Assessment of environmental tax and green bonds impacts on energy efficiency in the European Union

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Abstract
Owing to the increased greenhouse gas emissions and threat of environmental pollution, scholars have drawn attention to the issue of energy efficiency in recent decades. One of the main practical policies related to energy efficiency is deploying green tax and green financing tools. The main purpose of this paper is to analyze the impacts of issued green bonds and environmental taxes on energy efficiency in the 27 European Union (EU) member states from 2010 to 2021. The major results confirm that green bonds accelerate the process of improvement of the level of energy efficiency in EU members. In the EU, environmental taxation is an efficient fiscal policy to encourage enterprises to conduct different policies and projects to improve their energy efficiency levels. In addition, a 1% increase in the gross domestic product leads to an increase in energy efficiency of the EU by nearly 0.39%. The recommended practical policies are promoting the green bond market through more transparency and marketing among private investors, paying attention to the concept of green economic recovery, and issuing digital green bonds (DGBs).

Keywords  Green bonds · Green fiscal policy · European Union · Energy efficiency

JEL Classification  N10 · O14 · O23 · C14

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1 Introduction

Energy efficiency has become an essential concept in the energy economics literature. The simple meaning of energy efficiency is using less energy input to produce goods and services. Petterson (1996), Ning et al. (2022), and Bianco and Marmori (2022) defined energy efficiency as a wide range of policies to increase energy efficiency in the process of commodities production. Popkova and Sergi (2021) argued that energy efficiency had become a multifaceted and complex concept in recent decades, and countries should understand the different aspects of this concept with deep research. During recent decades, the challenges of lack of capital to invest in the field of energy efficiency, inefficient policies of the government in the field of supporting energy efficiency projects, the spread of COVID-19, severe fluctuations in global oil prices, etc., have caused the slow movement of improving energy efficiency in different countries (Rasoulinezhad and Taghizadeh-Hesary 2022; Phung et al. 2022). Bergman and Foxon (2020) expressed that despite the desire of countries to improve energy efficiency indicators, this issue has become challenging and complex. According to the Energy Efficiency Report 2021 (IEA), the energy efficiency index has experienced a 2.3% improvement between 2011 and 2016. Since 2016, due to various global problems and challenges, the countries of the world have not been able to improve significantly in this field. Figure 1 illustrates the improvement rate of energy intensity (an appropriate proxy for energy efficiency) from 2011 to 2020:

One of the reasons why policymakers pay much attention to the issue of the effectiveness of energy usage is the importance of improving this index in protecting the environment and eliminating the global threats of global warming or climate change (Saboori et al. 2022). In other words, the more energy efficiency improves, the amount of energy consumption will decrease, and the efficiency of an energy unit in the production of goods will increase. This will cause less emission of greenhouse gases or, in other words, environmental pollution. Li et al. (2022) confirmed that a 1% improvement in energy efficiency reduces carbon dioxide emissions by nearly

![Energy intensity improvement graph](image-url)

**Fig. 1** Energy intensity enhancement rate, 2011–2020, %. Source: Authors based on the Energy Efficiency Report IEA 2020
0.92%. In another study, Mirza et al. (2022) depicted the significant contributions of energy efficiency to CO₂ mitigating because any improvement in energy efficiency indicators can help a country use fewer fossil fuels and lower energy intensity, causing less carbon dioxide emission. It can be said that an increase in energy efficiency can lower the amount of energy needed to generate power and produce different commodities and residential consumption, which has a practical consequence of the reduction of greenhouse gas emissions.

Despite the importance and necessity of improving the energy efficiency index, the countries of the world have not been able to achieve the desired level of this index in recent years. One of the reasons for this is the use of inappropriate policies and tools in improving energy efficiency and developing projects related to this index. Many researchers like Tu et al. (2020) and Rasoulinezhad (2022) have indicated that to develop energy efficiency projects countries should move toward developing the market of green financing instruments such as green bonds. Another group of previous studies (e.g., Yoshino et al. 2021; Chien et al. 2021) insists that proper use of green financial policies, such as establishing a green (carbon) tax, can open the way to improve the energy efficiency index in the countries of the world. Which tool among green bonds or environmental tax impacts energy efficiency is vital for research. Because the policy makers for each of these two policies need to spend money and have formal planning, so knowing the sign and magnitude of the effect of these two policies on the effectiveness of energy can be a useful and practical finding for the policymakers and managers of the sustainable development of countries.

The necessity of this research is of great importance for EU countries. The member states of the EU are known as pioneers in the field of sustainable development and achieving a zero-carbon economy (according to the EU climate-neutral by 2050 plan) in the world. Therefore, studying the effects of green bonds and green taxes on the effectiveness of energy in these countries can provide strategic and practical results. On the other hand, due to the import of fossil fuels and dependence on foreign countries in this field, EU members are trying to implement strategies to reduce dependence on fossil fuels. One of the main strategies in this field is to improve energy efficiency, which can lead to less consumption of fossil fuels (Akram et al. 2020). Figure 2 shows the dependency of the EU on energy imports from abroad from 1990 to 2020.

According to the figure above, it is clear that the EU member states have become more than 50% dependent on energy imports from abroad in recent years, which shows the importance of prioritizing the improvement of energy efficiency in these countries.

Regarding the problem mentioned above and motivations to study the issue of energy efficiency and the impacts of green tax and green bonds on it for the case of the EU, this paper tries to contribute to earlier studies from the following aspects:

- First, the paper seeks to model energy efficiency by considering green bonds and green tax as explanatory variables. This type of energy efficiency modeling allows the researchers to explore the impacts of both variables of green tax and green bonds on energy efficiency.
Second, the panel causality test analyzes the causal relationships between energy efficiency-green bonds and energy efficiency-green tax. It provides the direction of causal linkages among these variables, bringing in-detail results for policymakers.

Third, an advanced econometric analysis based on the existence of cross-sectional dependency among series is employed to estimate the coefficients of independent variables. Following Feng et al. (2021), cross-sectional dependence is a common characteristic in the panel data approach that researchers should address.

The research structure is as follows: In the second Section, the authors try to clarify the literature gap the paper seeks to fill. Next Section debates data and estimation strategy. Section 4 provides empirical estimations results and a brief discussion. Section 5 presents robustness checks to ascertain the validity of empirical findings. The concluding remarks are provided in the final section, and some practical policies are recommended.

2 Literature review

A vast number of scholars have drawn the energy efficiency matter attention. For instance, in a study, Petterson (1996) highlighted the importance of energy efficiency to support of environmental protection. Lopes et al. (2012) argued that energy efficiency is a concept of an energy economy with social properties. Because households are an essential player in energy efficiency, consumption patterns can improve/weaken energy efficiency in a country. Backlund et al. (2012) revealed the need to invest in energy efficiency technologies that require appropriate policies and governance. Zakari et al. (2022) addressed the concept of energy efficiency as the main pillar of sustainable development. They argued that improvement in energy efficiency
could bring countries closer to the sustainable development indicators defined by the United Nations in 2015. In another study, Hassan et al. (2022) investigated the relationship between energy efficiency and air pollution reduction in OECD countries. The results of this research show the importance of energy effectiveness in operationalizing the concept of energy transition (moving toward less consumption of fossil fuels) and reaching a zero-carbon economy. Baniassadi et al. (2022) mentioned the role of energy efficiency improvement in the living conditions of the next generations on the earth. Any increase in the level of energy efficiency can lower greenhouse emissions. In another new study, Bertoli (2022) expressed that in post-COVID era, countries should implement practical policies to enhance energy efficiency and sufficiency to reach the goals of sustainable development.

A group of studies has concentrated on the importance of energy efficiency in reducing CO₂ emissions. For instance, Li and Lin (2015) highlighted the reasons for energy inefficiency in China and remarked on the role of fiscal policy and investment motivations in promoting energy efficiency. Ifitikhar et al. (2016) analyzed data for 26 countries and concluded that improving energy efficiency in the industrial sector will reduce the consumption of non-renewable energy and, as a result, reduce the emission of greenhouse gases such as carbon dioxide. Moretto et al. (2018) argued that energy efficiency is a crucial concept to environmental protection. Mirza et al. (2022) studied 30 developing economies and found out the significant role of energy efficiency in reducing CO₂ emissions. Regarding the case of China, Wang and Jia (2022) investigated the relationship between CO₂ emissions and energy efficiency in a panel of Chinese provinces. The major results confirmed the big contribution of energy efficiency to carbon dioxide emissions and sustainable economic growth.

Another strand of literature focused on the impacts of green tax and green bonds on the process of enhancement of energy efficiency in different economies. Miguel and Manzano (2011) discussed the necessity of green tax reforms to enhance the energy efficiency, energy transition, green recovery, and environmental protection. Silva et al. (2020) investigated the consequences of carbon tax policy on green energy promotion and lowering fossil fuel consumption. They confirmed the significant coefficient of green tax to impact green energy consumption, which is a way to improve energy efficiency. He et al. (2021) and Wang and Yu (2021) tried to seek the influence of environmental tax on the enhancement of energy efficiency levels in the OECD (Organization for Economic Co-operation and Development) economies. They found out that the impact is not clear and depends on countries’ economic size. In other words, in a large economic size country, environmental tax has a higher potential to accelerate energy efficiency improvement. Garcia-Quevedo and Jove-Liopis (2021) considered four different environmental policies in Spain and analyzed their impacts on energy efficiency investment. The estimation results depicted the low effect of green tax on energy efficiency investment in the industrial sector. Goenka et al. (2021) discussed the positive impacts of green taxes on decarbonization and green economic recovery progress. In another study, Bashir et al. (2021) aimed to seek the impacts of green tax on energy intensity for the case of OECD economies. The concluding remarks highlighted the positive role of an environmental tax on the improvement of energy efficiency and energy usage. Employing the game theory approach, Li et al. (2021) confirmed the scenarios of
efficiency of carbon tax policies to the reduction of energy usage to produce different commodities.

Regarding green bonds, Devine and McCollum (2022) expressed that green bonds can provide sufficient capital for countries to develop green energy projects and promote technologies to improve energy efficiency. In another study, Quang and Thao (2022) focused on the ASEAN member countries and found that the issued green bonds can reduce energy intensity (energy usage/GDP). This finding has been confirmed by Mamun et al. (2022), who also studied the relationship between green finance and the decarbonization process in 46 different nations. They showed long-term and short-term positive impacts of green financing on energy efficiency. Tan et al. (2022) investigated the different impacts of green tax on economic recovery. They found that the success of environmental tax depends on the appropriate tax based on the tax preferences in developing economies.

2.1 Regarding the literature gaps

By summarizing the results of the above studies, it can be realized that energy efficiency is an essential matter for the countries of the world in order to achieve sustainable development and green economic growth recovery during the COVID-19 and post-COVID-19 period.

Second, governments’ green policies (green financing or environmental taxation) affect energy efficiency differently.

This article will try to analyze the effect of green bonds and green taxes on the energy efficiency of EU member states. Based on the knowledge of the authors, such a study has not been done so far, so this article will fill in this literature gap.

3 Data and estimation strategy

Energy efficiency enhancement can be achieved through the implementation of various policies and strategies by the government. One of the new and effective policies in this field is the issuance of green bonds as a green financing tool by the government. By targeting projects related to the environment, including energy efficiency, green bonds can appropriately solve the lack of sufficient capital to invest in these projects and create appropriate capital accumulation from private sector investors and foreign investors. Another effective tool of the government for developing energy efficiency projects is the imposition of a green tax (environmental tax) on activities that cause environmental pollution. The imposition of such a tax leads to economic enterprises developing energy efficiency to reduce fossil energy consumption.

In terms of economic theory, the utility function of an economic unit to invest in a project related to energy efficiency can be assumed as Eq. 1:

\[ U_t = U(r_t, \sigma_t, \text{tax}_t) = r_t - \beta \sigma_t^2 + \delta \text{tax}_t + Z_t \]  

(1)
where the rate of return of investment in an energy efficiency project is showed by \( r \), while \( \sigma \) and \( \beta \) represent the risk weight and total risk for the project is related to energy efficiency. Tax denotes environmental tax, whereas \( Z \) is representative of all the variables (such as inflation rate, exchange rate, governance, carbon dioxide emissions per capita, geopolitical risk, etc.) that can affect the economic unit’s desirability to invest in energy efficiency projects.

It is important to note that other factors \( (Z) \) have many direct and indirect effects on decision-making and the desirability of the economic unit and risk, the investment return, and the green tax rate. For example, increasing carbon dioxide per capita will increase the green tax rate to pressure economic enterprises to improve their energy efficiency. Or, an increase in geopolitical risk in a country greatly increases the risk of investing in low-return or late-return projects. Therefore the desire to invest in energy efficiency projects, which are usually late-return or low-return projects, will decrease. In this situation, the tool of green bonds, which according to Markus and Adriana (2018)’s findings, significantly reduces the risk of green projects, and can increase the desirability of the economic unit to participate in energy efficiency projects.

If it is assumed that an economic unit invests in the project related to energy efficiency through bank facilities (with an interest rate of \( r \)), and buys issued green bonds (with an interest rate \( r^{\text{GBOND}}_t \)), then the total risk this investor is \( \text{Eq. 2} \) will be:

\[
 r_t = \alpha_t r^D_t + (1 - \alpha_t) r^{\text{GBOND}}_t
\]  

With a simple mathematical operation, \( \text{Eq. 2} \) can be inserted into the first equation, and the result is \( \text{Eq. 3} \):

\[
 U_t = U(r_t, \sigma_t, \text{tax}_t) = \alpha_t r^D_t + (1 - \alpha_t) r^{\text{GBOND}}_t - \beta \sigma^2_t + \delta \text{tax}_t + Z_t
\]  

Based on \( \text{Eq. 3} \) and previous studies in the energy efficiency field, the energy efficiency index is the dependent variable, and the variables of issued green bonds, environmental tax, carbon dioxide emissions, gross domestic product, green energy consumption, and inflation as explanatory variables were selected. The increase in the volume of issued green bonds is expected to lead to energy efficiency improvement due to the creation of favorable investment conditions. Environmental tax can also be a deterrent to the consumption of more fossil fuels by economic enterprises. Therefore, with the imposition and increase in green taxes, economic enterprises will be encouraged to develop more energy efficiency projects. Carbon dioxide emissions can also positively or negatively affect energy efficiency. With the increase in carbon dioxide emissions, governments will try to reprogram and pressure economic enterprises to develop green activities.

On the other hand, more carbon dioxide emissions can have a causal relationship with energy efficiency and increase carbon dioxide emissions. Carbon means the economic growth of most countries through the consumption of fossil fuels and not paying attention to sustainable development. Therefore, an increase in carbon dioxide emissions can mean a decrease in energy efficiency in a country.
In the case of GDP, which can mean the size of the economy and the economic power of a country, it is expected to have a positive effect on the energy efficiency index of a country. Because of the increase in GDP in a country, the ability of the government and the private sector to invest in green projects such as energy efficiency has increased, and it is expected that the energy efficiency index will improve. Also, the consumption of clean energy can significantly affect energy efficiency. With the increase in clean energy consumption in a country, the energy efficiency index is expected to increase. And finally, the inflation rate is expected to harm the development of energy efficiency since any increase in the general level of prices can lead to a rise in the cost of projects, technology imports, and energy transition.

In this research, to find out how issued green bonds and environmental taxes can change energy efficiency index, the case of 27 EU member countries is selected, and the econometric analysis is done through the panel data framework of these economies from 2010 to 2021. Hence the total observations for the estimation are 324 (12*27). The econometric equation (Eq. 4) based on the selected variables, period, and case study can be organized as follows:

$$\text{ENEF}_{i,t} = \beta_0 + \beta_1 \text{GBOND}_{i,t} + \beta_2 \text{GTAX}_{i,t} + \beta_3 \text{INF}_{i,t} + \beta_4 \text{GDP}_{i,t} + \beta_5 \text{CO}_{i,t} + \beta_6 \text{GEC}_{i,t} + \epsilon_{i,t}$$

In Eq. 4, ENEF stands for energy efficiency index. GBOND, GTAX, INF, GDP, CO, and GEC represent issued green bonds, environmental tax, inflation, gross domestic product, carbon dioxide emissions, and green energy consumption. Initial introduction of the selected variables is represented in Table 1.

Table 2 reports the variables amount in the EU from 2010 to 2021. According to the data in Table 2, it is clear that the energy efficiency index has decreased compared to 2010 despite the improvement of the situation from 2015 to 2021. Issuance of green bonds has grown exponentially in the EU, from 12 billion US dollars in 2010 to more than 260 billion US dollars in 2021. Also, the income of EU members from environmental taxes increased from 2010 to 2021, from about 251 billion euros in 2010 to more than 315 billion euros in 2021. Also, renewable energy consumption in the EU has made significant progress and reached from 0.65 exajoules in 2010 to about 7.5 exajoules in 2021.

| Variable                      | symbol | Unit         | Sources                          |
|-------------------------------|--------|--------------|-----------------------------------|
| Energy efficiency index of industry (ODEX) | ENEF   | –            | European environmental agency     |
| Issued Green bond             | GBOND  | US$          | Climate bond initiative           |
| Inflation, consumer prices    | INF    | Annual %     | World bank                        |
| Green tax                     | GTAX   | Million EURO | EUROSTAT                          |
| CO₂ emissions                 | CO     | Metric tons per capita | BP                                |
| GDP                           | GDP    | Current US $ | World bank                        |
| Green energy consumption      | GEC    | Exajoules    | BP                                |
In order to know the initial dimensions of the variables and their relationship with each other, several pre-tests should be performed before econometric estimation. The first required test is to study the existence or non-existence of cross-sectional dependence among the variables of the model. In order to study this matter, two Breusch-Pagan LM test (Breusch and Pagan 1980) and Pesaran CD test are implemented. If there is an inter-departmental dependence between the variables, it can be realized that for the next test, which includes the study of the existence of the unit root, an appropriate method should be used. In this research, the Cross-sectionally augmented IPS test (CIPS) method, proposed by Pesaran (2007), is employed as a reliable and efficient method. This method has the following equation (Eq. 5):

\[
CIPS(N, T) = N^{-1} \sum_{i=1}^{N} t_i(N, T)
\]  

(5)

If the panel data unit root test shows the existence of the mean of the model variables after differentiating once, it is possible to perform the co-integration relationship test between the model variables. For this purpose, Westerland’s (2007) method, which has four co-integration test statistics (Eqs. 6–9), is used.

\[
P_r = \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)}
\]  

(6)

\[
P_a = T\hat{\alpha}
\]  

(7)

\[
G_r = \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)}
\]  

(8)

\[
G_a = \frac{1}{N} \sum_{i=1}^{N} \frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)}
\]  

(9)

### Table 2  Variables amounts for the EU, 2010–2021. Source: Authors

| Variable                                      | Unit                  | 2010  | 2015  | 2020  | 2021  |
|-----------------------------------------------|-----------------------|-------|-------|-------|-------|
| Energy efficiency index of industry (ODEX)    | Index 1990 = 100      | 74    | 70    | 70    | 72    |
| Issued green bond                             | Billion US $          | 12    | 20    | 158.2 | 264.9 |
| Inflation, consumer prices                    | Annual %              | 1.5   | −0.1  | 0.5   | 2.6   |
| Green tax revenue                             | Billion EURO          | 251.6 | 284.5 | 299.9 | 315.7 |
| CO₂ emissions per capita                      | Metric tons per capita| 7.3   | 6.5   | 3.9   | 4.6   |
| GDP                                           | Current Trillion US $ | 14.56 | 13.55 | 15.3  | 17.09 |
| Green energy consumption                      | Exajoules Input-equivalent | 0.65 | 6.02  | 6.85  | 7.50  |
In the above equations, $\hat{\alpha}_i$, $\text{SE}(\hat{\alpha}_i)$, $\hat{\alpha}_i(1)$ represent the estimation of the error correction parameter, standard error, and $1 - \sum_{j=1}^{p_i} \hat{\alpha}_{ij}$, respectively.

In the next step, the empirical estimations of coefficients of explanatory variables are conducted through a continuous-updated fully modified (CUP-FM) estimator proposed by Bai and Kao (2006). Finally, the causality relationships between the variables are evaluated by the panel causality test method of Demitrescu and Hurlin (2012).

### 4 Empirical findings and discussion

In the first step, two cross-sectional dependence tests were performed, and the related findings, reported in Table 3, revealed that there is cross-sectional dependency among variables.

Hence, the appropriate panel data unit root test is the CIPS that its findings are represented in Table 4 as follows:

The CIPS panel unit root test results show that all the variables become stationary after the first difference, so there is a possibility of a long-term relationship between the variables. The Westerlund (2007) co-integration approach is employed to determine whether there is any long-term relationship between variables. The results

| Table 3 Result of test of cross-sectional dependency. Source Authors |
|---------------------------------------------------------------|
| Breusch-Pagan LM | Pesaran CD |
| 401.592 (0.00) | 34.103 (0.00) |

| Table 4 Results of panel unit root test. Source Authors |
|---------------------------------------------------------------|
| Variable | statistic |
| ODEX | $-0.664$ |
| D (ODEX) | $-4.920$ |
| Green bonds | $-1.058$ |
| D(Green bonds) | $-4.782$ |
| Inflation | $-2.119$ |
| D(Inflation) | $-4.093$ |
| Green tax | $-1.033$ |
| D(Green tax) | $-4.804$ |
| CO2 emissions per capita | $-1.004$ |
| D(CO2 emissions per capita) | $-4.111$ |
| GDP | $-1.132$ |
| D(GDP) | $-5.860$ |
| Green energy consumption | $-0.948$ |
| D (Green energy consumption) | $-4.505$ |

D shows the first difference.
of this test are expressed in Table 5 and confirm the existence of co-integration in the empirical model.

According to the conducted tests and their findings, especially the presence of cross-sectoral dependence, the CUP-FM estimator was used to estimate the coefficients of the explanatory variables. The results of the implementation of this estimator are listed in Table 6:

According to Table 6, the coefficient of issued green bonds positively affects the energy efficiency enhancement in the EU, expressing that by a 1% rise in the volume of issued green bonds in the EU, energy efficiency will be improved by nearly 0.83%. Therefore, for the EU member states, the green bond instrument is fruitful in improving the energy efficiency level, which is an essential factor for reaching a suitable level of environmental protection. It is consistent with Devine and McCollum (2022) and Ning et al. (2022), who confirmed that issued green bonds are a fruitful instrument for developing projects related to energy efficiency improvement. In addition, the positive impacts of green bonds on energy efficiency improvement have been confirmed by Rasoulinezhad and Taghizadeh-Hesary (2022) for the case of the top ten economies that support green finance by Zhang et al. (2022) for the case of E-7 economies. The inflation rate has a negative impact meaning that any increase in the general level of prices of commodities in the EU member countries is an obstacle to improving energy efficiency. The main reason is that inflation increases the cost of imports, the price of commodities in the local markets, affecting the expenditure required to run the economic projects and energy efficiency. Consequently, it reduces profit and return on investment. It is in line with Tang et al. (2022), who found out negative impacts of inflation on enterprise-environmental protection expenditure in the case of China. Carbon dioxide emissions have a statistically insignificant coefficient. It can be interpreted that in the EU, the issue of environmental protection through different policies like

Table 5  Results of panel co-integration test. Source Authors

| Tests   | Stat. (prob.) |
|---------|---------------|
| $P_r$   | $-9.834$ ($0.00$) |
| $P_a$   | $-13.138$ ($0.00$) |
| $G_r$   | $-4.014$ ($0.00$) |
| $G_a$   | $-17.804$ ($0.00$) |

Table 6  Estimation of coefficients. Source Authors

| Explanatory variable              | coefficient | $p$-value |
|-----------------------------------|-------------|-----------|
| Issued green bond                 | 0.831       | 0.035     |
| Inflation, consumer prices        | $-0.044$    | 0.000     |
| Green tax revenue                 | 0.052       | 0.061     |
| CO$_2$ emissions per capita       | $-0.04$     | 0.204     |
| GDP                               | 0.397       | 0.000     |
| Green energy consumption          | 0.518       | 0.029     |
energy coefficient has become an accepted and integrated program and task in the EU, which does not affect by CO₂ emissions. The environmental tax has a positive and statistically significant (at 1% level) coefficient, mentioning that the level of energy efficiency in the EU rises by nearly 0.05% by a 1% increase in green tax revenue. This result is consistent with Telatar and Birinci’s (2022) findings for the case of Turkey. The critical point here is that the magnitude of the coefficient of green bonds is larger than the coefficient of green tax, meaning that the impact of issued green bonds on energy efficiency improvement in the EU is more than the impact of green tax. The gross domestic product positively impacts energy efficiency, denoting that with a 1% rise in the economic size of the EU, the energy efficiency improves by approximately 0.39%. The increase in the production volume of EU economies means the availability of more capital to advance energy efficiency projects and increase the speed of the energy transition process. Finally, the estimation results reveal the positive and significant coefficient of green energy consumption, highlighting the positive impact of renewable energy consumption on energy efficiency improvement in the EU. The development of renewable energy consumption (in industry, electricity production, household consumption, and vehicle fuel) in the economies of the EU leads to more attention to increasing the effectiveness of energy and the development of investment in the technology progress and financial support for patents and innovative ideas in the field of energy efficiency in the EU.

To have more in-detail insights about the relationship between issued green bonds- energy efficiency and environmental tax energy efficiency, the Dumitrescu and Hurlin (2012) panel causality test, with the results shown in Table 7, is conducted.

According to the results and the p-values, it can be concluded that a uni-directional causality relationship exists between the volume of issued green bonds and the level of improvement of energy efficiency in the EU. It can be highlighted that there is a bi-directional causal link between green tax and energy efficiency in the EU. The main reason for this finding is that, generally, tax is an instrument for applying fiscal policy and as a means of regulation; it has impacted and is affected by energy efficiency. The governments of EU member states can adopt the green tax rate based on the level of energy efficiency and play a role as a regulator in this sector by changing the green tax rate according to the enhancement/deterioration of the energy efficiency level in the EU.

5 Robustness check

In order to ensure the reliability of the obtained results, two robustness tests are performed.

1. The first test is based on the strategy of changing the dependent variable. In this way, energy intensity, one of the essential proxies of energy effectiveness, is used instead of the Energy efficiency index of industry (ODEX). Energy intensity data
| Causality Relationship                                      | Direction                          | Cause                                      | p value       |
|------------------------------------------------------------|------------------------------------|--------------------------------------------|---------------|
| Green bond–energy efficiency causality relationship         | Issued green bonds do not homogeneously cause energy efficiency | 3.014 (0.02)                               |
|                                                            | Energy efficiency does not homogeneously cause issued green bond | 0.284 (0.48)                               |
|                                                            | Green tax does not homogeneously cause energy efficiency          | 4.699 (0.04)                               |
|                                                            | Energy efficiency does not homogeneously cause green tax          | 3.683 (0.00)                               |

*p values are shown in parenthesis*
were extracted from the World Bank website for EU countries, and coefficients were re-estimated. The results for only issued green bonds and environmental tax are reported in 8:

According to Table 8, it is clear that the sign of the coefficients of the two variables of published green bonds and environmental tax is positive and is in full agreement with the previous estimation results.

2. The second robustness check is based on the strategy of changing the sample size. For this purpose, the coefficients of the explanatory variables were estimated for a subset of 20 EU member states. In re-estimation, all pre-tests were performed as before. Table 9 outlines the findings of the new estimation as follows:

According to the results shown in Table 9, despite some differences (lack of significance of coefficients of the inflation rate and per capita carbon dioxide emissions), the signs of the coefficients of issued green bonds and environmental taxes are positive and utterly consistent with the previous results. Therefore, based on the two robustness tests’ findings, it can be concluded that the results of the estimations in Sect. 4 have complete reliability and validity.

### 6 Conclusions and policy recommendations

Protecting the environment, which has been heavily polluted in recent decades due to economic growth and industrialization, has become a vital global matter. Most countries are trying to reduce and control the rate of environmental pollution by implementing policies over time to achieve a zero carbon economy target in a horizon of 30–50 years which would be a good signal for moving toward sustainable
development. One of the anti-environmental pollution policies is to focus on the issue of energy efficiency to reduce fossil energy consumption and carbon dioxide emissions. This paper investigates the relationship between issued green bonds and environmental tax on the energy efficiency of the EU members. The methodology approach for econometric modeling is the panel data and annual data of variables from 2010 to 2021.

6.1 Conclusions

According to the major estimation findings, the concluding remarks can be highlighted as bellows:

1. The energy efficiency level can be enhanced by issuing green bonds in the EU members. Since the efficiency of this green financing instrument has been confirmed in the energy efficiency of the EU, the member states of this union can rely more on the green bond market in the post-COVID era to provide sufficient financing for the development of energy efficiency projects. The development of the green bond market can, on the one hand, increase the number of green projects in EU countries and, on the other hand, significantly improve the flow of investment in green projects. The development of the green bond market means a more favorable outlook for sustainable development.

2. The second conclusion is that environmental taxation is an efficient fiscal policy that encourages enterprises to conduct different policies and projects to improve their energy efficiency levels. However, the power of the green tax on energy efficiency in EU members has been less than that of the green bonds issued in these countries. Therefore, to increase the positive effect of the green tax on the market, EU member states need to set more efficient green tax rates and adjust the regulations related to green taxation. The effectiveness of environmental tax requires the appropriate determination of green tax rates and the existence of transparent laws.

3. Third, inflation can be addressed as an obstacle to promoting energy efficiency in the EU. An increase in prices will lead to more expensive production of economic enterprises, more expensive economic projects, and a decrease in the expected profit of investors. Therefore, investors and economic enterprises (especially small and medium enterprises) will be less willing and able to pay attention and give priority to energy efficiency matter. It can be concluded that policy making and controlling the EU’s inflation rate to develop energy efficiency in the member countries of this union should be given more attention. Uncontrolled inflation can cause stagnation in the sector of green projects and the development of the green bond market.

4. Another concluding remark regards the gross domestic product as representing economic size and power. This research confirmed the positive impact of GDP on energy efficiency enhancement. In general, with the increased GDP of the member countries of the EU, the financial power of governments in defining and
implementing green projects such as energy efficiency has increased (according to Phung et al. (2022)). GDP increases FDI volume accelerating green recovery in the post-COVID era, as well as the power of banks in granting green facilities and supporting energy efficiency projects.

5. Green energy consumption positively impacts energy efficiency in the EU. The increase in renewable energy consumption means a decrease in the share of fossil energy consumption in different sectors of the economy (industry, residential, transportation, and electricity generation) of the EU, which will cause more demand to improve energy efficiency in these countries.

6. There is a bi-directional causal link between green tax and energy efficiency in the EU. The governments of EU member states can adopt the green tax rate based on the level of energy efficiency and play a role as a regulator in this economic sector by changing the green tax rate according to the enhancement/deterioration of the energy efficiency level in the EU.

6.2 Practical policies and recommendations for further research

As practical policy implications, the EU member states can promote the green bond market through more transparency and marketing among private investors. Considering the development of the digital economy in the era of social distancing caused by the COVID-19 pandemic (Taghizadeh-Hesary et al. 2022), it is suggested to create an infrastructure for the issuance of digital green bonds (DGBs). This would reduce both the costs of issuing physical bonds and enables greater geographical scope for the participation of foreign investors in the energy efficiency projects of EU. Also, considering the efforts of the countries in the world, including the EU, in economic growth recovery in the post-COVID era, it is recommended to pay attention to the concept of green economic recovery. Following Phung et al. (2022), the green economic recovery is a new concept developed in the era of Covid-19. It refers to the return of the economic power of the countries to the level before the outbreak of the COVID-19 pandemic. In the shadow of green economic recovery, economic growth will be created by paying attention to environmental issues, one of which is the improvement of the energy efficiency index. Furthermore, developing projects related to the green generation of electricity (sustainable electricity proposed by Taghizadeh-Hesary et al. 2022) in the EU is another practical policy proposed by this research. Although the generation of green electricity in some countries of the EU has a history of several decades (For example, the contributions of green power generation in Germany have improved from 3.4% in 1990 to over 42% in 2019 to total power generation in the country), but considering the political tension between Russia and Ukraine since February 24, 2022, and the decrease in the security of the EU’s fossil energy supply from Russia, the need for faster and broader implementation of green electricity generation is essential.

In conducting this research, there were limitations, such as the lack of new data on environmental taxes and green financing tools, the lack of clarity about the effects of the war between Russia and Ukraine, and the spread of COVID-19 on the global economic mechanism. Despite the limitations in conducting
this research, according to the authors of this paper, it has a good and worthy contribution to the previous literature related to energy efficiency, the green bond market, and environmental tax. Future researchers can obtain additional findings by considering the COVID-19 pandemic as a variable in the econometric model, using country-level analyzes, and evaluating the effectiveness of different green tax rates. Other statistical and econometric methods such as scenario building, futurology, and artificial neural networks are also suggested to predict the trends and mega-trends of the research variables.

**Author contributions** We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all the authors.

**Declarations**

**Conflict of interest** We declare that there is no conflict of interest.

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