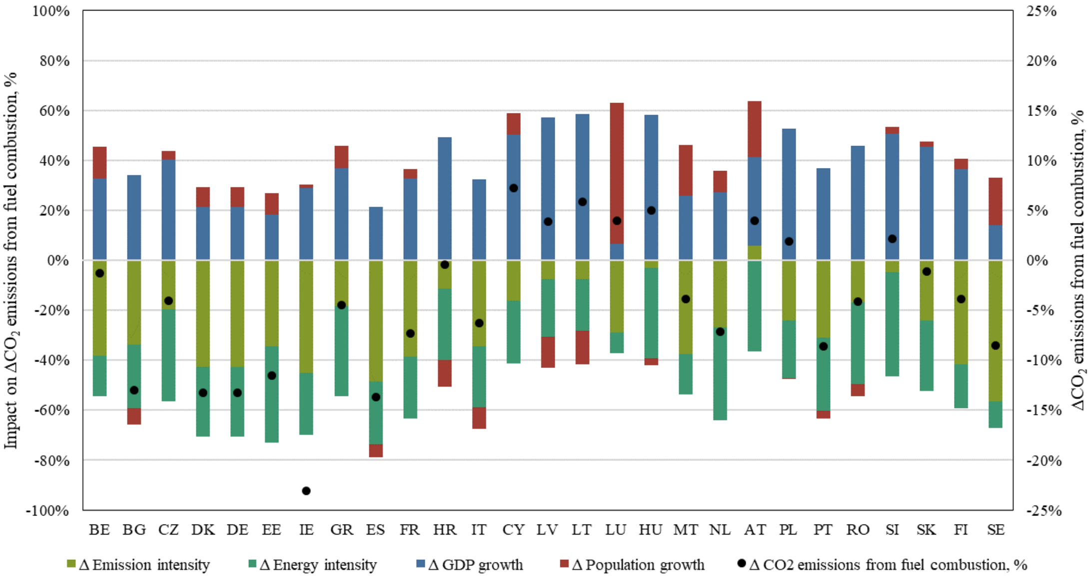

Fig.2. LMDI decomposition analysis results for changes in CO_2 emissions from fuel combustion from 2015 to 2019

an increase in overall emissions intensity during the period studied, implying that decarbonization of energy supply in Austria has not been strong enough overall. All sectors except households have seen an increase in total CO_2 emissions in Austria, with the transport and agriculture sectors being the most critical.

High population growth was the main cause of the increase in energy-related CO_2 emissions in Luxembourg, with significant reductions in emissions intensity not offsetting this growing effect. While industry, households and agriculture were able to achieve emission reductions, the increase in emissions in the service and transport sectors was more significant, leading to an increase in total CO_2 emissions in Luxembourg during the five-year period.

In Latvia, despite declining population growth, significant GDP growth was the main driver of the increase in CO_2 emissions from fuel combustion. Energy efficiency improvements did most to offset this trend, but not strongly enough. The transport and agriculture sectors were the main contributors to the overall increase in energy-related CO_2 emissions in Latvia, as the services, residential, and industrial sectors saw significant emission reductions.

Similar trends are observed in Slovakia and Poland, which indicated overall increase in energy-related CO_2 emissions, mainly due to increases in CO_2 emissions in transport, industry, and agriculture, while households and services sectors showed some improvements. Economic growth was the main reason for the increase in emissions in both countries, although energy efficiency and green transition improved.

The largest emission reductions from fuel combustion were achieved in Ireland (-23.05%), Spain (-13.68%), Denmark (-13.27%), Germany (-13.27%), and Bulgaria (-13.01). All of these countries achieved significant reductions in CO_2 emissions in all sectors except transport, although the increase in transport-related CO_2 emissions was slightly moderate. The common trend for these countries is significant reductions in emissions intensity, indicating strong policies toward decarbonization and green transition, while for other countries that have not achieved overall CO_2 emissions reductions, energy intensity reductions have been the most important predominant factor.

Overall, CO_2 emissions from fuel combustion in the EU decreased by 172 Mt CO_2 from 2015 to 2019. This decrease was achieved through a decrease in energy intensity (- 212.02 $MtCO_2$) and emissions intensity (-211.56 $MtCO_2$). However, the impact of economic growth (229.62 $MtCO_2$) and population growth (22.28 $MtCO_2$) prevented a greater reduction in emissions.

3.3. Combined results of ESCI and LMDI decomposition

The cross-country comparison of the combined LMDI and ESCI results shows alarming results for countries that rank high in the composite index of energy sustainability but show no or negative progress in reducing CO_2 emissions from fuel combustion over the five-year period from 2015 to 2019. Such results were shown for Latvia and Austria, which ranked in Group I in the ESCI but showed an increase in emissions over the period.

Both countries have a much higher share of renewable energy resources compared to other countries, due to the initial hydropower plants that were installed in the past and therefore were initially among the countries with a higher share of renewable energy. The initial high position may have prevented a more active role in making additional investments and moving towards diversification of the existing power mix, for example through wind energy.

On the other hand, countries such as Ireland and Germany, which were initially ranked lower in the ESCI, have reported significant progress in decarbonization by

Table 3. Changes in CO_2 emissions (including electricity) by sectors.

	Cyprus	Lithuania	Hungary	Austria	Luxembourg	Latvia	Slovakia	Poland
Industry	-1.2%	-7.7%	11.0%	3.3%	-5.3%	-6.6%	2.8%	2.0%
Transport	11.2%	23.4%	19.5%	7.5%	7.9%	5.7%	5.4%	34.9%
Households	5.7%	-5.7%	-0.6%	-0.8%	-15.3%	-10.7%	-4.4%	-10.3%
Agriculture	2.7%	2.6%	12.8%	6.2%	-7.0%	17.7%	1.0%	13.7%
Services	9.6%	-26.5%	-12.8%	1.5%	21.6%	-15.1%	-1.8%	-10.3%
Total	7.27%	5.87%	4.98%	3.94%	3.94%	3.90%	2.13%	1.89%

reducing CO_2 emissions from fuel combustion. This suggests that countries that initially trailed behind in demonstrating a high proportion of renewable energy resources in their total energy balances may be more motivated and driven toward a more active transition away from fossil fuels and towards renewable energy. It may be simpler for these countries to identify regions where decarbonization activities will result in substantial emission reductions.

Countries that outperformed all others are Sweden and Denmark, which are among the most energy sustainable countries in both the ESCI and LMDI, with consistent reductions in CO_2 emissions from fossil fuels. However, the worst results were shown by Cyprus and Lithuania, which ranked exceedingly low in the initial sustainability of the energy sector compared to other EU countries and encountered an increase in CO_2 emissions from fuel combustion from 2015 to 2019.

4 Conclusions

The present research introduced an innovative methodological framework for evaluating and comparing the levels of energy sustainability across different countries, as well as tracking their advancements towards green transition. Energy sustainability composite index (ESCI) integrated six indicators characterizing energy sustainability components – energy import dependency, share of renewable energy sources, primary energy intensity, energy efficiency, CO_2 emission intensity, and energy poverty. The results showed different profiles of energy sustainability in the 27 EU member states. The results show that there is untapped potential for all countries to enhance energy sustainability, which is reflected in all the indicators assessed.

Log-Mean Divisia Index (LMDI) decomposition analysis investigated which of the four components influenced past CO2 emissions from fuel combustion in each country – changes in emission intensity, changes in energy intensity, changes in economic growth or changes in population growth. The results revealed that although majority of EU-27 countries showed progress in reducing energy-related CO_2 emissions during the period from 2015 to 2019, a group of countries indicated negative trend by increasing emissions. Transport sector was the most critical for almost all the countries which did not show CO_2 emission reductions and pushed overall energy-related CO_2 emissions to increase. The highest energy-related CO_2 emission cuts over the 5 year period were reported by Ireland and Spain.

Sweden and Denmark with ESCI scores of 0.79 and 0.74 respectively stand out in energy sustainability and are frontrunners whose measures could serve as benchmarks for other countries. Both countries show a high level of commitment and consistent movement towards a green transition and a sustainable energy sector, which is reflected not only in the assessment of the existing situation compared to other countries, but also in the emission reduction data of the last five years.

The results revealed that countries with a higher initial level of energy sustainability, which is largely attributable to the historical development of hydropower plants, made slower progress in decarbonizing their energy systems than countries with a lower initial level of decarbonization.

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References

1. B. Lennon, N. P. Dunphy, and E. Sanvicente, "Community acceptability and the energy transition: a citizens' perspective," *Energ Sustain Soc*, vol. 9, no. 1, p. 35, Dec. 2019, doi: 10.1186/s13705-019-0218-z.
2. European Commission, "COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS REPowerEU Plan (COM/2022/230 final)." 2022. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN
3. M. F. Rabbi, J. Popp, D. Máté, and S. Kovács, "Energy Security and Energy Transition to Achieve Carbon Neutrality," *Energies*, vol. 15, no. 21, p. 8126, Oct. 2022, doi: 10.3390/en15218126.
4. T. P. Wiśniewski, "Investigating Divergent Energy Policy Fundamentals: Warfare Assessment of Past Dependence on

Russian Energy Raw Materials in Europe," *Energies*, vol. 16, no. 4, p. 2019, Feb. 2023, doi: 10.3390/en16042019.

5. S. Somosi and E. Megyeri, "A Moving Target: Changing Priorities in the Energy Policy of the European Union," *IJEEP*, vol. 12, no. 4, pp. 542–552, Jul. 2022, doi: 10.32479/ijeep.13052.
6. A. Gatto and D. Panarello, "Misleading intentions? Questioning the effectiveness and biases of Eurobarometer data for energy sustainability, development and transition research," *Energy Research & Social Science*, vol. 93, p. 102813, Nov. 2022, doi: 10.1016/j.erss.2022.102813.
7. M. Ammari, M. Chentouf, M. Ammari, and L. Ben Allal, "Assessing National Progress in Achieving the Sustainable Development Goals: A Case Study of Morocco," *Sustainability*, vol. 14, no. 23, p. 15582, Nov. 2022, doi: 10.3390/su142315582.
8. J. Koh, T. Huh, and M. Ye, "Developing an index of sustainable development goals for local governments: the case of Gyeonggi province in korea," *Ecosyst Health Sustain*, vol. 7, no. 1, p. 1980437, Jan. 2021, doi: 10.1080/20964129.2021.1980437.
9. S. Cîrstea, C. Moldovan-Teselios, A. Cîrstea, A. Turcu, and C. Darab, "Evaluating Renewable Energy Sustainability by Composite Index," *Sustainability*, vol. 10, no. 3, p. 811, Mar. 2018, doi: 10.3390/su10030811.
10. V. Ş. Ediger, E. Hoşgör, A. N. Sürmeli, and H. Tatlıdil, "Fossil fuel sustainability index: An application of resource management," *Energy Policy*, vol. 35, no. 5, pp. 2969–2977, May 2007, doi: 10.1016/j.enpol.2006.10.011.
11. K. Dolge, A. Kubule, S. Rozakis, I. Gulbe, D. Blumberga, and O. Krievs, "Towards Industrial Energy Efficiency Index," Environmental *and Climate Technologies*, vol. 24, no. 1, pp. 419–430, Jan. 2020, doi: 10.2478/rtuect-2020-0025.
12. Eurostat, "Energy import dependency by products (NRG_IND_ID)." https://ec.europa.eu/eurostat/databrowser/view/SDG_07_50/default/table?lang=en (accessed Apr. 28, 2023).
13. Eurostat, "Share of renewable energy in gross final energy consumption by sector (NRG_IND_REN)." https://ec.europa.eu/eurostat/databrowser/view/SDG_07_40/default/table?lang=en (accessed Apr. 28, 2023).
14. Odysee Mure, "Primary energy intensity at purchasing power parities (ppp) with climatic corrections." https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html (accessed Apr. 28, 2023).
15. Odysee Mure, "Total final consumption with climatic corrections." https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html (accessed Apr. 28, 2023).
16. Eurostat, "Population on 1 January by age and sex (DEMO_PJAN)." https://ec.europa.eu/eurostat/databrowser/view/DEMO_PJAN/default/table?lang=en (accessed Apr. 28, 2023).
17. Odysee Mure, "Total CO2 emissions from fuel combustion activities." https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html (accessed Apr. 28, 2023).
18. Eurostat, "Population unable to keep home adequately warm by poverty status (ILC_MDES01)." https://ec.europa.eu/eurostat/databrowser/view/SDG_07_60/default/table?lang=en (accessed Apr. 28, 2023).
19. M. M. Hasan and W. Chongbo, "Estimating energy-related CO2 emission growth in Bangladesh: The LMDI decomposition method approach," *Energy Strategy Reviews*, vol. 32, p. 100565, Nov. 2020, doi: 10.1016/j.esr.2020.100565.
20. V. Miskinis, A. Galinis, V. Bobinaite, I. Konstantinaviciute, and E. Neniskis, "Impact of Key Drivers on Energy Intensity and GHG Emissions in Manufacturing in the Baltic States," *Sustainability*, vol. 15, no. 4, p. 3330, Feb. 2023, doi: 10.3390/su15043330.
21. Eurostat, "Complete energy balances (NRG_BAL_C)." https://ec.europa.eu/eurostat/databrowser/view/NRG_BAL_C/default/table?lang=en (accessed Apr. 28, 2023).
22. Eurostat, "GDP and main components (output, expenditure and income) (NAMA_10_GDP)." https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_GDP/default/table?lang=en (accessed Apr. 28, 2023).
23. C. Huang, Y.-J. Zhou, and J.-H. Cheng, "Research on Energy-Related CO2 Emissions Characteristics, Decoupling Relationship and LMDI Factor Decomposition in Qinghai," *Front. Energy Res.*, vol. 9, p. 700385, Dec. 2021, doi: 10.3389/fenrg.2021.700385.
24. L. Ma et *al.*, "LMDI Decomposition of Energy-Related CO2 Emissions Based on Energy and CO2 Allocation Sankey Diagrams: The Method and an Application to China," *Sustainability*, vol. 10, no. 2, p. 344, Jan. 2018, doi: 10.3390/su10020344.