The Opportunity Cost of Net Zero Emissions: Is Green Trade at Risk?

Abstract

This paper investigates the role of green trade, energy efficiency and carbon tax on energy-driven GHG in achieving an energy-efficient ecosystem, by using quantile regression. The findings reveal several critical insights with significant policy implications. Firstly, green exports are a significant determinant of energy GHG throughout all the quantiles. Secondly, the green export has not yet reached a level where it exerts green technological effects. This suggests that a higher level of exports currently leads to an increase in production, which may increase energy-related GHG emissions. Thirdly, green trade has an inverted U-shaped relationship with energy-driven GHG. This means that as green trade increases, energy-related pollution initially rises, reaches a peak (or threshold), and then begins to decline. This reflects the "Technical Effect" and "Composition Effect" of trade, showing how trade impacts emissions differently in the long run. Fourthly, green imports, energy efficiency and carbon tax are negative determinants of energy GHG emissions; thus, they are helpful to achieve an energy-efficient ecosystem. To enhance the effectiveness of carbon reduction policies, it is essential to incorporate the interplay among key stakeholders.

Keywords: Green Trade, Energy Efficiency, Carbon Tax, Energy efficient Eco-system, Threshold Association, Energy Driven GHG Emissions

1 Introduction

Eradicating carbon emissions has become a complex problem due to the twisted and intertwined balance between economic growth, environmental objectives, and sustainability. Policy makers face the challenge of designing policies that effectively reduce carbon emissions without compromising economic growth and development. Quantifying the economic impact of environmental sustainability, finding solutions and policy recommendations that can direct economic and environmental objectives remain a significant challenge in G7 countries. G7 is an intergovernmental organisation that consists of advanced economies with significant socio-economic and environmental policies held at the global level (Zheng et al., 2023). These developed economies, due to the acceleration of economic growth, rapid globalisation and industrialisation, face a challenging task of policy implementations to reduce the carbon emissions along with maintaining or even increasing economic growth and development (Chaudhry et al., 2020).

As per the Paris Agreement, the eradication of carbon emissions is a significant objective of SDGs 13 (Sustainable Development Goals- 13), which revolves around reducing the world temperature to 1.5°C (Zahra & Fatima, 2024). To reduce the world temperature to 1.5°C by 2050, CO_2 emissions need to be limited by 45% from the 2010 level by 2030 to achieve the target of net zero emissions (Commission, 2017; UN, 2020). Sources of energy are the main drivers of carbon emissions (Zahra & Badeeb, 2022)Therefore, it is important to monitor significant determinants of energy-driven GHG emissions to ultimately reduce carbon emissions in order to achieve environmental objectives.

Since energy is a significant production input and an important factor in the consumption process, it has led to an escalation in the emissions level. This detrimental impact has urged different countries and international organisations to unite and come forward with a collective worldwide solution. Therefore, it is important to focus on significant drivers of energy-driven greenhouse gas emissions. Green trade (J. Li et al., 2022), energy efficiency (Zheng et al., 2023) and carbon tax policies (Xu et al., 2023) play a pivotal role in achieving the target of net zero emissions, especially for developed countries like the G7 countries. These economies have a significant role in achieving the environmental targets since they account for nearly 50% of GDP (Zheng et al., 2023), with practically huge contributions to energy-driven emissions. Figure 1 shows the energy-related greenhouse gas (GHG) emission shares of G7 countries. The distribution of energy-related GHG emissions among the G7 countries highlights notable differences, with each share representing a percentage of the total energy driven GHG emissions contributed by the G7 countries rather than the global emissions. The United States accounts for the largest share, contributing 60% of the total G7 energy-related GHG emissions, reflecting its significant reliance on energy-intensive industries and fossil fuels. Japan follows with 12%, while Germany contributes 9%, likely due to its energy-intensive resource extraction activities. Japan accounts for 6%, reflecting its industrial energy demands. France, Italy, and the United Kingdom each contribute 4% and 5% (respectively) of the G7 total emissions. These figures emphasize the need for tailored and country-specific policy measures to address energy-related GHG emissions within the G7, contributing to global efforts to combat climate change.

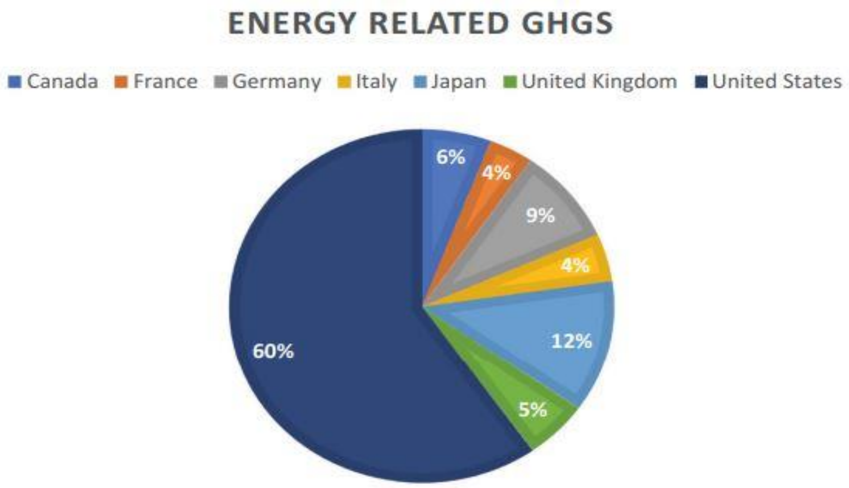

Figure 1: Energy related GHG Emissions (OECD, 2022)

Balance between imports and exports presents both opportunities and challenges to reduce energy consumption and, in return, also energy-driven GHG emissions, as these countries transition towards environmental sustainability. The efficient transition of imports and exports may form a sustainable, energy-efficient ecosystem. Therefore, a special focus should be placed on understanding the opportunity costs of green trade to reduce energy-driven GHG emissions and create a sustainable roadmap for the G7 countries. Figure 2 shows that there are significant variations in the share of green imports, exports, and overall green trade in G7 countries. Japan leads in green imports (11.73%) and green trade (28.5%), while Germany and the UK also have relatively high green trade figures (18.88% and 16.37%, respectively). In contrast, Canada has the smallest share of green imports (0.98%) but sees a higher share in green exports (5.98%).

Figure 2: Comparison between green imports, green exports and green trade shares (IMF, 2023)

Although trade is a significant driver to increase the environmental degradation (Zahra, Khan, Gupta, et al., 2022), but it can also give countries the chance to implement new, environmentally friendly and energy-efficient technology, which will slow down environmental degradation (Managi et al., 2009). Some existing literature determines that enhancing trade in green products increases business competitiveness, particularly in the global trade market where green trade duties and restrictions exist (Papadas et al., 2019). The import of green technologies and environmentally friendly goods is a negative determinant of carbon emissions, which promotes technological innovations and improves production processes in favour of environmental quality. While economic growth generally correlates with an increase in carbon emissions, the integration of green imports can mitigate this effect. Such as the import of green technologies can enhance energy efficiency and lower the carbon intensity of production, thereby reducing overall carbon emissions even in developing countries (Tariq et al., 2022). However, effective policies are essential to maximise the benefits of green imports. Countries should encourage the reduction of tariffs on environmental goods, promote trade facilitation, and support research and development in green energy and technologies. Such measures can enhance the capacity of local industries to adopt cleaner technologies and improve their environmental performance (Yuan et al., 2023).

To use less energy to produce the same or even higher level of output, by enhancing technological innovations, and to eliminate energy waste, is called "Energy Efficiency", which is also helpful to reduce carbon emissions (Javid & Khan, 2020). However, the severity of its impact depends on other economic policies such as technological innovations and renewable energy transitions (Akram et al., 2020). Energy efficiency is an essential strategy for reducing energy-driven carbon emissions, but its overall impact is influenced by a variety of factors, including regional differences, economic growth, and the potential for rebound effects (Javid & Khan, 2020). A critical challenge to the effectiveness of energy efficiency is the "rebound effect." This occurs when efficiency improvements reduce energy costs, which leads to higher energy demand and consumption, potentially offsetting some of the benefits. This effect is particularly significant in industrial countries, where efficiency gains can sometimes increase total emissions (Mahapatra & Irfan, 2021). In conclusion, energy efficiency is a vital tool in reducing carbon emissions and thus energy-driven GHG emissions, but its effectiveness depends on consistent improvements and the management of rebound effects. Policies promoting energy efficiency must be comprehensive and integrated with other measures, such as renewable energy adoption, to maximize their impact on reducing global carbon emissions. Figure 3 shows the energy efficiency levels across G7 countries, showing their relative contributions. The UK leads with 17%, followed by Italy at 16%, and Germany at 15%. Japan and France both contribute 14%, while Canada and the USA have the lowest shares, at 13% and 11%, respectively. This suggests the UK and Italy perform best in energy efficiency among the G7.

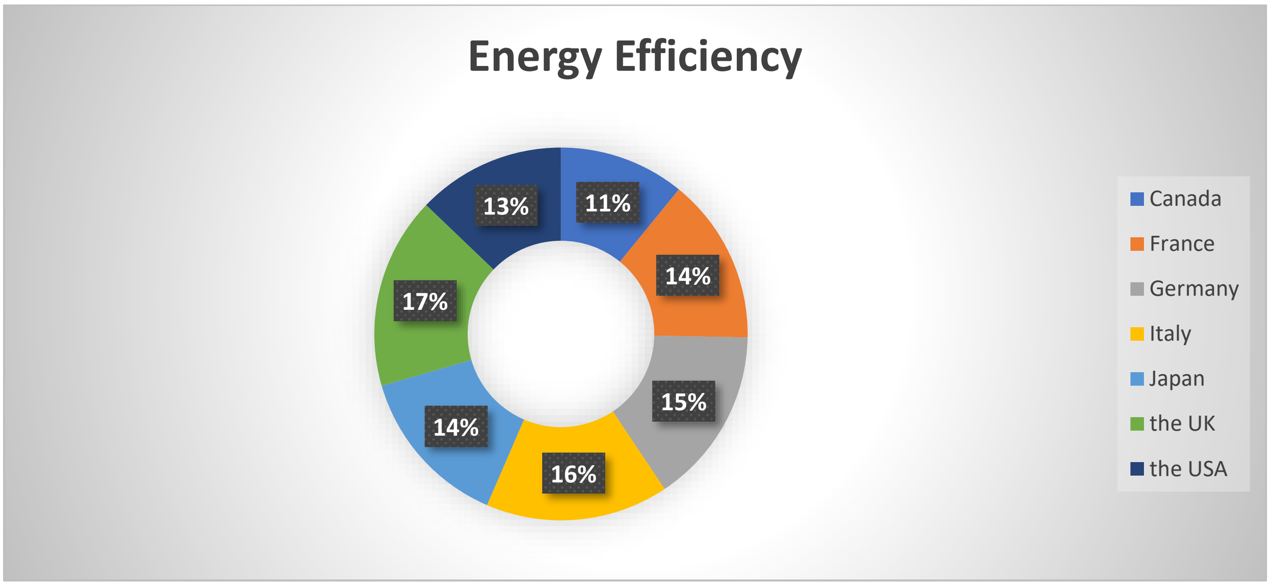

Figure 3:Energy Efficiency of Individual G7 Countries in Comparison to the Total Energy Efficiency within the G7 (WDI, 2023).

Carbon tax, also called carbon policy, is an economic mechanism to impose price on carbon emissions for accelerating the pace towards the goal of net zero emission targets. A carbon tax is a type of Pigovian tax, which is imposed to correct the economic failures determined by negative externalities. By making carbon emissions costly, carbon tax enhances sustainable economic practices and encourages renewable energy transition (Kinoshita, 2024). Carbon tax increases the cost of production, allowing producers to divert this cost to consumers, which will reduce the demand for carbon-intensive good and services (Zhang et al., 2023). However, there are certain challenges which are associated to encourage carbon tax as financial tool to control carbon emissions, for example, carbon tax can disproportionately effect low and middle income individuals by increasing the cost of living (Fremstad & Paul, 2019). To achieve energy efficient ecosystem, G7 countries actively design and impose carbon tax policies as a part of their comprehensive strategy for achieving environmental sustainability (Doğan et al., 2022). Figure 4 represents a comparison of carbon emissions and the percentage share of carbon tax among G7 countries. The USA has the highest share of carbon emissions while the tax is comparatively low, which indicates an imbalance between its carbon emissions and carbon taxation. Contrary, France and Italy have lower carbon emissions, but their carbon tax shares are significantly higher which shows their efforts of carbon pricing to achieve the target of net zero emission. On the other hand, Canada and Japan have smaller part of carbon emission and comparatively lower carbon tax but these rates are more proportional to their emission level.

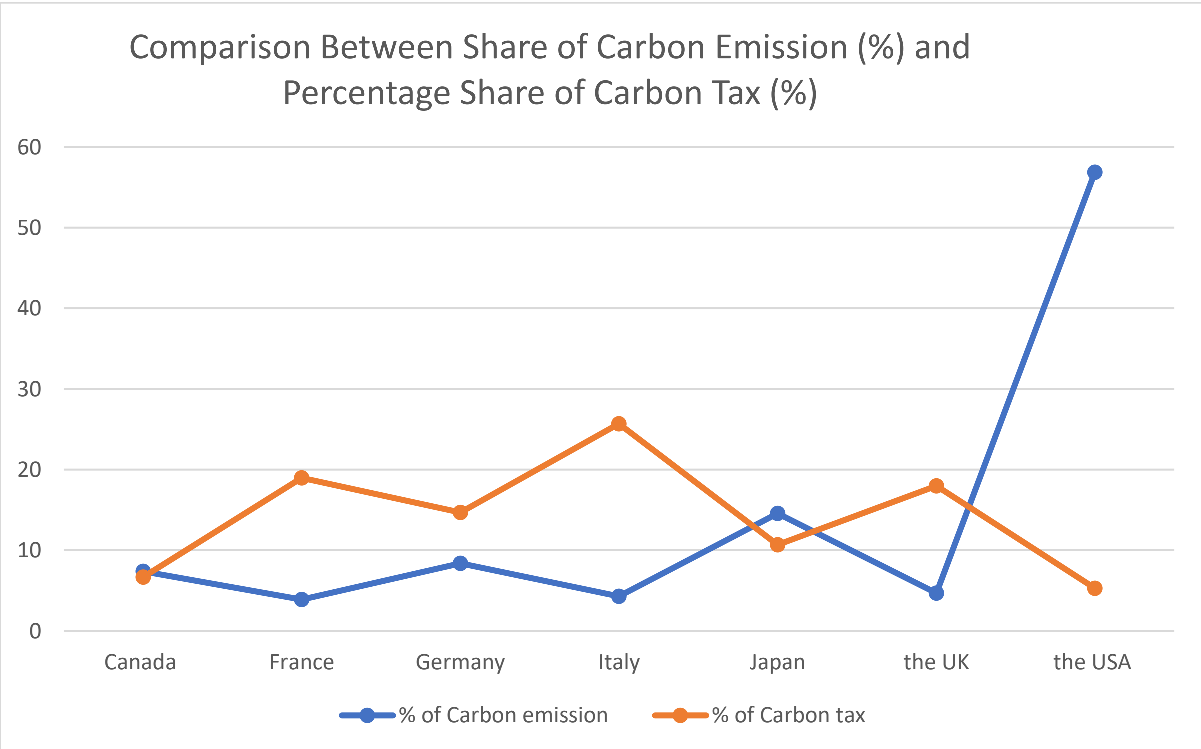

Figure 4: Comparison of the Share of Carbon Emissions and the Share of Carbon Tax among G7 Countries (OECD, 2022).

According to existing literature, there are several significant determinants of carbon emissions, however, there is a research gap to find the determinants of energy driven GHG emission with social, economic, and environmental aspects. As a result, this study empirically investigates the following objectives. First, this study investigates the impact of green imports and green exports on energy related GHG emissions. Second, this study attempts to determine the impact of carbon tax and energy efficiency on energy driven GHG to achieve the status of energy efficient eco-system. Third, by considering the complex relationship between green trade and carbon emission towards the target of sustainable energy efficient system, the quadratic nexus between green trade and energy related GHG emissions is analyzed in G7 countries.

The existing literature depicts several research gaps that require investigation by using modern econometric techniques. These gaps, along with the novelty and primary contributions, are outlined as given below:

1. Despite significant research to investigate the relationship between green trade and carbon emissions, there remain a significance gap to explore the impact of green trade on energy driven GHG emissions. Most of the existing literature focus primarily on carbon emissions as a singular measure of environmental degradation but ignore the broader aspect of energy-related GHG emissions (see for example Can et al. (2022), which includes methane, nitrous oxide and other pollutants, which are relatively unexplored.
2. Furthermore, while prior research has explored the effect of green trade as an aggregate unit (see for example (J. Li et al., 2022)), there is limited analysis that disaggregates the impact of green imports and green exports separately on energy-related GHG emissions. It is important to understand the impact of green exports and green imports separately on energy-related greenhouse gas emissions in order to give a comprehensive policy recommendation.
3. While the impact of energy efficiency on overall carbon emissions has been explored in various contexts (see for example R. Li et al. (2022) Mostafavi et al. (2021) Akram et al. (2020)The relationship between energy efficiency and energy-related GHG emissions in G7 countries needs to be re-evaluated. Empirical research on G7 countries can provide a valuable insight for policy making as these countries play a crucial role in climate commitments and emission reductions.
4. Although the relationship between carbon taxes and carbon emissions has been the subject of extensive research, there is limited empirical research on how carbon taxes

affect broader energy-related greenhouse gas (GHG) emissions in G7 countries. Much of the existing literature focuses on the impact of carbon taxes solely on carbon emissions (see, for example, Nong et al. (2021), Pretis (2022), Ghazouani et al. (2020)) without considering other significant energy related GHGs which also contribute to global warming and are linked to energy production and consumption. Thus, this is another research gap which needs to be investigated. Furthermore, most studies adopt a global or region-wide perspective without examining the G7 as a distinct group of nations with unique economic and environmental policies. The G7 countries, due to their economic size and energy demands, play a crucial role in global energy markets and climate change mitigation efforts. Investigating the impact of carbon taxes specifically on energy-related GHG emissions within these nations is essential for evaluating the effectiveness of such policies to achieve broader climate goals beyond carbon reduction only. This research gap presents an opportunity to assess how carbon tax policies in G7 countries influence a wider range of GHG emissions linked to energy use.

5. While numerous studies have examined the linear relationship between green trade and carbon emissions, there remains a critical gap in exploring the non-linear, quadratic impact of green trade on energy-related GHG emissions. The potential for a threshold effect, where the benefits of green trade in reducing GHG emissions could either U shaped or inverted U shaped has not been thoroughly investigated. This quadratic relationship is crucial to understand whether there is a turning point after which further increases in green trade might lead to diminish energy driven GHG emissions or even an increase in emissions due to indirect factors. This is a critical research gap which needs further consideration and investigation. Previous studies have predominantly concentrated on either the positive or negative linear impact of green trade on carbon emissions (Zahra, Khan, Gupta, et al., 2022), which neglects that green trade may exhibit non-linear dynamics with respect to a broader set of energy-related GHG emissions. Identifying a threshold point in green trade effectiveness can provide policymakers with insights into optimizing trade policies for better climate outcomes.
6. Additionally, it’s methodological strategy is another noticeable novelty of this paper, which is utilizing the method of moments quantile regression (MMQR) to empirically assess the quadratic or threshold association (U shaped or Inverted U shaped relationship) of green trade, as well as the linear effects of green exports, green imports, energy efficiency, and carbon tax on energy-related GHG emissions in G7 countries.

MMQR in this study is presented as a reliable analytical tool. By estimating the conditional quantile functions of energy driven GHG emissions, this approach accounts for potential variations or heterogeneity and nonlinear patterns in the data, allowing for a more comprehensive understanding of the relationships being examined. This work also attempts to determine the distributional impacts of exogeneous variables on energy driven GHG emission by moment quantile regression, offering insights into how various energy driven GHG emissions quantiles react to differences in independent variables. In addition, this study uses BSQR (bootstrap quantile regression) as an additional test to evaluate the results obtained from the MMQR approach, thus enhances the robustness of our analysis. These two econometric techniques provide a robust analysis to examine the distributional impact of green trade, energy efficiency and carbon tax on energy driven GHG emission, which has the potential to present a valuable insight for policymakers to modify sustainable economic policies.

2 Literature Review

To achieve the target of energy efficient ecosystem, it is important to understand the role of economic strategies. The existing literature exhibits that there are many determinants of environmental degradation but the importance of green imports, green exports, green trade, energy efficiency and carbon tax on energy driven GHG emissions in G7 countries cannot be ignored. To examine the role of these factors, this paper assesses their effectiveness in achieving sustainable environmental goals and reducing the carbon footprint of energy consumption. The need to reduce the impact of climate change enhances interest in policies and practices that can reduce energy-related greenhouse gas emissions. Understanding these relationships is essential for guiding policy decisions and fostering a low-carbon economy.

Green Trade and Energy related Greenhouse Gas Emissions

The target to improve environmental quality and to achieve net zero emission, can only be accomplished if the root causes and effects of environmental deterioration can be assessed and effects be done to provide workable remedies to reduce their detrimental effects (Can et al., 2021). In recent decades, researchers have extensively explored the effects of international trade as a vital component of economic growth and national income on environmental quality and on carbon emissions (see for example, Zahra, Khan, Gupta, et al. (2022), Wang et al. (2024), Waris et al. (2023), Li et al. (2023)). However, there is no consensus reached among the researchers on impact of international trade on environmental sustainability, but we can summarize these findings into following three major outcomes. The first conclusion is that international trade reduces the environmental degradation and can be helpful to achieve the environmental sustainability (Xu et al., 2020). The second category of outcome is about positive effects of international trade on carbon emissions and thus proved to aggravate environmental sustainability (Jiang et al., 2022). The last results determined inconclusive and uncertain relationship between trade and environmental sustainability (Grossman & Krueger, 1993). Thus, these contradictory results extend researchers' attentions to promote green trade instead of traditional international trade.

The relationship between international trade and low-carbon development, with a particular focus on green taxation and its role in reducing carbon emissions, suggests trade policies can support low-carbon transitions through taxation strategies aimed at reducing greenhouse gas emissions (Jabeen et al., 2024). Similarly; J. Li et al. (2022) investigates the impact of green trade on carbon emission in China, and found the negative relationship between green trade and carbon emission thus suggest that increase in green trade can mitigate the environmental effects of the trade.

There is a controversy in the existing literature about the role of trade to achieve the environmental objectives. This study differs from previous literature in many ways as it examines the nonlinear or quadratic impact of green trade on energy driven GHG emissions, while previous studies primarily focus on linear effects of trade on carbon emissions. Considering the controversy and a research gap in existing literature, we reach a conclusion to reinvestigate and formulate three possible hypotheses as follows:

H_{11}: Green imports (disintegrated green trade head) have a significant negative impact on energy related GHG emission in G7 countries.

H_{12}: Green exports (disintegrated green trade head) are a significant negative determinant of energy related GHG emission in G7 countries.

H_{13}Green trade has a nonlinear association with energy-driven GHG emission and thus is helpful to attain an energy-efficient ecosystem after surpassing a threshold in G7 countries.

Energy Efficiency and Energy related Greenhouse Gas Emissions

Energy efficiency has been recognized as a critical component to reduce carbon emissions, particularly in the context of global climate change mitigation strategies. Studies over recent years have examined various sectors, revealing that improved energy efficiency not only reduces overall energy consumption but also significantly decreases carbon emissions. Qing et al. (2023) determined that the energy efficiency is a negative determinant of energy related GHG emissions in all quantiles by applying MMQR, but the study also suggests that in developing countries because of structural changes energy efficiency increases the environmental degradation. Moreover, the development of renewable energy systems has further demonstrated the potential to increase energy efficiency and reduce emissions, particularly in integrated systems that incorporate solar and hydrogen technologies (Gursoy & Dincer, 2024). Thus, these technologies are advancing, which emphasizes its importance to use renewable energy sources and increase energy efficiency simultaneously to obtain sustainable ecosystem. Similarly, Vakili et al. (2022), Hassan et al. (2022) , Lei et al. (2022) investigated the negative impact of energy efficiency on carbon emissions and determine it as an important determinant to improve the environmental sustainability. In summary, recent literature indicates that energy efficiency improvements across various sectors, whether through technological innovation or policy intervention, play a pivotal role in reducing carbon emissions and to achieve the sustainability goals. These strategies are seen as essential in the global effort to combat climate change and transition towards a low-carbon economy and energy efficient ecosystem.

Thus, considering the importance of energy efficiency in environmental goals, this study has reached to a testable hypothesis given below. This study differs from previous research in two manners. First, it investigates the impact of energy efficiency on energy driven GHG emissions, whereas prior literature has focused solely on its impact on carbon emissions. Second, it employs Method of Moments Quantile Regression (MMQR) to capture heterogeneous effects across different emission levels, which will provide a thorough understanding of this relationship compared to previous literature.

H_{14}: Energy efficiency is a significant but negative determinant of energy driven GHG emission in G7 countries.

Carbon Tax and Energy related Greenhouse Gas Emissions

A carbon tax is a financial cost which is imposed on the carbon emissions of fossil fuels, to reduce greenhouse gas emissions by making carbon emissions more costly (Xu et al., 2023). The impact of carbon tax has been widely investigated as a policy tool to reduce GHG emissions (Nong et al., 2021). It is a cost of carbon emissions or carbon footprint, which encourages industrial and consumption sectors to reduce carbon footprint. Macaluso et al. (2018) determines that carbon tax is strategy to increase the cost of carbon emission, has the capacity to shift the production process towards renewable energy consumptions. A comprehensive analysis of this research indicates that carbon taxes effectively reduce greenhouse gas emissions through a combination of renewable energy transition, energy efficiency, and through switching the economic activity from fossil fuels-based industries. This transition is effective to reduce the use of fossil fuels, increase the green investment especially in cleaner energy heads, promote energy efficiency (Pretis, 2022) and increase the green energy consumption. A coordinated global approach to carbon pricing could enhance the effectiveness of individual efforts of carbon taxes by different countries, which ensures that carbon emissions should be reduced at global level (Zahra & Badeeb, 2022; Zahra, Khan, & Nouman, 2022). In summary, carbon tax is an effective economic policy to reduce carbon emissions.

As existing literature mostly determine the impact of carbon tax on carbon emissions, this study contributes to the ongoing debate by investigating the impact of carbon tax on energy related GHG emissions in context of achieving the energy efficient ecosystem and postulate a testable hypothesis as follows:

H_{15}: Carbon tax is a significant negative determinant of energy related GHG emission in G7 countries.

3 Theoretical Framework and Methodology

3.1 Green Trade Measurement

To investigate the impact of green trade on energy related GHG emissions, it is important to understand and analyze the green trade. By following J. Li et al. (2022), the index of green trade (denoted as G_rT) can be calculated as follows which is also showing the intensity of green trade in each country.

$$G_rT_{ij} = \left(\sum_{i=1}^{n}(G_rE_{x_{ij}} + G_rI_{m_{ij}}) \middle/ \sum_{i=1}^{n}(TE_{x_{ij}} + TI_{m_{ij}})\right) \tag{1}$$

$$= \left(\sum_{i=1}^{n} G_rT_{ij} \middle/ \sum_{i=1}^{n} TT_{ij}\right)$$

G_rT_{ij} is green trade of i_{th} country in j_{it} year. G_rE_{ij} and $G_rI_{m_{ij}}$ represents green exports and green imports respectively. $TE_{x_{ij}}$ and $TI_{m_{ij}}$ exhibit the value of total export and the value of total imports. G_rT_{ij} shows green trade combined by green exports and green imports, while TT_{ij} represents total value of trade combined by total value of exports and total value of imports.

By following J. Li et al. (2022), Green export index (represented by $G_rE_xI_{ij}$) which is the proportion of green exports to total exports values, green import index (represented $G_rI_mI_{ij}$) which is green imports to total imports values, and total value of trade (represented by TT_{ij}) can be calculated as follows:

$$G_rE_xI_{ij} = \left(\sum_{i=1}^{n}(G_rE_{x_{ij}} / TE_{x_{ij}})\right) \tag{2}$$

$$G_rI_mI_{ij} = \left(\sum_{i=1}^{n}(G_rI_{m_{ij}} / TI_{m_{ij}})\right) \tag{3}$$

$$TT_{ij} = \left(\sum_{i=1}^{n} TE_{x_{ij}} + TI_{m_{ij}})\right) \tag{4}$$

A theoretical model of this study based on a traditional model of the influence of trade on the environment proposed by (Grossman & Krueger, 1993). There are three forms of trade effects and the final impact of green trade on greenhouse gas emissions and ultimately on energy related greenhouse gas emissions is exhibited by the combination of all these three factors. These effects include scale effects, technical effects and composition effects. By following Copeland and Taylor (1993) and Copeland and Taylor (2017), the production process including its impact on pollution is as follows:

$$P_r = \int_0^{\bar{x}} d(x)dx = \frac{I_1 \alpha_0(\overline{x})}{I_2 \alpha_1(\bar{x})} \tag{5}$$

By differentiating the above Equation 5 we get as follows:

$$dP_r = \frac{\partial P_r}{\partial I_1} dI_1 + \frac{\partial P_r}{\partial I_2} dI_2 + \frac{\partial P_r}{\partial I_3} dI_3 \tag{6}$$

Where x is total product produced I_1 is income, I_2 is utility maximation indirectly and I_3 is replaced by $\bar{x}$. The first term in above Equation $\frac{\partial P_r}{\partial I_1}$ is called scale effect of the trade, the second part is $\frac{\partial P_r}{\partial I_2}$ is technical effect of trade and third term $\frac{\partial P_r}{\partial I_3}$ is composite effect. Thus, we assume that $\frac{\partial P_r}{\partial I_1}$ >0 because proportionate increase in factors of production (inputs) and greenhouse gas emissions which will ultimately increase energy driven GHG emission. On the other hand, we assume that technical effects as negative $\frac{\partial P_r}{\partial I_2}$ <0, because of green trade promotion, environmental laws and regulations, green technological innovations and environmentally friendly production techniques. Thirdly, by assuming the positive influence of green trade in green economic growth, and negative relationship with environmental pollution, we assume composition effect of green trade as negative, thus $\frac{\partial P_r}{\partial I_3}$ <0. Figure 5 shows the impact mechanism of green trade on energy related greenhouse gas emissions.

Figure 5: Impact Mechanism of Green Trade on Pollution (Green color shows -ve determinant and red color shows +ve determinants)

Apart from green trade, energy efficiency is a crucial strategy for reducing carbon emissions, as it minimize energy consumption across different sectors, thus directlyfemissions (Peng, 2024). Similarly, carbon taxes effectively reduce greenhouse gas emissions by placing a financial cost on carbon output, which encourage industries to adopt green technologies and reduce their carbon footprint (Ding et al., 2019). Figure 6 presents the theoretical framework of this study while the notion of each variable is explained in the next section. To link with hypotheses of this study, the negative impact of green import and green export on energy driven GHG emissions is assumed, thus they both are hypothesized as a helpful determinant to achieve energy efficient ecosystem. Therefore, it is assumed $\frac{\partial EnGHG}{\partial GrImI} < 0$ and $\frac{\partial EnGHG}{\partial GrExI} < 0$, where *GrImI* and *GrExI* represents green import index and green export index and *EnGHG* is Energy driven GHG emissions. From the discussion in literature review, thus study assumes that green trade may have U shaped or inverted U-shaped relationship with energy driven GHG emissions which implies that when green trade increases, the rate of energy driven GHG emissions continues to decline up to a turning point (also called threshold point) and starts increasing afterwards and vice versa. Thus, given as in Figure 6, it is assumed $\frac{\partial EnGHG}{\partial GrT}$ >0 and $\frac{\partial^2 EnGHG}{\partial (GrT)^2}$ <0. Similarly, Figure 6 also represents $\frac{\partial EnGHG}{\partial EnEf} < 0$ and $\frac{\partial EnGHG}{\partial CT} < 0$ and these assumptions are based on the hypotheses of this study which assumes the negative relationship between energy efficiency (*EnEf*) and energy driven GHG emissions (*EnGHG*) and carbon tax (*CT*) and energy driven GHG emissions (*EnGHG*).

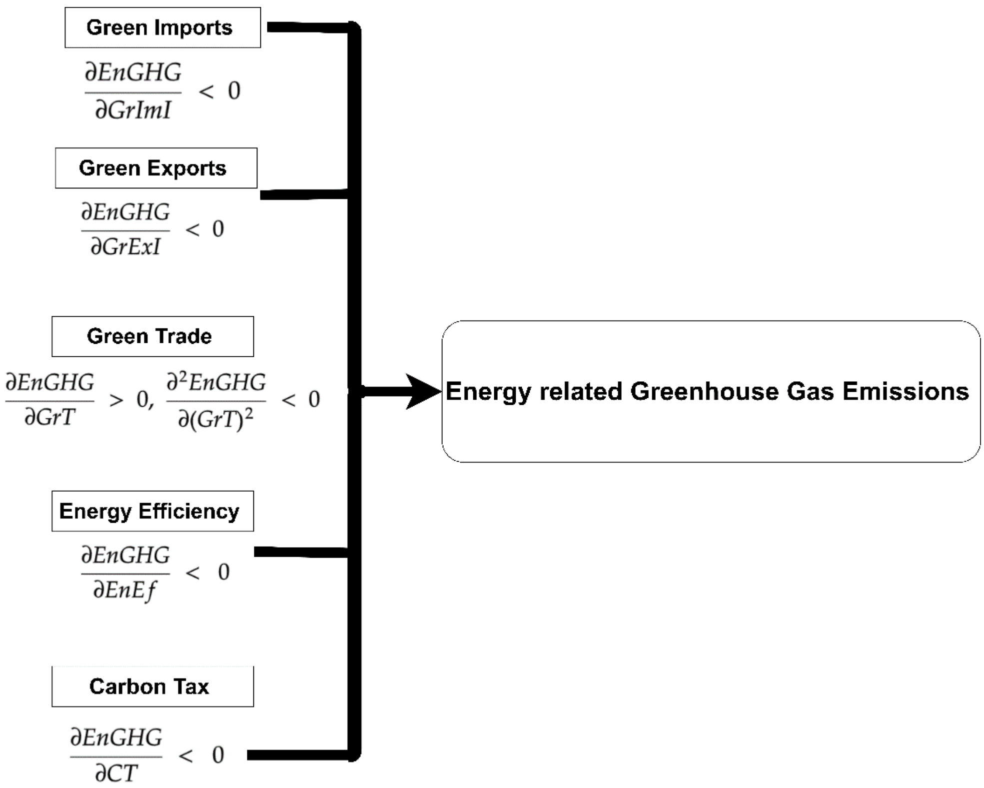

Figure 6: The Theoretical Background of Study

3.2 Data Source, the Models and Estimation Strategies

The annual time series data has been used for the G7 countries, cover the period between 1990 and 2023. The data for energy related GHG emissions and carbon tax is taken from OECD, the data for energy efficiency is taken from WDI and the data to construct the green trade index, green export index and green import index has been taken from IMF.

Based on literature review, energy related GHG (E_nGHG) is proposed as the function of green export index (G_rE_x), green import index (G_rI_m), green trade index (G_rT), energy efficiency (E_nE_f) and carbon tax (CT).

$$E_nGHG = f(G_rE_x , G_rI_m , G_rT, E_nE_f , CT) \quad (7)$$

We specify the functional form of Equation 7 as like Cobb Douglas production function in the following mathematical equation:

$$E_nGHG = e^{\beta_0}\, G_rE_x^{\beta_1}\, G_rI_m^{\beta_2}\, G_rT^{\beta_3}\, E_nE_f^{\ \beta_4}\, CT^{\beta_5}\, e^{\mu} \quad (8)$$

By taking the log-log model of Equation 8, we linearize this function as follows:

$$lE_nGHG_{it} = \beta_0 + \beta_1 lG_rE_{x_{it}} + \beta_2 l\, G_rI_{m_{it}} + \beta_3 lG_rT_{it} + \beta_4 l\, E_nE_{f_{it}} + \beta_5 l\, CT_{it} + \mu_{it} \quad (9)$$

Where subscript t refers to time, *i* represent individual country, and *l* represents to natural logarithm and μ_t is the stochastic disturbance term.

The literature review exhibits the importance to investigate nonlinear relationship between energy related GHG and green trade in the empirical estimation in the form of quadratic equation to find the threshold point (turning point). In the result the Equation 9 is transformed in following three models to investigate empirically while one of them is nonlinear equation to derive the threshold between green trade and energy related GHG emissions. In the result the Equation 9 is converted in to following three models:

$$lE_nGHG_{it} = \beta_0 + \beta_1 lG_rE_{x_{it}} + \beta_2\, lG_rI_{m_{it}} + \beta_3\, lE_nE_{f_{it}} + \beta_4 CT_{it} + \mu_{it} \quad (10)$$

$$lE_nGHG_{it} = \beta_0 + \beta_1 lG_rT_{it} + \beta_2\, lE_nE_{f_{it}} + \beta_3 CT_{it} + \mu_{it} \quad (11)$$

$$lE_nGHG_{it} = \beta_0 + \beta_{11} lG_rT_{it} + \beta_{12} l(G_rT_{it})^2 + \beta_2\, lE_nE_{f_{it}} + \beta_3 CT_{it} + \mu_{it} \quad (12)$$

Where $(lG_rT_{it})^2$ is the square term of log of green trade for G7 countries at *t* (time). Thus Equation 10 exhibits model 1 (linear model), Equation 11 depicts the model 2 (linear model) and Equation 12 determines the model 3 (quadratic or threshold model for green trade). These equations examine how energy driven GHG emissions is influenced by green trade, energy efficiency and carbon tax. Green trade is included in both linear and quadratic terms to capture potential nonlinear effects, which mean its impact on energy driven GHG emissions may change as green trade increases. Energy efficiency reflects how improvement in energy consumption affect energy related GHG emissions, while carbon tax represents policy measures to reduce energy driven GHG emissions to provide the deeper insight into environmental and economic policies.

As we assume the non-linear association between green trade index and energy driven GHG emission while considering the complete distribution, quantile regression is suggested technique for empirical estimation (Uribe et al., 2020). The quantile regression not only investigates the association between dependent and independent variables at the center but also at the entire conditional distribution, which are not necessarily at the symmetric position of the mean (Le Cook & Manning, 2013; Uribe et al., 2020). MMQR is an addition of quantile regression which associates those use of methods which are appropriate in the conditional mean analysis, and also exhibits the information of independent variables that can affect the whole conditional distribution (Machado & Silva, 2019). Unlike conventional OLS regression, which focuses solely to estimate the mean of the dependent variable, MMQR enables an examination of the conditional distribution across various quantiles. This approach not only incorporates techniques traditionally employed for estimating conditional means, such as addressing individual effects within the model, but also offers valuable insights into how the explanatory variables influence the entire distribution. These informational advantages are one of the most attractive aspects of quantile regression(Machado & Silva, 2019).

4 Empirical Results and Discussions

This section presents an in-depth analysis of the results obtained through the previously outlined methodology. The interpretation follows a chronological order, beginning with the pre-estimation statistics, followed by the long-run evaluation, regression analysis, and finally, the robustness check.

4.1 Descriptive Statistics

Table 1 describes descriptive statistics of the data and there is no significance difference between mean and median values of the data, which depicts that there are no outliers in selected models. On the other hand, the standard deviation of the data shows the extent to which each variable deviates from its mean value or the volatility of the data.

Table 1: Descriptive Statistics

	E_nGHG	**G_rE_x**	**G_rI_m**	**G_rT**	**G_rT^2**	**E_nE_f**	**CT**
Mean	5.91	0.59	0.56	0.90	0.85	0.98	0.25
Median	5.80	0.68	0.53	0.90	0.79	0.99	0.33
Maximum	6.80	1.07	1.07	1.37	1.88	1.27	0.56
Minimum	5.48	-0.32	0.16	0.56	0.32	0.63	-0.24
Std. Dev.	0.40	0.33	0.20	0.18	0.34	0.16	0.20

Source: Authors' calculations.

4.2 Cross Sectional Dependence and Tests of Homogeneity

After analysis of descriptive statistics, the next step is to find the cross-sectional dependence and slope of homogeneity in the data. Various social, financial and technical factors may influence the panel or cross-sectional data; therefore, it is important to conduct tests for slope of homogeneity and cross-sectional dependence prior to formal estimation analysis. Table 2 shows that the slope of the coefficient is significant at 1% level of significance in all three models which depicts the presence of heterogeneous effects among the variables which leads to apply the tests for the cross-sectional dependence in the data.

Table 2: Test of Homogeneity

Test	Model 1	Model 2	Model 3
	Statistics	Statistics	Statistics
Δ	12.71***	15.31***	14.67***
	(0.0)	(0.0)	(0.0)
Δ Adj	14.00***	16.56***	16.17***
	(0.0)	(0.0)	(0.0)

***, **, * is 1%,5% and 10% level of significance respectively (probability values are in parentheses)

Table 3 shows the results of four different cross sectional dependence tests which determine that all the variables of the data is cross sectionally dependent at 1% level of significance. The presence of cross-sectional dependence in the data leads the analysis towards second generation unit root tests.

Table 3: Cross Sectional Dependence Tests

Variables	Tests			
	Breusch-Pagan LM	Pesaran Scaled LM	Bias-Corrected Scaled LM	Pesaran CD
E_nGHG	265.89*** (0.0)	37.79*** (0.0)	37.68*** (0.0)	9.63*** (0.0)
G_rE_x	295.12*** (0.0)	42.30*** (0.0)	42.19*** (0.0)	8.45*** (0.0)
G_rI_m	568.14*** (0.0)	84.42*** (0.0)	84.32*** (0.0)	23.81*** (0.0)
G_rT	532.53*** (0.0)	78.93*** (0.0)	78.82*** (0.0)	23.02*** (0.0)
G_rT^2	527.15*** (0.0)	78.10*** (0.0)	77.99*** (0.0)	22.90*** (0.0)
E_nE_f	629.38***(0.0)	93.87***(0.0)	93.77***(0.0)	25.04***(0.0)
CT	256.87*** (0.0)	36.39*** (0.0)	36.29*** (0.0)	11.05*** (0.0)

***, **, *represent 1%,5% and 10% level of significance respectively (p-values are in parentheses)

4.3 Stationarity and Cointegration Tests

It is important to start the econometric analysis with the unit root test to find the order of the integration because the analysis in the model with the presence of unit root effects will give the spurious result and thus may derive the misleading coefficient analysis (Granger & Newbold, 1974). We employ the CIP test by Pesaran (2007) to determine the order of integration in the data. Table 4 shows that E_nGHG, G_rE_x, G_rI_m and CT have the unit root at level but are significant at order one that is I (1) at 1% level of significance. These outcomes suggest examining the long run association among the variables in all three models.

Table 4: Test of Stationarity

Variables	CIPS		Level of Integration
	I (0)	I (1)	
E_nGHG	-2.15	-5.80***	I (1)
G_rE_x	-2.15	-5.05***	I (1)
G_rI_m	-2.2	-4.93***	I (1)
G_rT	-2.67***	--	I (0)
G_rT^2	-2.67***	--	I (0)
E_nE_f	-3.08***	--	I (0)
CT	-1.43	-5.30***	I (1)

***, **, *represent 1%,5% and 10% level of significance respectively (values in parenthesis are probability values)

Kao (1999) test in employed to check the existence of the long run relationship in all three models and determine the rejection of the null hypothesis at 1% and 5% level of significance which depicts there is at least one long-run relationship exists.

Table 5: Panel Cointegration Test

Kao Panel Cointegration Test						
	Model 1		Model 2		Model 3	
	Test statistics	P-value	Test statistics	P-value	Test statistics	P-value
Modified Dickey Fuller t	-1.91**	0.02	-1.96**	(0.03)	-2.09**	(0.02)
Dickey Fuller t	-2.14***	0.02	2.24***	(0.01)	-2.32***	0.01
Augmented Dickey Fuller t	-2.41***	0.0	-2.51***	(0.0)	-2.60***	(0.0)
Unadjusted Modified Dickey Fuller t	-2.37***	0.0	-2.51***	(0.0)	2.75***	(0.0)
Unadjusted Dickey Fuller t	-2.33***	0.01	-2.47***	(0.0)	-2.57***	(0.0)

***, **, *represent 1%,5% and 10% level of significance respectively

4.4 Method of Moments Quantile Regression (MMQR)

The non-normality in the data suggests that applying the Methods of Moments Quantile Regression (MMQR) is an appropriate technique to investigate the determinants of energy related GHG emissions. Table 6 depicts the outcomes of MMQR for all selected 3 models in quantiles that are $Q_{0.25}$, $Q_{0.50}$, $Q_{0.75}$, $Q_{0.95}$ respectively. These results are discussed below with description.

Table 6 depicts that in Model 1 green export index is a positive factor of energy driven GHG emissions. The export in the green product can lead to an increase in energy driven GHG emissions through several mechanism. First the complete decoupling of emission from the production process even if it is production of green products, is almost impossible (Hickel & Kallis, 2020). Thus, production of green products such as renewable energy technologies and energy efficient products requires energy inputs while G7 countries dominates the fossil fuel for production process. Therefore, manufacturing these products for exports drive higher energy consumption and consequently higher energy related GHG emissions which means that these products consumption can have a significant carbon footprint due to the energy required for their production. Second, the transportation of green products over long distances, particularly in international trade, contributes to significant emissions due to the reliance on energy-intensive modes of transport (Zahra, Khan, Gupta, et al., 2022). Additionally, the widespread adoption of green technologies, facilitated by exports and potentially lower costs, may trigger a rebound effect, where energy savings are offset by increased overall energy consumption, further increase emissions (Dong et al., 2023).

Model 1 shows that green imports have the negative association with energy related GHG emissions in all four quantiles. Thus, to import the green products such as energy efficient technologies can help countries to transit away from the fossil fuels production (Yuan et al., 2023) as these products can increase the energy efficiency (Tariq et al., 2022; Zheng et al., 2023), which will reduce the overall energy consumption (Zahra & Badeeb, 2022) and ultimately reduce the energy related GHG emissions. The impact of low-carbon technology imports or green imports on energy driven GHG emissions in developed countries like G7 economies is complex and multifaceted, with both direct and indirect effects. Green imports generally have a positive impact on reducing carbon emissions in developed countries. Low-carbon technology imports can potentially reduce energy driven GHG emissions through improved efficiency and cleaner production processes, the overall impact of imports on carbon emissions in developed countries may be offset by increased economic activity and consumption. The effectiveness of low-carbon technology imports to reduce energy driven GHG emissions likely depends on how well these technologies are integrated into existing systems and the broader policy framework supporting their implementation.

The model 2 reveals that green trade index has the positive association with the energy related GHG emissions but model 3 reveals that green trade index has a significant inverted U-shaped relationship with energy related GHG emissions in G7 countries. These result depict that when green trade increases, the rate of energy related GHG emissions also continues to increase up to the turning point ranging between 1.0 to 1.2 units (in log) across four quantiles and starts decline afterwards. Figure 7 shows the inverted U-shaped impact of green trade on energy related GHG emissions with the turning point ranges between 1.0 and 1.2 units (in log) across all quantiles. The combination of scale, composition and technical effects is cause of inverted U shaped relationship between green trade and energy related GHG emissions (Zhang, 2012). In first stage of trade expansion, the scale effect leads this inverted U-shaped relationship because of increase in transport and production to meet the increase in the demand of the trade market which leads to increase in the energy consumption and fossil fuels (Wang et al., 2023), and ultimately this reliance will increase the energy related GHG emissions at first stage. Although, as there is a continues expansion in the green trade, the technical effects comes into notice with increase in the use of advanced green technologies which enables energy efficient production and green production (Ansari & Khan, 2021). This shift is noticed in the threshold point of inverted U-shaped relationship where energy related GHG goes at the highest level and starts to decline. These findings are also align with existing literature (see, for example, Ling et al. (2015) and Ansari and Khan (2021)). Thus the negative association between green trade and energy related GHG emission is also in line with (Can et al., 2021; He & Huang, 2022; J. Li et al., 2022), which shows the negative association between green trade and carbon emissions in the long run, but it is important for the governments to initiate the appropriate trade policy to achieve the environmental targets (He & Huang, 2022).

Table 6: Outcomes of Methods of Moment Quantile Regression

Variables	**Location**	**Scale**	**$Q_{0.25}$**	**$Q_{0.50}$**	**$Q_{0.75}$**	**$Q_{0.95}$**
			Model-1			
G_rE_x	0.90***	-0.009	0.91***	0.89***	0.89***	0.88*
	(0.0)	(0.68)	(0.0)	(0.0)	(0.0)	(0.0)
G_rI_m	0.59***	-0.09***	-0.50***	-0.61***	-0.67***	-0.77***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
E_nE_f	-0.95***	0.075	-1.02***	-0.94***	-0.89***	-0.81***
	(0.0)	(0.17)	(0.0)	(0.0)	(0.0)	(0.0)
CT	-1.48***	-0.02	-1.45***	-1.48***	-1.50***	-1.52***
	(0.0)	(0.51)	(0.0)	(0.0)	(0.0)	(0.0)
Constant	7.03***	0.08**	6.95**	7.04***	7.09***	7.18***
	(0.0)	(0.05)	(0.0)	(0.0)	(0.0)	(0.0)
			Model-2			
G_rT	0.57**	-0.19	0.74***	0.60***	0.38***	0.14
	(0.0)	(0.02)	(0.0)	(0.0)	(0.05)	(0.62)
E_nE_f	-0.20	-0.04	-0.17	-0.20	-0.25	-0.29
	(0.40)	(0.79)	(0.47)	(0.40)	(0.46)	(0.54)
CT	-1.35***	-0.45***	-0.96***	-1.30***	-1.84***	-2.41***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Constant	5.93***	0.51	5.49***	5.87***	6.50***	7.12***
	(0.0)	(0.83)	(0.0)	(0.0)	(0.0)	(0.0)
			Model-3			

G_rT	8.07***	0.47	7.71***	8.06***	8.49***	9.05***
	(0.0)	(0.45)	(0.0)	(0.05)	(0.08)	(0.0)
G_rT^2	-3.77***	-0.37	-3.48***	-3.76***	-4.10***	-4.54***
	(0.0)	(0.22)	(0.0)	(0.0)	(0.0)	(0.0)
Turning Points			1.1	1.2	1.04	1.0
E_nE_f	-1.04***	-0.03	-1.02***	-1.04***	-1.06***	-1.09**
	(0.0)	(0.88)	(0.0)	(0.0)	(0.07)	(0.20)
CT	-1.02***	-0.25**	-0.83***	-1.0***	-1.23***	-1.53***
	(0.0)	(0.04)	(0.0)	(0.0)	(0.0)	(0.0)
Constant	3.10***	0.12	3.01***	3.09***	3.21***	3.35***
	(0.0)	(0.64)	(0.0)	(0.0)	(0.0)	(0.0)

***, **, *represent 1%,5% and 10% level of significance respectively (p-values are in parentheses)

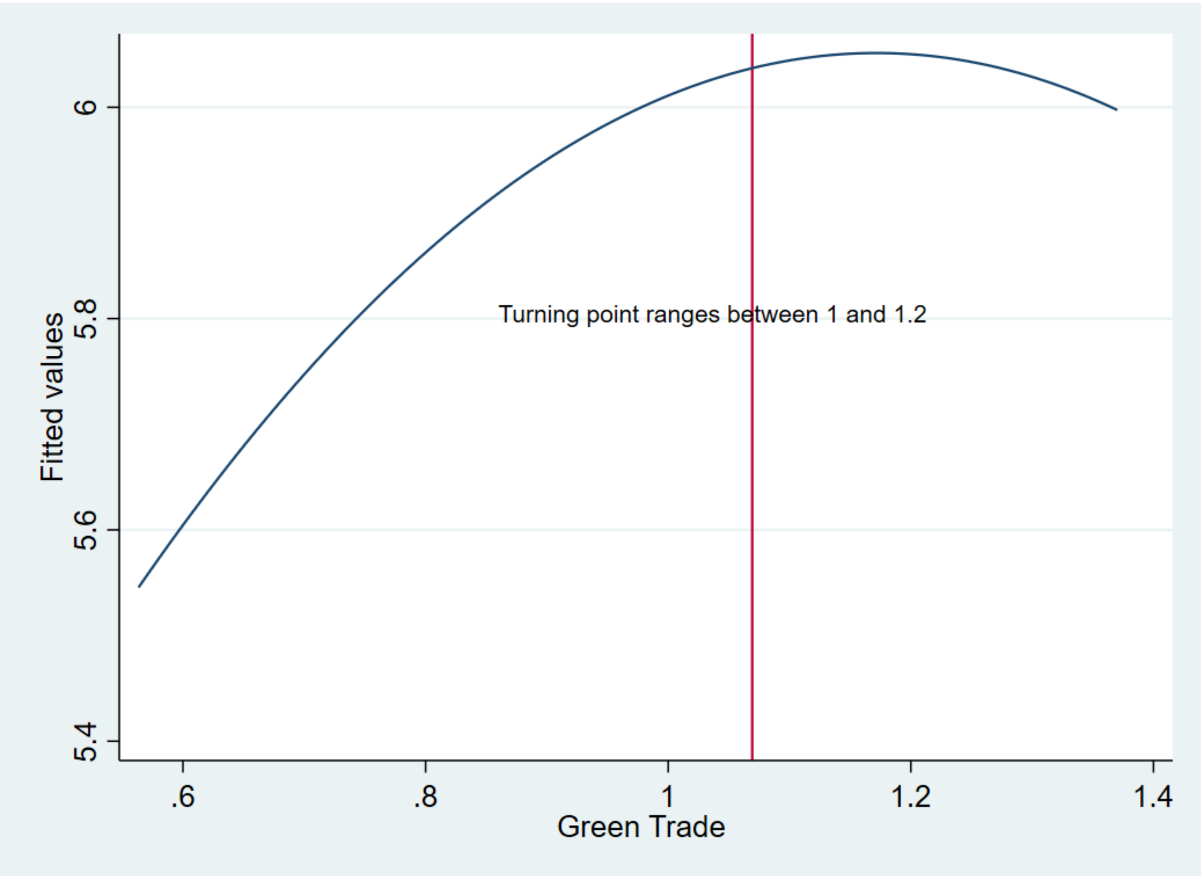

Figure 7: The nonlinear relationship between green trade and energy related GHG emission

Another assumed determinant of this study is energy efficiency, and the outcomes exhibit that energy efficiency is a negative determinant of energy driven GHG emission in all four quantiles. This outcome is also in line with the existing literature (see, for example, Qing et al. (2023) , R. Li et al. (2022), Mirza et al. (2022), Akram et al. (2020), Lei et al. (2022)).

The last determinant of energy related GHG emissions is carbon tax. Results show that the carbon tax is a negative determinant of energy related GHG emission in all three models across all four quantiles. Implementing a carbon tax leads to reductions in carbon emission (Pretis, 2022), however the evidence of impact and it's magnitude on aggregate emissions is mixed (Nong et al., 2021). The magnitude of emission reductions depends on the level of the carbon tax, its coverage and implementation, and sectoral differences in emission responses (Du et al., 2022; Siriwardana et al., 2011) and thus this reduction in the carbon emission leads to reduction in energy related GHG emissions.

Figures 8-10 provide a graphical representation of the MMQR process for the coefficients of the three models, illustrating the quantile trends of energy driven GHG emission and their determinants over time. These graphs depict the relationship between the variables across different quantiles (percentiles), with the slopes of the lines indicating the change in the dependent variable for a one-unit change in the respective independent variable at each specific quantile (percentile).

The results of this study offer insights for policymakers which aim to achieve sustainable reduction in energy driven GHG emissions. The inverted U-shaped relationship between green trade and energy driven GHG emissions suggests that while at first stage, increase in green trade may contribute to rising emissions due to production costs and after surpassing a threshold or turning point leads to significant reduction in energy emissions. This highlights the importance of sustained investment in green trade to reach the turning point where energy driven GHG emissions begin to decline. Furthermore, the consistent negative associations between green imports, carbon tax, and energy efficiency with energy driven GHG emissions determines the effectiveness of these measures to achieve the energy efficient eco-system. Policymakers should prioritize to reduce trade barriers for green imports and exports, implement robust carbon pricing mechanisms, and should promote energy efficiency initiatives to multiply these benefits. Collectively, these findings provide a roadmap to integrate trade and environmental policies to achieve net-zero targets.

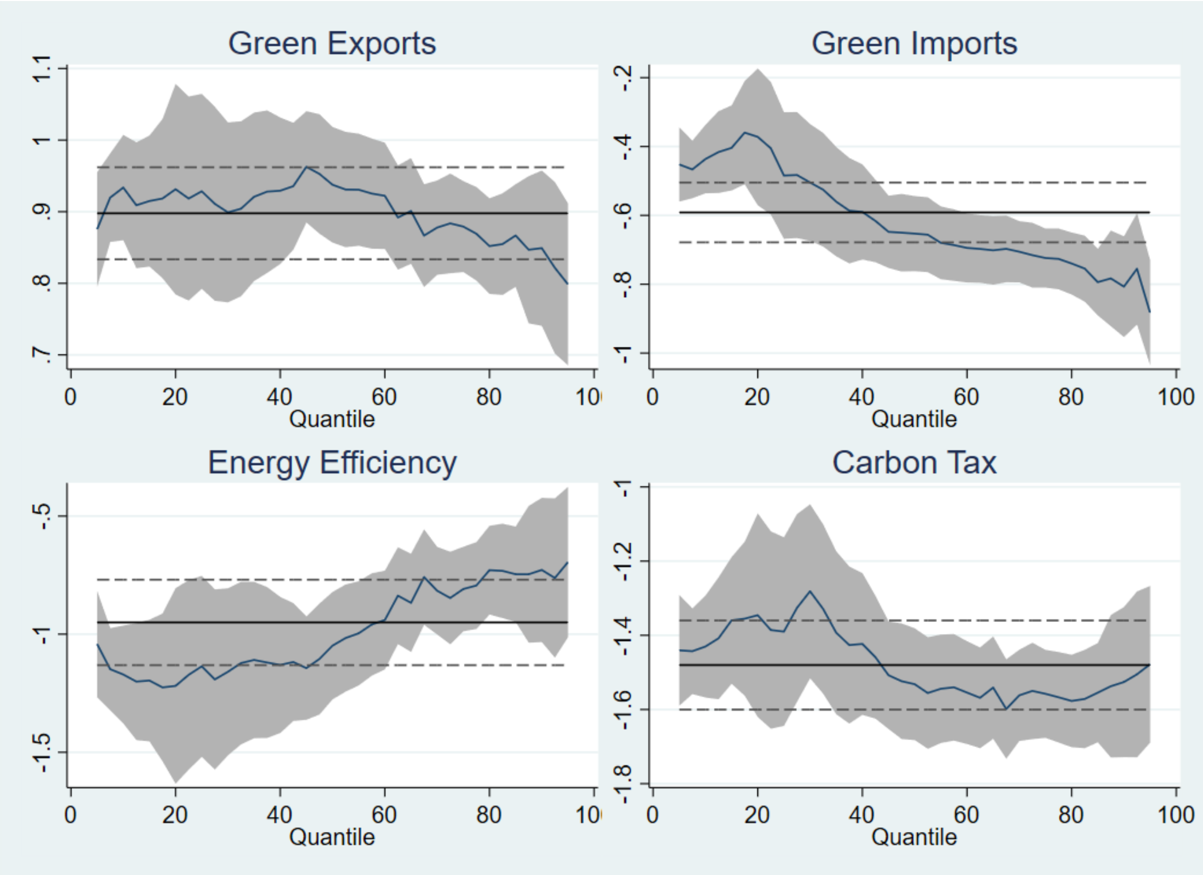

Figure 8: The graphical representation of MMQR coefficients (Model-1)

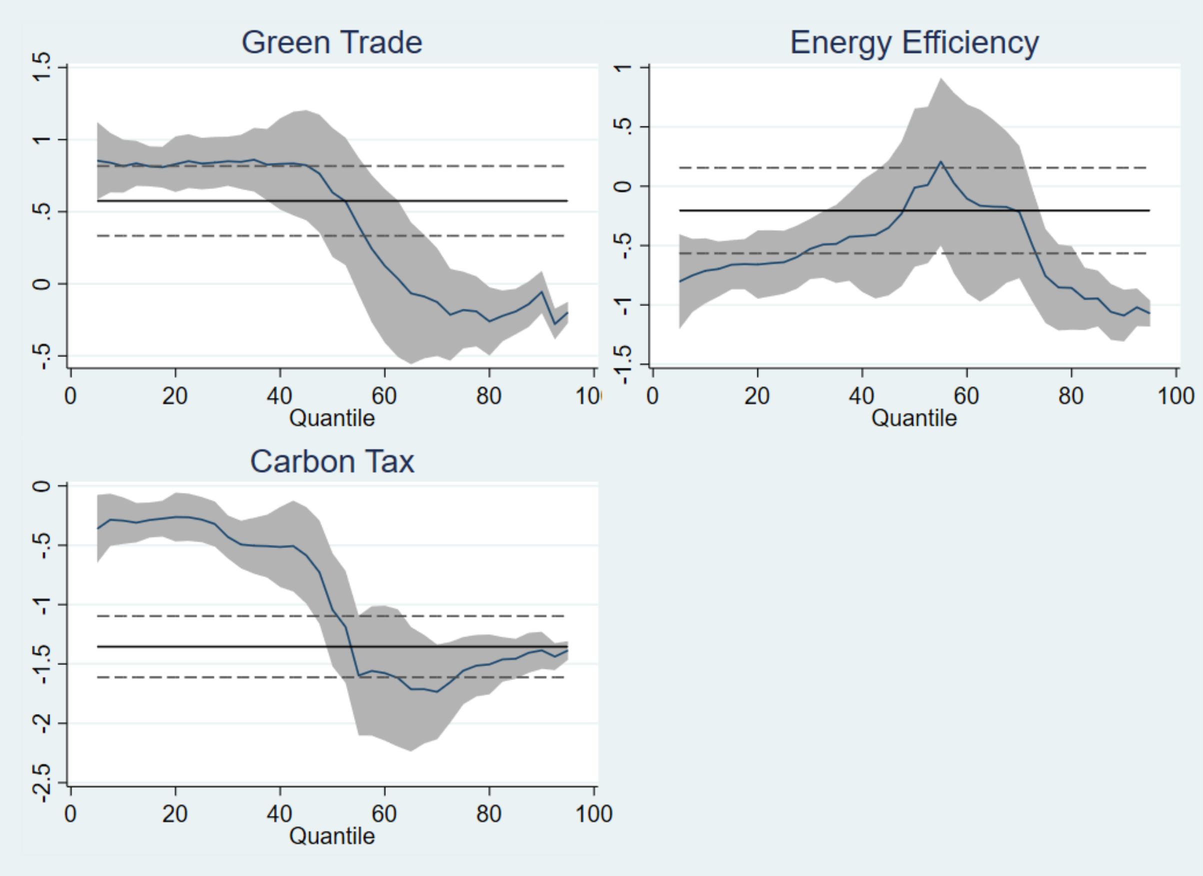

Figure 9: The graphical representation of MMQR coefficients (Model-2)

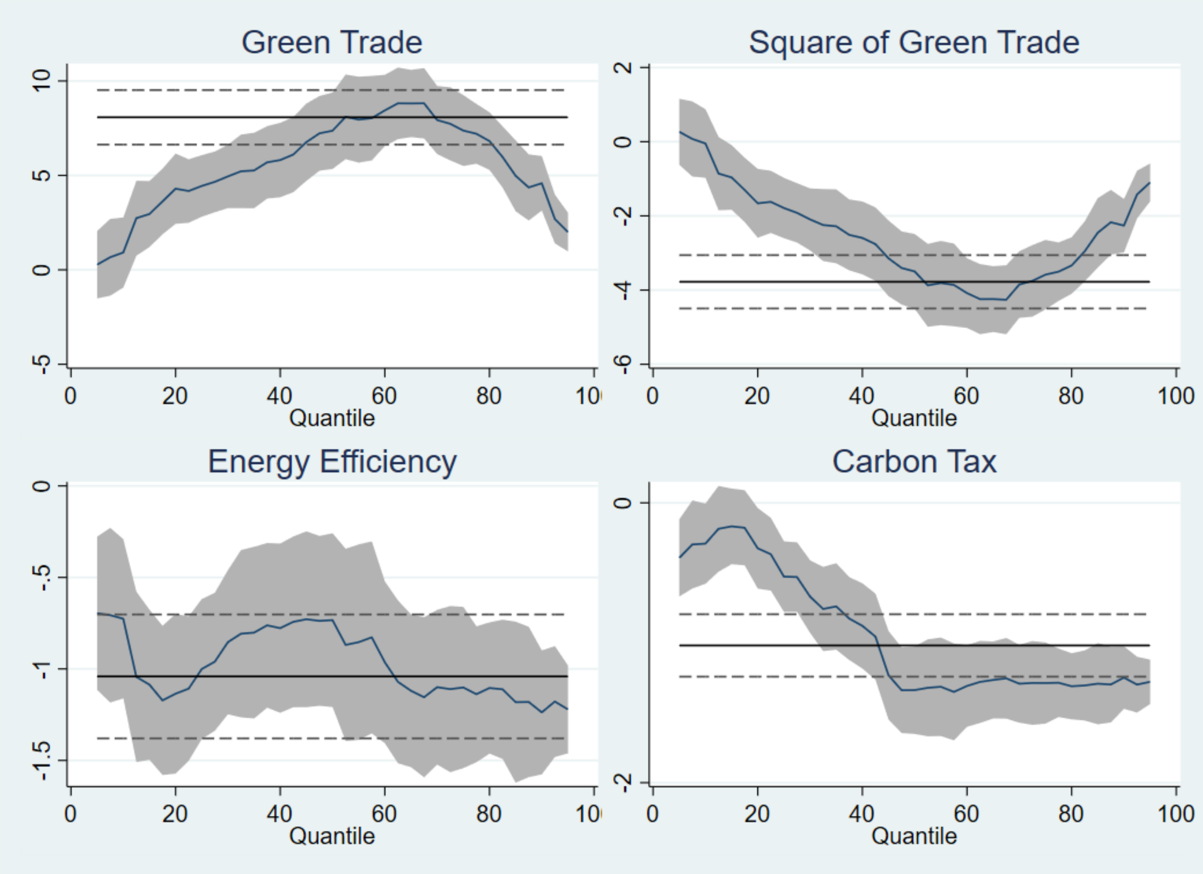

Figure 10: The graphical representation of MMQR coefficients (Model-3)

4.5 BSQR as Robustness Test

Bootstrap Quantile Regression (BSQR) is applied to check the robustness of all three models and Table 7 depicts the outcomes which determine that the primary model MMQR has demonstrated the significant, efficient and reliable results. The results of the BSQR analysis are consistent with the primary findings obtained from MMQR. Specifically, the inverted U-shaped relationship between green trade and energy driven GHG emissions remains same across all quantiles. These results confirm the non-linear dynamics, and the threshold effects identified in the main analysis. The alignment between BSQR and MMQR outcomes reinforces the reliability of our conclusions. Both methods highlight the critical role of green trade and energy driven GHG emissions across all quantiles. This consistency exhibits the robustness of the relationships presented in this study and demonstrates that findings are not sensitive to the choice of quantile regression technique.

Table 7: BSQR-robustness check

Variables	**$Q_{0.25}$**	**$Q_{0.50}$**	**$Q_{0.75}$**	**$Q_{0.95}$**
		Model 1		
G_rE_x	0.93***	0.94***	0.88***	0.88***
	(0.0)	(0.0)	(0.0)	(0.0)
G_rI_m	-0.48***	-0.65***	-0.73***	-0.88***
	(0.0)	(0.0)	(0.0)	(0.0)
E_nE_f	-1.14***	-1.15***	-0.81***	-0.70***
	(0.0)	(0.0)	(0.0)	(0.0)
CT	-1.39***	-1.53***	-1.55***	-1.48***
	(0.0)	(0.0)	(0.0)	(0.0)
Constant	7.03***	7.16***	7.07***	7.20***
	(0.0)	(0.0)	(0.0)	(0.0)
		Model 2		
G_rT	0.83***	0.63***	-0.20***	-1.20
	(0.0)	(0.0)	(0.05)	(0.31)
E_nE_f	-0.64***	-0.012	-0.76**	-1.07***
	(0.0)	(0.97)	(0.05)	(0.54)
CT	-0.28**	-1.04**	-1.56***	-1.38***
	(0.03)	(0.05)	(0.0)	(0.0)
Constant	5.67***	5.56***	7.43***	7.80***
	(0.0)	(0.0)	(0.0)	(0.0)
		Model 3		
G_rT	4.44***	7.36***	7.37***	2.00
	(0.0)	(0.05)	(0.0)	(0.17)
G_rT^2	-1.78***	-3.49***	-3.59***	-1.09*
	(0.0)	(0.0)	(0.0)	(0.10)
Turning Points	1.2	1.05	1.03	0.92
E_nE_f	-1.00***	-0.73***	-1.10***	-1.22**
	(0.0)	(0.0)	(0.0)	(0.0)
CT	-0.53***	-1.34***	-1.30***	-1.28***
	(0.0)	(0.0)	(0.0)	(0.0)

Constant	4.39***	3.30***	3.84***	6.83***
	(0.0)	(0.0)	(0.0)	(0.0)

***, **, * are 1%,5% and 10% level of significance respectively (p-values are in parentheses)

4.6 Causality Test

Dumitrescu- Hurlin Panel Causality test has been employed to investigate the causal relationship between carbon emission and assumed determinants of the carbon emission. The pairs $GrE \neq EnGHG, EnGHG \neq GrE, EnGHG \neq GrI, EnGHG \neq GrT, EnEf \neq EnGHG, EnGHG \neq EnEF$ determines the rejection of null hypothesis which exhibits the presence of homogenous causality across panels with 1% and 5% and 10% level of significance. On the other hand, $GrI \neq EnGHG, GrT \neq EnGHG, CT \neq EnGHG$ *and* $EnGHG \neq CT$ do not show any significant causal association between these pair variables. These results determine that green imports and energy GHG emissions, green exports and energy GHG emissions, carbon tax and energy GHG emissions in both ways cause to accept the null hypothesis which means that heterogeneous causality exists across the panels.

Table 8:Dumitrescu-Hurlin Panel Causality Test

H_0	W-Stats	$\overline{Z}$ Stats	P-value
$lGrE \neq lEnGHG$	2.43**	2.24	0.03
$lGnGHG \neq lGrE$	2.94*	3.09	0.0
$lGrI \neq lEnGHG$	1.18	0.20	0.86
$lGnGHG \neq lEGrI$	3.06*	3.20	0.0
$lGrT \neq lEnGHG$	1.44	0.62	0.54
$lGnGHG \neq lGT$	2.90*	3.02	0.0
$lEnEf \neq lEnGHG$	2.86*	2.95	0.0
$lEnGHG \neq lEnEf$	2.21***	1.88	0.06
$lCT \neq lEnGHG$	1.25	0.29	0.77
$lEnGHG \neq lCT$	1.37	0.51	0.62

***, **, *represent 1%,5% and 10% level of significance respectively

5 Conclusion and Policy Recommendations

This study investigates the impact of green export, green import, green trade, energy efficiency and carbon tax on energy driven GHG emissions in G7 countries. This study also investigates the nonlinear or inverted U-shaped relationship between green growth and energy related GHG emissions. These findings are novel with respect to investigate the non-linear impact of green trade on energy driven GHG emission, to find the threshold points. Similarly, the impact of green export index, green import index and carbon tax on energy related GHG is also investigated for the first time. This study concludes the negative impact of green imports, energy efficiency and carbon tax on energy related GHG emission all in all four quantiles, on the other hand it depicts the positive association between green export and energy related emissions. The green trade has the inverted U-shaped determinant of energy emissions, which suggests that it will increase the energy related GHG emissions at first but after surpassing a threshold or turning point, an additional unit of green trade will reduce the energy related GHG emissions. Thus, these outcomes suggest that green trade will not help to reduce the energy emission at start but after a turning point it will help to reduce the energy emissions. Based on these finding various policy recommendations have been proposed. Firstly, green investment to promote green growth transition in renewable energy heads should be given the top priority by policy makers. This target can be achieved by private- public partnerships, tax innovation, tailoring carbon tax strategies and subsidies to the green energy sector. Secondly, green technological innovations should be promoted to enhance the industrial sector in favor of economic and environmental sustainability. Thirdly, the digital economy, smart technologies and the use of artificial intelligence (AI) for the protection of environment should be promoted to reduce the energy related GHG emissions. Leveraging AI plays an important role reduce carbon emissions and drive sustainability. The data centers running AI research currently consume massive amounts of energy and contribute substantially to energy driven GHG emissions. However, the emerging field of Green AI presents solutions by building environmental sustainability directly into AI systems. This has the potential to significantly reduce emissions across the entire value chain. Therefore, the investment in sustainable AI solutions that can help realize this vision of using AI to drive a transition towards a more environmentally friendly economy (Ali, 2023). Fourthly, the portion of green trade in the total trade should be increased. The role of government in promoting green technological innovation transformation has been suggested in export sector.

G7 countries need to handle a regular energy efficient ecosystem and need to focus on improving the green growth in favor of environmental sustainability through carbon policy. Specially more concentration should be allocated to enhance the production and utilization capacity of green growth to curtail the upheaval of continuous energy driven GHG emissions.

To improve the agricultural eco-efficiency in favor of environment, the subsidies should be given to curtail the fossil fuels consumption in agricultural sector and for replacement of renewable energy resources in this sector. Additionally, landfill energy should be introduced in the agricultural sector to reduce over all footprint of energy driven GHG emissions.

Similarly, trade liberalization plays its important role to stimulate the carbon footprint both in long run and in short run (Zahra, Khan, Gupta, et al., 2022), therefore strict environmental regulatory policies should be implemented to reduce the environmental degradation in selected countries and steps should be taken to shift the trade paradigm to green trade. Renewable energy trade should be promoted to facilitate the trade of renewable energy technologies and products such as solar panels, wind turbines and energy efficient appliances.

5.1 Limitations

Despite these policy recommendations, certain limitations of this study should not be ignored. Firstly, this research is restricted to G7 economies only. A similar analysis can be replicated in developing countries and in top carbon emitters. The independent variables of this study can be reinvestigated while keeping other Sustainable Development Goals (SDGs) into account, especially with reference to responsible consumption and production SDG-12. Other important direct and indirect economic factors and novel econometric techniques can be applied to determine the synergies and trade-off with reference to energy related GHG emissions in G7 countries. If long time series data available, then the choice of econometric technique can also be replaced to perform long run and short run analysis. While quantile regression is powerful to capture heterogeneous effects, it may be more complex to interpret compared to traditional mean regression models. This can make it challenging to communicate the results to policymakers. Quantile regression provides insights across different points of the distribution, but the results may not be easily generalizable to the entire population. Different quantiles may show varying effects that could complicate policy recommendations or interpretation. Lastly, this study focuses on broad economic trends, but sector-specific dynamics such as differences between manufacturing, agriculture, or energy sectors may not be fully accounted for, which potentially limit the applicability of the findings across all sectors. Future research studies could explore this approach for a more comprehensive cost-benefit analysis.

Declaration of Competing Interest

The authors declare that they have no known competing interests that could have appeared to influence the work reported in this paper.

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