Navigating Between Environmental and Social Sustainability: Different Paths of EU Electricity Production Transformation and Their Impact on Household Consumers Electricity Prices

DOI
https://doi.org/10.18690/um.epf.7.2026.51

ISBN
978-961-299-166-1

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The phase-out of asbestos in urban environments represents a complex challenge across European municipalities. Despite European Union targets to achieve asbestos-free cities, implementation remains uneven because municipalities face fragmented regulations, differing inspection and disclosure requirements, limited funding, technical constraints, and variable public awareness. The paper identifies key barriers, including regulatory heterogeneity, inadequate disposal infrastructure, financing gaps, and institutional coordination challenges, alongside enabling factors such as harmonized policies, innovative treatment technologies, capacity-building programs, community engagement, and transparent governance. Based on these insights, a typology of municipal transition pathways is developed, including compliance-driven, retrofit-integrated, innovation-led, community-driven, and market-based approaches. The findings underline equity considerations, emphasizing the need to prevent disadvantaged communities from remaining disproportionately exposed to asbestos hazards. By framing asbestos removal as a material legacy transition within broader urban sustainability transitions, the paper contributes to theoretical understanding of socio-technical and ecosystem dynamics while offering practical guidance for policymakers, urban planners, and other stakeholders seeking resilient, equitable, and sustainable asbestos-free municipalities across Europe. It also highlights the importance of integrated governance, long-term financing, systematic monitoring, knowledge sharing between municipalities, stakeholder collaboration, regulatory consistency, public communication, workforce training, and continuous policy learning to accelerate safe, effective, scalable implementation across diverse European regions sustainably.

Keywords:
renewable energy,
energy markets,
energy economics,
sustainable electricity production,
household electricity prices

University of Maribor Press

1 Introduction

Modern society is fundamentally dependent on electricity, with a trend accelerated by the proliferation of digital devices, automated systems, and smart technologies that enhance comfort and efficiency for people and industrial entities. This dependence ranges from automated home management (such as lighting and climate control) to large-scale societal changes like the adoption of electric vehicles. Globally, there was a 2.66-fold increase in global electricity consumption from 10,243 TWh to 27,246 TWh over the period from 1990 to 2024, and it is expected to rise to 64,513 TWh by 2050, reflecting an estimated annual growth rate of 3% (Gvozdenac et al., 2025). This increase is primarily attributed to steady economic growth, high demand from industry due to the ongoing shift towards greater automation, digitalisation, rising electric vehicle charging, use of artificial intelligence (AI), and consequently new data centres and increased cooling needs to run AI (Enerdata, 2025). Vries (Vries, 2023) asserts that Google search utilises 10 times less energy than ChatGPT search and 13.8 times less energy than Bloom search.

As global electricity demand increases, new, more efficient, and sustainable technologies need to be implemented. Sustainable electricity entails generating power in an environmentally responsible way, minimizing environmental impact, and addressing long-term resource availability (Electric, 2023). Renewable energy sources, including wind, solar, geothermal, hydropower, bioenergy and tidal energy, are categorised as sustainable and environmentally acceptable technologies (IEA, 2025).

The European Commission has systematically changed and tightened energy policy with the primary goal of reducing greenhouse gas (GHG) emissions. This supports European Green Deal commitments to reduce GHG emissions by at least 55% by 2030 and become climate neutral by 2050 (European Commission, 2019). In 2007, the European Union (EU) set three key targets for 2020: (a) a 20% cut in GHG emissions compared to 1990 levels; (b) a 20% increase in EU renewable energy; and (c) a 20% improvement in energy efficiency (European Commission, 2009). The Renewable Energy Directive (European Commission, 2009) and REPowerEU Plan (European Commission, 2022) were developed to achieve an affordable and environmentally acceptable EU energy supply. Current targets include a 11.7% reduction in final energy consumption by 2030 relative to the 2020 projection (European Commission, 2025) and increasing the share of renewables in the energy mix to at least 42.5% by 2030 (European Commission, 2023a). Policy efficiency and sustainability outcomes are strengthened by integrated policy design rather than fragmented programs, which result in high costs and duplication of efforts (Colombo, 2025).

EU countries are implementing different approaches to achieve those EU targets, and their levels of success vary significantly. Therefore, this study provides an overview of different approaches across EU countries and evaluates their success in the transition toward sustainable electricity production.

2 Literature review

In the literature, the energy sector is widely examined from different points of view. Many studies have focused on countries' natural resource endowments and the availability of renewable sources. Bessin et al. (Bessin et al., 2025) examined the potential for implementation of specific technologies in the EU and highlighted that the countries with the highest wind turbine potential include Denmark, Ireland, the Netherlands, Belgium, northern Germany and France. Areas with significant potential for solar photovoltaic have been identified in the Netherlands, Germany, flat regions in Italy, southern and central Spain, Poland, the Czech Republic, and Hungary. However, considerable variation remains among countries, due to the uneven distribution of renewable resources, which depends heavily on a country's geographical location and natural resources.

Studies have also focused on the environmental perspective of electricity production evaluating the correlation between the adoption of renewable energy sources and the mitigation of GHG emissions. For example, Bilan et al. (Bilan et al., 2019), examined the interrelationship between GDP, renewable energy, and emissions, concluding that economic growth is associated with increased energy consumption from renewables. Contrastingly, Gao et al. (Gao et al., 2026) indicate that a high reliance on natural resources significantly undermines the financial sustainability in the long term, which confirms the resource curse theory. Moreover, producing energy only from the renewable sources until 2050 is not realistic, while renewable electricity could contribute only up to 44% of Europe's primary energy consumption mix by 2050 under the most ambitious policy scenarios (Salim et al., 2026).

While some of the scientific papers are mainly related to economic factors and the growth and share of electricity produced from renewable sources, others focus more on the environmental impacts associated with energy from renewable sources. Fajdetić and Festić (Fajdetić & Festić, 2022), studied the role of solar energy and solar systems in reducing GHG emissions in the EU for the period from 2010 to 2020, concluding that solar energy has a statistically significant impact on GHG emissions reduction. Schürmann (Schürmann, 2024) examined the correlation between reference market selection for real-time electricity tariffs and the emissions associated with electricity procurement. He concluded that there is no advantage in associated carbon emissions for the intraday market over the day-ahead market, even when carbon intensity is factored into the optimisation. While other authors focused on energy in general, Rybaczewska-Błażejowska and Jezierski (Rybaczewska-Błażejowska & Jezierski, 2024) focused only on electricity and conducted life cycle assessment of the environmental impacts caused by different electricity mixes, analysing the electricity consumption mixes of EU countries and highlighting the importance of selecting the right life cycle impact assessment (LCIA) method.

Based on the literature review, the authors mostly evaluated only one aspect of sustainability and are focused on the energy sector rather than electricity specifically.

In addition to the aforementioned parameters, energy source dependency and security must be considered as strategic aspects of the energy sector. Muhammad et al. (Muhammad et al., 2025) found that energy diversity and energy dependency risk contribute significantly to electricity prices, while geopolitical risk shows no significant direct effect. However, the interaction between energy dependency and geopolitical risk was found to increase electricity prices (Muhammad et al., 2025).

This study evaluates electricity production in EU countries from environmental and economic point of view. It examines the interrelationship between the share of renewables in the electricity production mix and household electricity prices, especially if a higher share of renewable electricity decreases the household electricity prices as foresighted by EU. Additionally, since specific empirical studies, which quantify the extent to which the transition to renewable electricity has succeeded in reducing GHG emissions and total environmental impacts, this study provides an analysis of environmental performance for national electricity mixes from 2003 to 2023.

3 Methodology

3.1 Eu countries efficiency assessment

In the assessment of efficiency regarding the EU Commission goals to achieve climate neutrality by 2050, a two-decade period was considered to determine the trend of replacing fossil-based electricity production technologies with renewable ones. The study focusses solely on EU countries where data on electricity production by specific technology are available for the period from 2003 to 2023. The year 2023 was selected as the end year, as data for 2024 and 2025 are currently unavailable. The electricity production data are based on the IRENA database, a leading intergovernmental agency for energy transformation that serves as the principal platform for international cooperation, supports countries in their energy transitions, and provides state of the art data and analyses on technology, innovation, policy, finance and investment (IRENA, 2025a). Electricity generation data from the IRENA database (originally in GWh) were converted into percentage shares (%) to reflect the specific technology mix analysed in this study. Shares of renewable sources in the electricity production mix were calculated using Equation 1.

$$s_i = \frac{E_i}{\sum_{i=1}^{n} E_i} \cdot 100 \tag{1}$$

Where:

i – electricity production technology [/]
s_i – share of produced electricity with specific technology i [%]
n – number of all electricity production technologies [/]
E_i – amount of produced electricity with specific production technology i [GWh]

3.2 EU countries economic data acqusition

The data on household electricity prices were obtained from two Eurostat databases. The first database contains bi-annual data up to 2007 (Eurostat, 2021), and the second database contains bi-annual data from 2007 onwards (Eurostat, 2025). This study incorporates electricity prices excluding and including taxes and levies, separately, thereby providing a clearer perspective on how a countries' taxation and incentives influence the final household electricity prices.

3.3 Life cycle assessment (LCA)

The environmental performance of electricity mixes was calculated using the LCA method, with a special focus on global warming impacts and total environmental impacts. The LCAs were performed in accordance with the international standards ISO 14040 (*ISO 14040*, 2006) and ISO 14044 (*ISO 14044*, 2020).

The goal and scope:

The goal of this study was to quantify the total environmental and global warming impacts of specific national electricity mixes. For this purpose, a cradle-to-gate life cycle assessment was conducted. The environmental part of the study evaluated Slovenia alongside the four EU countries demonstrating the highest growth in renewable electricity generation (Denmark, Germany, Lithuania, and the Netherlands). Environmental impacts were assessed annually for each country over the period from 2003 to 2023. The functional unit was defined as 1 MJ of electricity produced using a specific mix of technologies.

Life cycle inventory analysis (LCI):

Data collection was based on available electricity generation shares by technology from the International Renewable Energy Agency (IRENA) database (IRENA, 2025b). Secondary background data were sourced from Ecoinvent 3.11 database (Ecoinvent Association, 2023), which encompasses more than 26.000 peer-reviewed datasets. This database was selected for its country-specific datasets, enabling comprehensive environmental reporting and sustainable decision-making.

Life cycle impact assessment (LCIA) phase:

To characterise the environmental impact profile of the national electricity mixes, two LCIA methods were used. Global warming impact category was quantified using ReCiPe 2016 Midpoint from hierarchist perspective (H), whereas the total environmental impact was calculated using ReCiPe 2016 Endpoint (H). Although the ReCiPe 2016 Endpoint (H) method also supports global warming calculations, the ReCiPe 2016 Midpoint (H) method was selected to ensure results expressed in kg CO_2 eq rather than in Ecopoints (Pt). The assessment was conducted in SimaPro software (version 10.2.0.3 Analyst).

The life cycle results interpretation:

The LCA results were collected and analysed for the five selected EU countries (Denmark, Germany, Lithuania, the Netherlands and Slovenia) over the same time frame and electricity output capacity. These results are discussed regarding both global warming and total environmental impacts (Figure 3).

3.4 Pearson correlation coefficient

Considering only the growth of renewable electricity and its associated environmental mitigation does not provide the full socio-economic complexity of the electricity transition. From a consumer standpoint, price remains a primary determinant in decision-making; consequently, this assessment also integrates economic indicators alongside environmental ones. Specifically, the relationship between the share of renewable electricity and household electricity prices was evaluated to determine whether a correlation exists. It is imperative to acknowledge that a correlation expressed by Pearson's coefficient does not inherently imply a causal relationship; consequently, the interpretation of results should be conducted with caution.

For the EU member states, the strength of the relationship between household electricity prices excluding taxes and levies; and the share of electricity generated from renewable sources was analysed using the Pearson correlation coefficient. While the first calculation of Pearson correlation coefficient excludes taxes and levies, additional calculation was conducted using household electricity prices including taxes and levies, to evaluate the impact of taxes and levies on the Pearson correlation coefficient values. While the price does not depend only on taxes and levies, it can also be influenced by other national measures such as subsidies and social transfer mixes, meaning the Pearson correlation coefficient results cannot be used as the definitive and sole interpretation of the connection between household electricity prices and the share of renewable electricity in the national mix.

The Pearson correlation coefficient was calculated for each country using annual data on household electricity prices (in € per kWh) and data regarding shares of renewable sources in electricity production mix (in percentage) for the period from 2003 to 2023. The calculation employed the standard computational formula for Pearson correlation coefficient as shown in Equation 2 (Lane et al., 2018).

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (2)$$

Where:

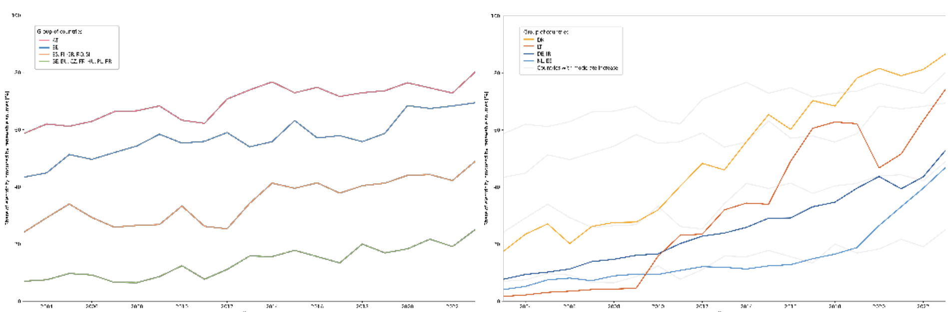
r – Pearson correlation coefficient
x – household electricity price excluding taxes and levies or household electricity price including tax and levies
y – share of electricity produced from renewable sources

The analysed countries were aggregated into seven distinct groups based on comparable trends in the growth of renewable electricity. For each individual country, a specific Pearson correlation coefficient was first calculated and further averaged within each group of countries.

4 Result and discussion

4.1 Trends of electricity production from renewable sources in eu countries

Under the REPowerEU Plan , EU Member States are required to increase the share of renewables sources in their energy mixes to binding target of at least 42.5% by 2030 (European Commission, 2023a), and to achieve climate neutrality by 2050 (European Commission, 2019). To evaluate national progress toward these EU goals, this study analyses renewable electricity production trend from 2003 to 2023. Based on the national data, EU countries can be categorised into two distinct groups: (a) countries with a moderate (linear regression curves with comparable slopes) increase of electricity production from renewable sources in the national electricity production mix (Figure 1a) and (b) countries with a significant (non-linear shape) increase of electricity production from renewable sources in the national electricity production mix (Figure 1b). If the countries could be described with both the linear regression curves, the slopes would be greater than those for the group of countries with moderate increase. Additionally, the countries with a moderate increase were divided into four groups, where the countries with a similar starting and ending share of renewables in the electricity mix were combined. On Figure 1a only the most representative country from each group of countries is presented.



(a) (b)

Figure 1: Comparison of electricity integration from renewable sources in the national electricity mix (2003 – 2023): (a) countries with a moderate progress, (b) countries with a significant increase in renewable electricity integration.

Source: Based on International Renewable Energy Agency (IRENA) database (IRENA, 2025b).

Most of the EU countries took a moderate approach, characterised by a steady, incremental increase in the share of renewables in their electricity mixes. As illustrated in Figure 1a, the four groups of countries have a similar growth pattern, with a linear regression curve slope of approximately one, despite variations in their initial baseline shares of renewables in the electricity mixes. On average, these countries increased production of renewable electricity by 27.28 percentage point (p.p.) over the two-decade period.

Certain countries were even more effective and responsive in implementing the EU's long-term strategy to reach 45% share of energy from renewable sources in the EU's gross final energy consumption by 2030, as outlined in the Renewable Energy Directive (RED) (European Commission, 2023a). Lithuania (72.5 p.p.), Denmark (69.1 p.p.), Germany (45.1 p.p.) and the Netherlands (42.7 p.p.) have increased their production of renewable electricity most significantly (Figure 1b). Two distinct growth patterns are evident among these four nations: (a) a consistently high increase in electricity from renewables with a regression slope of approximately 3.8, for Denmark and Lithuania, and (b) an initial moderate phase followed by accelerated growth in the second decade, resulting in a regression slope of approximately 1.7, as seen in Germany and the Netherlands. These four countries were selected for an in-depth analysis due to their demonstrated leadership in the transition from non-renewable to renewable electricity generation within the study of EU member states.

Over the past two decades, Denmark, for example, has reduced its share of fossil fuels in its electricity production mix by 69.1 p.p. (Figure 2), while significantly increasing the contributions of wind (45.5 p.p.), bioenergy (13.7 p.p.), and solar (10.0 p.p.). This rapid transition has been driven by ambitious national goals to achieve 100% renewable energy supply by 2050 (Hvelplund & Djørup, 2017). Denmark has focused primarily on expanding its wind energy infrastructure, with a strategic goal to increase offshore wind capacity sevenfold by 2030 (International Energy Agency, 2023). This commitment persists despite research by Ryu and Sovacool (Ryu & Sovacool, 2025), which indicated that cost overruns for offshore wind facilities are increasing annually, in contrast to decreasing overruns for onshore wind facilities. Research by Lund et al. (Lund et al., 2022) concludes that the Denmark's ambitious national targets are achievable within the constraints of its global share of biomass resources, by structural transformation of the energy sector from centralised systems to a decentralised structures owned by municipals or cooperatives (Pinson et al., 2017).

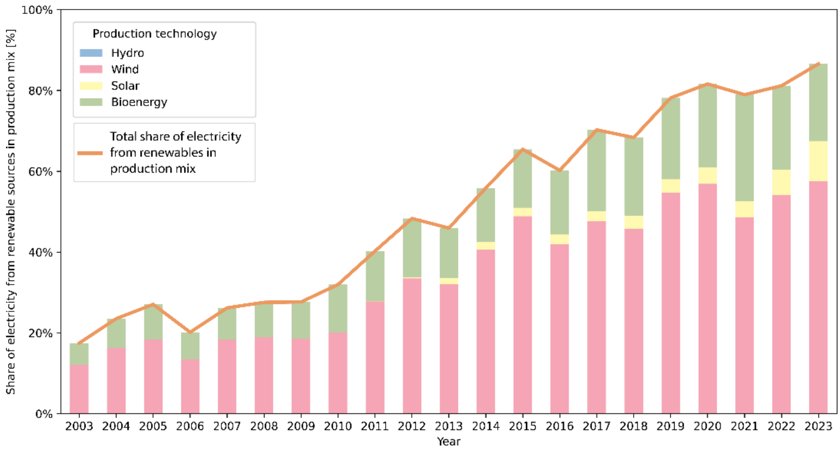


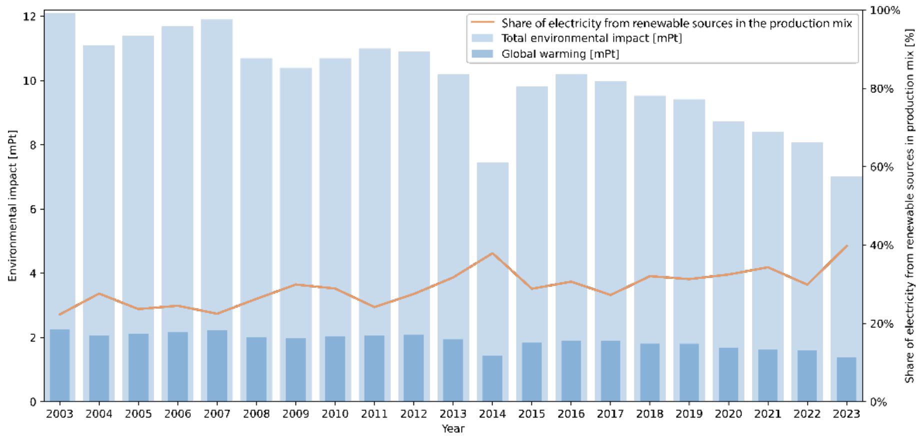
Figure 2: Share of electricity from renewable sources within the Danish electricity mix (2003 – 2023), disaggregated by production technology.

Source: Based on International Renewable Energy Agency (IRENA) database (IRENA, 2025b).

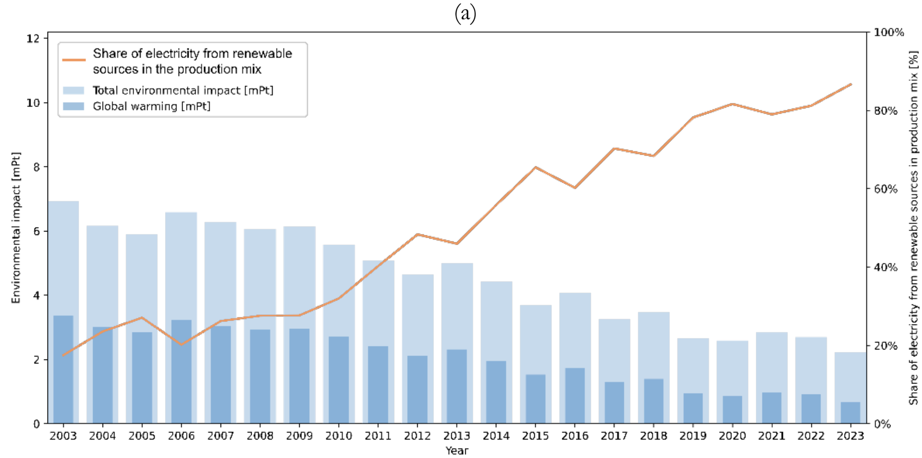
4.2 Environmental impacts of national electricity production mixes

While EU Member States have successfully reduced their dependency on non-renewable energy technologies, this trend does not inherently reflect a decrease in environmental impacts. To meet the European Green Deal commitments, EU countries must adhere to established GHG reduction targets and achieve climate neutrality by 2050 (European Commission, 2019). Consequently, the environmental impacts associated with the electricity production for Slovenia and countries with the highest growth in renewable electricity (Denmark, Germany, Lithuania and the Netherlands) for the period from 2003 to 2023 were considered.

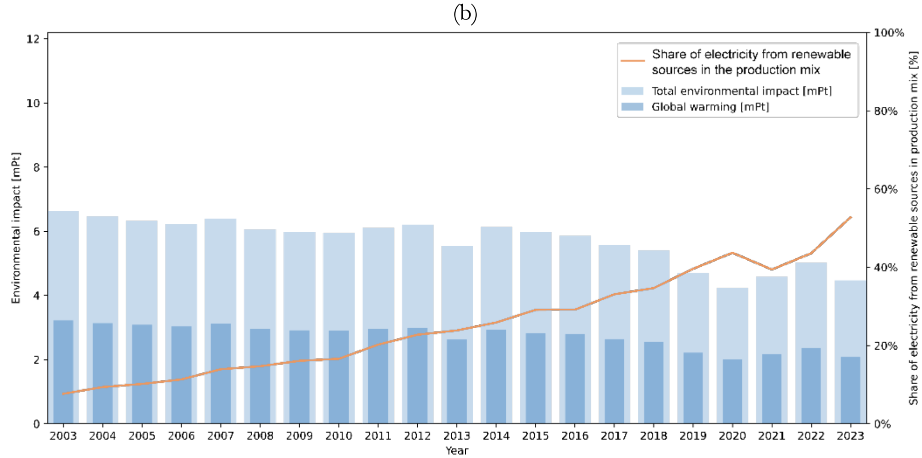
The environmental burdens per 1 MJ of generated electricity were quantified for each year from 2003 to 2023 employing the ReCiPe 2016 Endpoint (H) method. Only the global warming impact category, which provides information on GHG emissions, and the total environmental impact were considered and compared against the share of renewable electricity in selected countries.


Share of electricity from renewable sources in the production mix
Total environmental impact [mPt]
Global warming [mPt]
Environmental impact [mPt]
Share of electricity from renewable sources in production mix [%]
Year

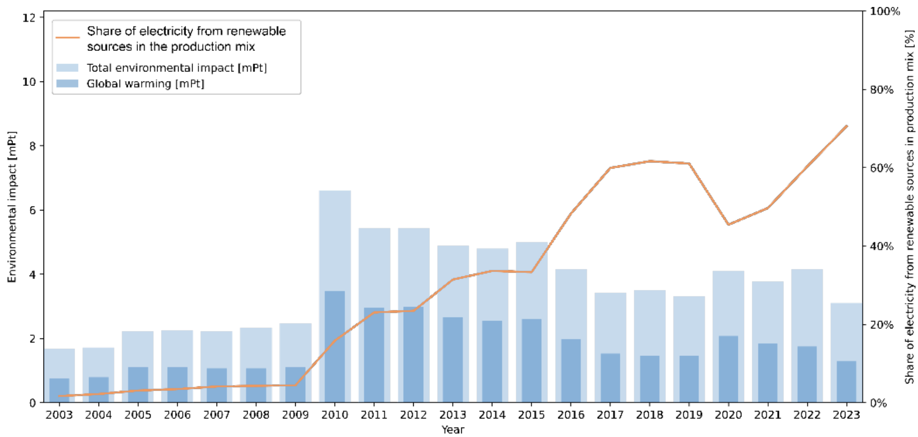
(a)


Share of electricity from renewable sources in the production mix
Total environmental impact [mPt]
Global warming [mPt]
Environmental impact [mPt]
Share of electricity from renewable sources in production mix [%]
Year

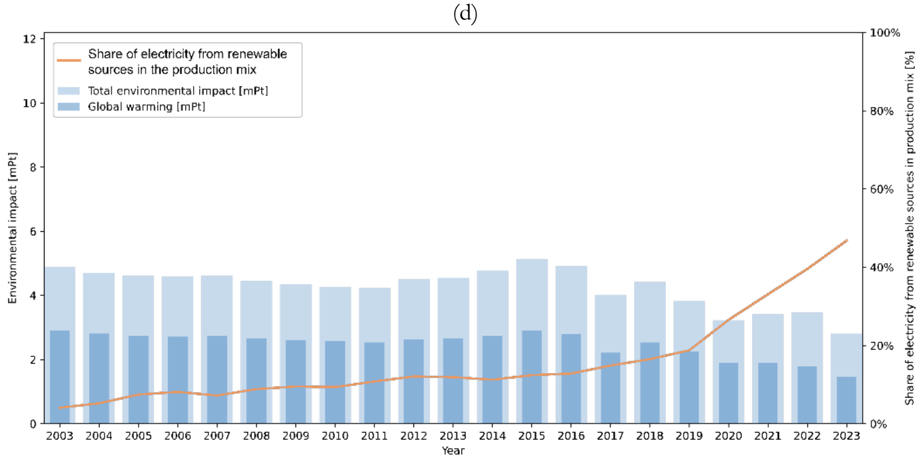
(b)


Share of electricity from renewable sources in the production mix
Total environmental impact [mPt]
Global warming [mPt]
Environmental impact [mPt]
Share of electricity from renewable sources in production mix [%]
Year

(c)



(d)



(e)

Figure 3: Share of electricity from renewable sources (orange) and environmental impacts of electricity mix (2003 – 2023), based on the ReCiPe 2016 Endpoint (H) method. Global warming impact category (dark blue) and total environmental impact (light blue) are expressed in ecopoints [Pt] for: (a) Slovenia, (b) Denmark, (c) Germany, (d) Lithuania and (e) Netherlands.

Source: Share of renewable electricity based on International Renewable Energy Agency (IRENA) database (IRENA, 2025b), while environmental impact are based on the calculations using SimaPro software (Pré Sustainability, 2024).

Figures from Figure 3a to Figure 3e present the correlation between the share of electricity from renewable sources in electricity production mix and environmental performance, with light blue presenting total environmental impact and dark blue indicating global warming impact category.

Among all evaluated countries, the Slovenian electricity mixes have the highest environmental impacts and the largest differences between total environmental and global warming impacts (Figure 3a). This indicates that the technologies used in Slovenia exert a greater influence on the impact categories such as particulate matter and ionizing radiation, rather than on global warming. While global warming accounts for majority share of the total environmental impact in all other evaluated countries, its contribution in Slovenia is limited to approximately 20% of total environmental impact.

Despite the marginal growth in renewable electricity share from 22.3% to 39.7% (17.4 p.p. in total) depicted in Figure 3a, Slovenia managed to decrease absolute values of the total environmental impact caused by its electricity production mix the most. Specifically, over the period from 2003 to 2023 the total environmental impact has decreased from 12.10 mPt to 7.02 mPt per MJ of produced electricity (for 5.08 mPt per MJ). In comparison, Denmark decreased its total environmental impact from 6.93 mPt to 2.22 mPt per MJ (for 4.71 mPt per MJ), Germany from 6.63 mPt to 4.47 mPt per MJ (for 2.16 mPt per MJ) and the Netherlands from 4.89 mPt to 2.81 mPt per MJ (for 1.43 mPt per MJ). The only exception is Lithuania, where the total environmental impact increased from 1.68 mPt to 3.11 mPt per MJ (for 1.43 mPt per MJ) with the implementation of renewable electricity.

Regarding the reduction of global warming impacts, Denmark was the most successful country with the reduction from 3.38 mPt per MJ to 0.67 mPt per MJ (equal to 0.167 kg CO_2 eq per MJ of produced electricity mix). Decrease was also recorded in the Netherlands where global warming impacts have decreased from 2.90 mPt to 1.47 mPt (equal to 0.088 kg CO_2 eq), in Germany from 3.22 mPt to 2.08 mPt (equal to 0.071 kg CO_2 eq) and in Slovenia from 2.26 mPt to 1.37 mPt (equal to 0.054 kg CO_2 eq). Conversely, Lithuania increased its impact on global warming from 0.76 mPt to 1.29 mPt (equal to 0.033kg CO_2 eq).

Lithuania recorded the largest increase in its share of renewable electricity (by 72.5 p.p.), leading to significant increase of both overall environmental impact as well as global warming. The most notable change occurred in 2010 by a transition from nuclear power to mostly fossil fuels, which are less environmentally acceptable, and partially with the renewable sources (IRENA, 2025b). However, from 2010 onward, Lithuania began reducing its reliance on fossil fuels by mostly replacing them with wind energy, resulting in significant increase in the renewable electricity share and decrease in environmental impacts. Despite the upward trend in renewable energy integration in Lithuania's electricity mix, renewable energy share declined substantially in 2020. Unstable hydrological conditions necessitated a compensatory reliance on fossil fuels, with the deficit primarily addressed through natural gas- fired power generation (IEA, 2021).

4.3 Correlation between household electricity price and share of renewable sources in electricity production mixes

Evaluating whether an increase in renewable electricity is sustainable cannot be based solely on numerical values for shares of produced electricity from renewables, which are generally associated with a lower price, nor on the environmental pillar of sustainability. Additionally, from an economic perspective more economic indicators need to be considered, specifically how the transition in production technologies affects the final consumer. By addressing these two pillars of sustainability, a more comprehensive assessment can be made of weather an increase in renewable electricity is truly more sustainable.

In this study, the economic pillar of sustainability was based on household electricity prices with and without taxes and levies. Two types of household electricity prices were considered to gain a better view of how a country's subsidies and taxation influence the electricity price.

Figure 4 presents household electricity prices in Denmark for the period from 2003 to 2023, where blue dots show the prices without tax and levies, while orange dots show the prices with tax and levies.

Household electricity prices, both with and without tax and levies, differed over the period from 2003 to 2023, with major changes in 2008 and 2022. In 2008, Phase II of the EU Emissions Trading System (ETS) began, with the EU setting a cap on carbon emissions and allowing the trading of emissions allowances (Dormady & Englander, 2016). Since then, countries have systematically incorporated carbon prices into wholesale electricity prices, effectively shifting the financial burden onto end consumers (Freitas & Silva, 2015), who ultimately pay the price for carbon emissions despite having no direct control over the electricity mix. Ahmada and Kirat (Ahamada & Kirat, 2015) further confirmed that Phase II of the EU ETS had an impact on the power-generation sector in France and Germany, leading to much higher household electricity prices.

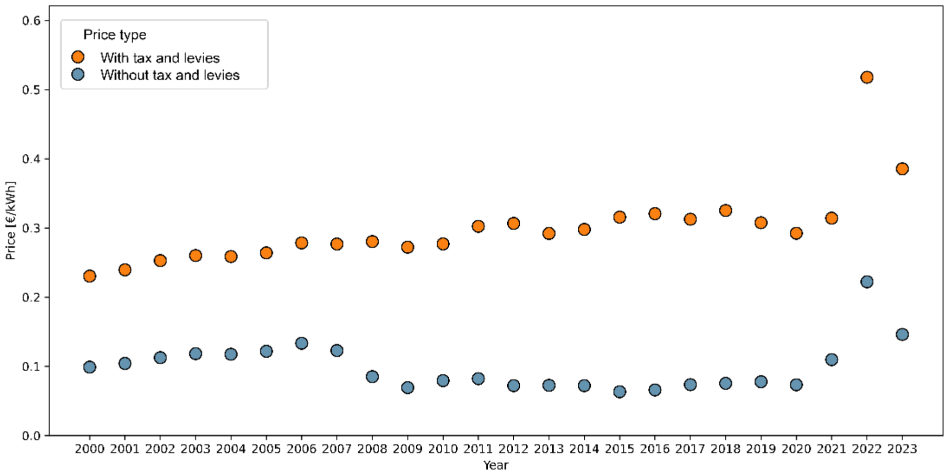


Figure 4: Evolution of Danish household electricity prices (2003 – 2023) with (orange) and without (blue) tax and levies.

Source: Based on Eurostat database (Eurostat, 2021; Eurostat, 2025).

In 2022 an energy crisis led to an unprecedented spike in EU electricity prices, as record-high natural gas prices and major cuts in Russian pipeline supply (Goldthau & Youngs, 2023) pushed wholesale power benchmarks in the third quarter of 2022 to around 339 € per MWh (European Commission, 2023b). To mitigate the socio-economic impact, several EU countries such as Belgium, Finland, Germany, Lithuania and the Netherland implemented temporary reduction in electricity taxes and levies, while Austria, France, Hungary, Spain, and Slovenia set the electricity price cap (Arregui, 2022; Galgóczi, 2023), to shield households from the full extent of the market volatility.

Household electricity pricing is not only contingent upon annual inflation and country regulatory frameworks but is also driven by the cost-efficiency of the electricity generation technologies. Figure 5 presents Danish household electricity prices with (orange) and without (blue) tax and levies in correlation with the share of electricity from renewable sources in the Danish electricity mix.

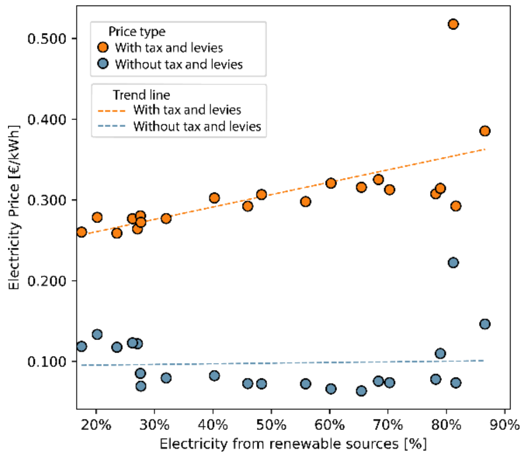


Figure 5: Correlation between Danish household electricity price and share of electricity from renewable sources in Danish electricity mix (2003 – 2023). Orange marks present prices with tax and levies, while blue marks present prices without tax and levies, with corresponding regression lines (dashed lines).

Source: Electricity prices are based on Eurostat database (Eurostat, 2021; Eurostat, 2025), while share of electricity from renewable sources is based on International Renewable Energy Agency (IRENA) database (IRENA, 2025b).

In Denmark, household electricity prices generally decreased as the share of renewable electricity increased, consistent with current Levelized Cost of Energy (LCOE). According to Lazard's analysis (Lazard, 2025), renewable generation remains more cost-competitive than conventional generation; utility-scale solar photovoltaic (38–78 $ per MWh) and onshore wind (37–86 $ per MWh), significantly undercut coal-based generation (71–173 $ per MWh). While household prices, excluding tax and levies, remain largely stagnant or diminish with renewable electricity growth, household electricity prices including tax and levies show positive correlation (slope = 0.153). These differences can be attributed to the implementation of green taxes and carbon pricing mechanisms. Furthermore, Oyewole and Thopil (Oyewole & Thopil, 2025) investigated industrial electricity markets of 22 countries from the Organisation for Economic Co-operation and Development (OECD), determining that the expansion of renewable electricity exerts negligible influence on pricing, while taxation represents the most significant factor contributing to the increase in industrial electricity prices.

To evaluate variations in correlation coefficients, the average correlation between electricity prices and the growth of renewable electricity was calculated for seven group of countries. For each individual country, a specific Pearson correlation coefficient was first calculated and further averaged within each group of countries. Groups 1-4 represent countries with a moderate increase in renewable electricity, while groups 5, 6, and 7 include countries with high increase of renewable electricity. Lithuania was excluded from this part of the study because the correlation coefficient could not be calculated for the same period due to insufficient data on household electricity prices. In Figure 6, two average correlation coefficients are presented for each group: one including tax and levies (green) and one excluding tax and levies (orange). The blue bars indicate the average share of electricity produced from renewable sources for the years 2003, 2013, and 2023, while a grey dashed line indicates the zero-correlation threshold.

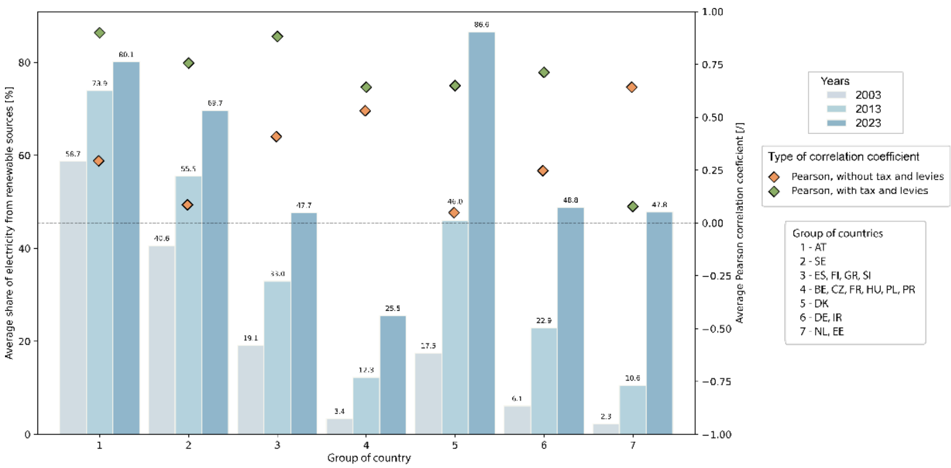


Figure 6: Mean Pearson correlation coefficient (*r*) for household electricity price and share of electricity produced from renewable sources in the electricity production mix for groups of countries (2003 – 2023).

Source: Electricity prices are based on Eurostat database (Eurostat, 2021; Eurostat, 2025), while share of electricity from renewable sources is based on International Renewable Energy Agency (IRENA) database (IRENA, 2025b).

Figure 6 illustrates that Pearson correlation coefficients do not follow a uniform trend across the studied countries. All the evaluated groups of countries exhibit a positive correlation coefficient. Low correlation is evident for Sweden (2) and Denmark (5) when comparing renewable electricity to prices excluding tax and levies. Most countries exhibit higher correlation when tax and levies are included in the electricity price, except the Netherlands and Estonia (7). Additionally, the smallest discrepancies between the two price types are found in Group 4, while the highest difference is found in Sweden (2).

Based on Figure 6 it cannot be concluded that a simple correlation exists between price and the share of renewable electricity in the national electricity mix. Many other factors such as national fundings, vouchers, social welfare policies, and carbon taxes influence final electricity prices (Rosenow et al., 2023). Consequently, electricity costs are driven by complex fiscal policies and levies rather than being exclusively dictated by generation technology or environmental externalities (George et al., 2024).

5 Conclusion

In this study, electricity generation mixes for selected EU countries were analysed for the period from 2003 to 2023. EU countries have adopted different strategies in their electricity production systems to align with the EU Green Deal commitments and mitigate climate change. Based on these national strategies and increase in production of renewable electricity in national electricity production mixes, countries can be categorised into eight different groups: four with a moderate renewable electricity growth and four with a more accelerated growth (Denmark, Germany, Lithuania and the Netherlands).

The study revealed that increasing the share of renewable energy sources in the national electricity production mix does not guarantee the reduction in environmental burdens, while the environmental impacts are highly related with the selection of electricity production technologies (hydro, wind, solar, geothermal, fossil based, nuclear, etc). Moreover, focusing only on GHG emission reductions through global warming impacts can lead to false conclusions, as the global warming impact category is not necessarily the most influential one. In the case of Slovenia, it is crucial to reduce other environmental impacts in the energy sector, as these contribute more significantly to total environmental impacts than global warming impacts, which are emphasized by the EU Renewable Energy Directive.

Additionally, the relationship between household electricity prices (excluding and including taxes and levies) and the share of electricity generated from renewable sources was analysed for EU countries, using the Pearson correlation coefficient, resulting in no uniform trend across the studied countries. A higher share of electricity produced from renewable sources does not ensure that such electricity will have lower costs for households, therefore consumers might not benefit from higher shares of electricity produced from renewables.

The transition to renewable energy sources is not solely a matter of increasing their share in the generation mix, but also involves the design of market structures, investments in grid infrastructure, regulatory frameworks, and fiscal policy. It is consequently challenging to make a straightforward comparison between the prices in correlation with the share of renewables in the electricity production mix across all EU member states. Planning one aspect of sustainability is difficult enough, while planning sustainable business operations is an even more demanding task.

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