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RESEARCH ARTICLE

Sustainable Energy Transitions in OECD Economies: Examining the Influence of Eco-Innovation, Alternative Energy Sources, and GDP on Energy Efficiency

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ABSTRACT

This study investigates the impact of eco-innovation, alternative energies, and GDP on energy efficiency (EE) in OECD countries from 1990 to 2021. Despite the recognized importance of EE in mitigating climate change, progress has been slow, and the influencing factors are not fully understood. Using panel data from OECD countries, we employ the CIPS unit root test, Westerlund cointegration technique, and CS-ARDL estimation to examine the long-run relationships between the variables. The results reveal a positive and significant impact of eco-innovation, alternative energies, and GDP on EE, suggesting that investments in environmentally friendly technologies, renewable energy sources, and economic growth can contribute to improved EE. The findings have important implications for policymakers seeking to promote sustainable energy transitions and highlight the need for further research on the complex interplay between technological, economic, and policy factors in shaping EE outcomes.

INTRODUCTION

Climate change has become a vexing issue to the whole humankind these days. It requires significant joint efforts from different nations to deter the negative impacts on our life and the planet. The atmospheric CO_2 content has increased drastically by 47% since the industrial revolution, accelerating the greenhouse effect and contributing to global warming (IPCC 2019). Industrialization increases the number of toxic gases in the atmosphere. Unplanned modern urbanization and rapid industrialization around the globe have affected air, water, soil and sound pollution. The sources of water polluted in line for to the industrialization, urbanization and sewage waste. In the same foot, smoke released by vehicles and poisoned gases released by industries and dust particles poison the air. Since humans began to practice outfits and designed a society, human has played a crucial role in the advancement of the natural environment (Gu et al., 2023). Environmental degradation is not only a serious threat to human health but also affects all types of development projects across countries. The environment is somewhat we are accustomed to good environmental management is the most

important need time for economic prosperity and development across countries. Sometimes it is fallaciously associated with the luxury of the beauty of wealthy nations.

To combat global carbon emissions, EE is receiving more attention than regulation of industrial activities. Globally, EE has been recognized as a crucial factor in reducing CO_2 emissions. EE not only reduces manufacturing costs through innovation, but it also helps consumers save money and reduce their carbon footprint, thereby contributing to the global challenge of mitigating climate change. Moreover, enhancing energy efficiency substantially reduces CO_2 emissions and enhance energy security. The current energy matrix is the consequence of historical decisions, but new government commitments are required to implement and sustain a non-fossil fuel-based alternative. To mitigate climate change, it is unquestionably necessary to transition away from fossil fuels, which requires global CO_2 emissions to plateau by 2025 and reach net zero by 2050. Future energy systems will also require technological innovation, and we must leave a safety margin to prevent calamitous climate change. Despite the impossibility of isolating a single cause for the global economic crisis, it is difficult to overlook the role of fossil fuel emissions, which exacerbated an already dangerous climate change scenario when a series of extreme weather events pushed Earth over the threshold for abrupt climate change. Unfortunately, the current rate of CO_2 emissions is still inconsistent with the Paris Agreement's objective of keeping global warming well below 2^0C (IPCC, 2021).

The necessity of mitigating the effects of climate change has led to an increased emphasis on EE, which is the capacity to use energy in a way that minimizes waste while maximizing economic and environmental benefits (Safi, Chen, and Zheng, 2022), is a crucial means of achieving this goal. Energy efficiency is one of the driving factors behind sustainable development, and it is increasingly recognized as a vital component of international energy policy. EE is widely regarded as an essential strategy for reducing the carbon footprint (Ali et al., 2021). The Paris Agreement, adopted in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC), aims to limit global warming to well below 2^0C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5^0C. Energy efficiency is explicitly mentioned in the agreement as a means to reduce greenhouse gas emissions and enhance climate resilience. Article 4 of the Paris Agreement calls for the promotion of sustainable development and the implementation of measures to improve energy efficiency. Moreover, The SDGs, adopted by the United Nations in 2015, provide a comprehensive framework for global development and sustainability. Energy efficiency is directly linked to several SDGs, including Goal 7: Affordable and Clean Energy and Goal 13: Climate Action. Goal 7 specifically highlights the need to ensure access to affordable, reliable, sustainable, and modern energy for all, while Goal 13 emphasizes the urgent action required to combat climate change and its impacts, including through energy efficiency measures. Also, The United Nations Sustainable Development Summit held in 2015 resulted in the adoption of the 2030 Agenda for Sustainable Development. The agenda includes a set of 17 SDGs, and energy efficiency is recognized as a key strategy for achieving several of these goals. The summit highlighted the role of energy efficiency in reducing energy consumption, improving energy access, and promoting sustainable economic growth.

In recent years, EE has become a pressing concern due to the rising demand for energy and the imperative to take action to reduce carbon footprint. Although the EE has been noted as critically important, the positive changes have been seldomly witnessed, while the influencing factors are not always grasped in full. Because the energy industry has such a significant impact on the environment, efforts to increase energy efficiency are crucial for mitigating the adverse effects of climate change (Safi et al., 2021). According to a report by the International Energy Agency (IEA), energy efficiency improvements in OECD countries have resulted in a 20% reduction in energy consumption per unit of GDP over the past decade (IEA, 2021). However, despite these improvements, there is still a significant potential for further energy efficiency gains in OECD countries. The IEA estimates that cost-effective energy efficiency measures could reduce energy consumption in these countries by an additional 18% by 2040 (IEA, 2021). Previous research studies have focused on various

determinants of energy efficiency in OECD countries. For example, a study by Zhang and Choi (2013) found that technological innovation and government policies play a crucial role in promoting energy efficiency in these countries. Another study by Zhu et al. (2019) examined the impact of energy prices and income levels on energy efficiency in OECD countries. The findings suggested that higher energy prices and higher income levels are associated with greater energy efficiency. Despite these research efforts, there is still a lack of comprehensive understanding of the determinants of energy efficiency in OECD countries. Many factors, such as eco-innovation, alternative energies, and GDP, have been identified as potential drivers of energy efficiency, but their specific impacts and interactions are not fully explored.

The OECD countries have made significant strides in EE in recent years, with some countries serving as models in terms of the laws and practices they have enacted regarding EE (World Bank, 2021). Energy efficiency is an essential component of the energy strategies adopted by OECD nations. These nations have set their sights on lowering their overall energy consumption while simultaneously bolstering their economic growth and enhancing their energy security. In order to accomplish this, they undertake strategies such as boosting the use of alternative energies, increasing the use of smart grid technology, promoting the use of energy-efficient products and appliances, and enhancing the building insulation. In addition, a number of nations that are members of the OECD have set goals for EE and have enacted policies to stimulate EE investments. These policies include construction regulations and standards, labeling and labeling schemes, and financial incentives. When it comes to the development of EE policies, the involvement of governments cannot be overstated; hence, several countries that are members of the OECD have formed national or regional EE bodies to coordinate and monitor developments (Zhang, X., & Choi, Y., 2013). The countries that make up the OECD have made great strides in recent years toward improving their EE, which has resulted in a decrease in energy consumption as well as an increase in alternative energy sources. However, there is still a lot of work to be done because these countries continue to face challenges such as increasing population, increasing urbanization, and changing technological landscapes, all of which have an effect on the demand for energy and the security of energy supplies.

Although energy efficiency is widely acknowledged as a key strategy for mitigating the effects of climate change and reducing greenhouse gas emissions, its roots remain inadequately understood. This is due, in part, to the complexity of the energy system and the large variety of factors that might affect energy consumption. In other words, this is a result of the wide range of factors. According to Grossman and Krueger (1992), there is a wide variety of factors that can have an effect on environmental economics. These elements include developments in technology, changes in consumer behavior, policy actions, and the regulatory environment. Important elements that have the potential to influence EE include eco-innovation, alternative energies, and GDP. The term "eco-innovation" refers to the development of new and improved goods, services, and methods that have a smaller negative effect on the surrounding natural environment. The use of energy sources that are regenerated naturally, such as wind, solar, and hydropower, is an example of what is referred to as alternative energy. This study highlights the progress that has been accomplished and the problems that still need to be addressed with energy efficiency in OECD countries till 2021 by presenting facts and numbers on EE in those countries. The primary objective of this undertaking is to provide classifications for the important aspects of EE. The implications of the findings for future energy policy will also be investigated, as will the potential contribution that energy efficiency can make to reducing the negative effects of climate change. The findings of this study will add to a better knowledge of the whole environment of equal employment, and they will inform future policy decisions that aim to promote more EE. These findings will assist foster a better understanding of the significance of EE and the role it plays in mitigating the effects of climate change, and they will be of interest to policymakers, energy specialists, and the general public.

Examining the impact of eco-innovation, alternative energies, and GDP on EE contributes significantly to the existing literature and policy debates in several ways. Firstly, despite the recognition of energy efficiency as a crucial strategy for reducing carbon emissions and mitigating climate change, there is still a lack of comprehensive understanding of the factors that influence EE. By analyzing the impact of eco-innovation, alternative energies, and GDP on EE in OECD countries, this study aims to fill this knowledge gap and provide valuable insights into the determinants of energy efficiency. Secondly, Energy efficiency policies play a vital role in achieving sustainable development goals and transitioning to a low-carbon economy. By examining the relationship between eco-innovation, alternative energies, GDP, and EE, this research can inform the formulation of effective policies that promote energy efficiency. Policymakers can use the findings to design targeted interventions and incentives to encourage eco-innovation, the adoption of alternative energies, and sustainable economic growth. Thirdly, Eco-innovation, which involves the development of new and improved goods, services, and methods with a smaller negative impact on the environment, is crucial for enhancing energy efficiency. By highlighting the positive impact of eco-innovation and alternative energies on EE, this study can contribute to the promotion and adoption of environmentally friendly technologies and practices. It can encourage investment in research and development of energy-efficient solutions and foster a culture of innovation in the energy sector. Fourthly, the findings of this research emphasize the positive relationship between GDP growth and energy efficiency. This highlights the importance of economic growth for sustainable energy transition. By understanding the link between GDP and EE, policymakers can develop strategies that prioritize both economic development and energy efficiency, ensuring a balance between economic prosperity and environmental sustainability. Last but not least, climate change is a pressing global challenge, and reducing carbon emissions is a key objective. Energy efficiency, driven by eco-innovation and the adoption of alternative energies, plays a crucial role in achieving these goals. By examining the impact of these factors on EE, this study contributes to the broader efforts to address climate change and reduce greenhouse gas emissions.

In short, the problem statement of the paper is that despite the recognized importance of EE in mitigating the effects of climate change and reducing carbon emissions, there have been few developments in the field and the determinants of EE are not fully explored. The research gap is that there is a lack of understanding of the impact of eco-innovation and alternative energies on EE in OECD countries, as well as the relationship between GDP growth and EE. The paper aims to fill this gap by analyzing the impact of eco-innovation and alternative energies on EE in OECD countries over a period of 1990 to 2021 and examining the relationship between GDP growth and EE. The research objectives are to investigate the impact of eco-innovation and alternative energies on energy efficiency in OECD countries, as well as to examine the relationship between GDP growth and energy efficiency in these countries. The hypotheses are that eco-innovation has a positive impact on energy efficiency, alternative energies are positively associated with energy efficiency, and GDP growth is positively correlated with energy efficiency. These objectives and hypotheses address the research gaps in understanding the impact of eco-innovation, alternative energies, and GDP growth on energy efficiency in OECD countries.

Therefore, the research is structured as follows: First, a general introduction to the problem of climate change and its implications for human life and the earth as a whole is provided. Second, an explanation of energy efficiency and a discussion of the elements that can have an impact on energy efficiency are provided. In the third section, we give some facts and numbers on energy efficiency in OECD nations, and in the fourth section, we analyze the objectives of the study as well as its contribution to the area. In the final step, both the implications of the results and the conclusions formed from them are analyzed.

LITERATURE REVIEW

The world is currently confronting a significant challenge in the form of climate change, which has far-reaching repercussions not just for human lives but also for the globe itself. The necessity of reducing the impact of climate change has resulted in an increased emphasis on EE as a crucial means of accomplishing this objective. There have been many studies done to investigate EE in the context of various cross sections and groups of countries (Zhang & Choi, 2013; Zhang et al., 2011; Zhu et al., 2019; Xu et al., 2020; Yao et al., 2021a; Wang et al., 2012; Wijayatunga & Siyambalapitiya, 2017). However, in spite of the significance of EE, development in this field has moved at a glacial pace. The factors that contribute to energy efficiency are many and multifaceted. These factors include new technology developments, changes in consumer behavior, policy actions, and the regulatory environment. The impact that these elements have on EE, as well as the potential that they have to cut emissions, has been the subject of a number of studies. Research has shown, for instance, that technological advancements such as the development of energy-efficient appliances and buildings can significantly reduce energy consumption and emissions (Patterson, 1996; Masuda, 2018; Jain & Goswami, 2021; Khraiche, Kutlu & Mao, 2021; Li & Lin, 2015; Li, He & Tao, 2017; Hu & Wang, 2006; Hassan et al., 2022). In a similar vein, it has been demonstrated that consumer behavior, such as the implementation of methods that save energy, plays a significant part in the process of lowering overall energy consumption.

Another significant component that plays a role in EE is ecological innovation. Ecological innovation refers to environmentally sound approaches that lessen the toll that energy production and consumption take on the planet's natural resources (Amin et al., 2022). Studies (Ahmadi & Frikha, 2022; Amin, Zhou & Safi, 2022; Atalla & Bean, 2017; Bashir et al., 2020; Chen, Song & Wang, 2021; Saidi & Omri, 2020; Ali, Maryam & Rabbi, 2014; Voigt et al., 2014; Wang et al., 2020; Yu & He, 2020) have shown that environmentally friendly technologies can significantly cut down on energy consumption and emissions. These studies have also elaborated that transitioning to the use of energy-saving and environmentally friendly technologies can dramatically cut overall energy usage as well as emissions.

In the literature, the influence of alternative energies on EE is well documented (Danish & Khan, 2020; Gu et al., 2023; Ding, Khattak & Ahmad, 2021; Go et al., 2020; Gvozdenac-Uroevi, 2010; Hasanbeigi et al., 2013). As a means of lowering emissions and mitigating the effects of climate change, the use of alternative energies is gaining popularity. Numerous studies have concluded that renewable energy can substantially reduce energy consumption and greenhouse gas emissions (Ali et al., 2021; Ding, Khattak & Ahmad, 2021). The researches have also demonstrated that the adoption of wind power can substantially reduce energy consumption and emissions, especially in nations with abundant wind resources.

Both GDP and EE are connected in some way. Researchers Hassan, Song, and Kirikkaleli (2022), Hassan et al. (2022), He, Fu, and Liao (2021), Lin & Chen (2018), and Lin & Raza (2019) have examined the relationship between GDP and EE, and they have revealed that with increase in GDP, the emissions also increase. Lin & Raza (2019) have shown that as GDP increases, so does energy consumption and emissions. Nevertheless, research has also shown that this relationship is not linear, and that there is the possibility of decoupling the expansion of GDP from increases in energy consumption and emissions.

In fact, there is a vast body of research available on environmental economics, climate change, and the elements that contribute to EE. The studies that were looked at for this literature review highlighted the reputation of EE as a method for reducing emissions, and they also examined the complexity of the factors that affect EE (Mahapatra & Irfan, 2021; Mehmood, 2021; Ouyang, Chen & Du, 2021; Ozbuday & Erbas, 2015; Pei, Zhu & Wang, 2021; Safi et al., 2021). This study makes a significant contribution to the subject of energy by providing an in-depth analysis of EE across OECD nations and by focusing on the most important drivers of EE.

To begin, the study gives empirical sign on the influence of environmental innovation on alternative energies and EE, which has been a topic of interest for both policy makers and researchers alike. The findings of this project can be used to inform the creation of policies that promote eco-innovation and alternative energies as a means of improving environmental efficiency. Second, this initiative provides insights into the role, in which alternative energies play in enhancing EE. This, in turn, can inform the formulation of policies that are targeted at encouraging the use of renewable energy and lowering greenhouse gas emissions. Thirdly, this work contributes to the body of literature on the relationship between GDP and EE by providing evidence that economic expansion has a beneficial effect on EE in countries that are members of the OECD. Because of this, development is important for the transition to a sustainable energy source, and it can help inform the formulation of policies that aim to promote sustainable economic growth while simultaneously reducing energy use. In its conclusion, the research presents a thorough investigation into the interrelationships between eco-innovation, alternative energy, gross domestic product, and environmental efficiency in OECD nations between the years, 1990 and 2021. This makes a substantial contribution to the established literature and has the potential to guide the direction of further investigation in this field. In conclusion, the paper presents original evidences on the impact of eco innovation, alternative energies, GDP, and EE in OECD nations. Additionally, it offers insights into the potential for eco innovation and alternative energies to contribute to EE by providing these potential contributions. The conclusions of this study have significant repercussions for energy policy, and it is hoped that the findings will serve to inform future policy decisions and contribute to the global effort to increase energy efficiency. The findings of these studies not only offer useful insights into the current state of EE, but they will also inform future research that aims to promote greater EE.

To sum up, the major literature review can be understood through the sub-sections of contents, based on the key variables, including:

Eco-Innovation and Energy Efficiency:

– Studies showing a positive impact of eco-innovation on energy efficiency.

– Studies reporting mixed or inconclusive results regarding the relationship between eco-innovation and energy efficiency.

– Factors influencing the effectiveness of eco-innovation in improving energy efficiency.

Alternative Energies and Energy Efficiency:

– Studies demonstrating a positive association between alternative energies and energy efficiency.

– Studies finding limited or no significant impact of alternative energies on energy efficiency.

– Challenges and barriers to the adoption and integration of alternative energies for improving energy efficiency.

GDP Growth and Energy Efficiency:

– Studies suggesting a complementary relationship between GDP growth and energy efficiency.

– Studies highlighting the "energy efficiency paradox" and questioning the link between GDP growth and energy efficiency.

– Factors influencing the relationship between GDP growth and energy efficiency, such as technological advancements and policy frameworks.

Interrelationships among Eco-Innovation, Alternative Energies, GDP Growth, and Energy Efficiency:

– Studies examining the combined effects of eco-innovation and alternative energies on energy efficiency.

– The role of GDP growth as a mediating or moderating factor in the relationship between eco-innovation, alternative energies, and energy efficiency.

– Synergies and trade-offs among these variables in achieving sustainable and efficient energy systems.

The existing literature on the relationship between eco-innovation, alternative energies, GDP growth, and energy efficiency in OECD countries has provided valuable insights but has also shown inconsistencies and contradictions in the findings. Some studies have found a positive impact of eco-innovation on energy efficiency, while others have reported mixed or inconclusive results. Similarly, the literature on alternative energies and energy efficiency has yielded conflicting findings, with some studies showing a positive association and others finding limited or no significant impact. The relationship between GDP growth and energy efficiency has also been debated, with some studies suggesting a complementary relationship and others highlighting an "energy efficiency paradox.". This study aims to address these inconsistencies by conducting a comprehensive analysis of the impact of eco-innovation, alternative energies, and GDP growth on energy efficiency in OECD countries. By considering these factors together and utilizing advanced econometric techniques, the study aims to provide a more robust and nuanced understanding of the drivers of energy efficiency and their interrelationships. The findings of this research will contribute to resolving the contradictions in the existing literature and inform the development of effective energy policies for sustainable development.

Based on the reviewed literature, a theoretical model can be developed to guide the empirical analysis afterwards. This model incorporates the key variables of eco-innovation, alternative energies, GDP growth, and energy efficiency, and their interrelationships. The major studying framework consists of the followings:

Eco-Innovation:

– Eco-innovation refers to the development and implementation of new or improved goods, services, and methods that have a smaller negative impact on the natural environment.

– Eco-innovation is expected to positively influence energy efficiency by promoting the adoption of energy-saving technologies, processes, and practices.

– The impact of eco-innovation on energy efficiency may be influenced by factors such as technological advancements, policy support, and market incentives.

Alternative Energies:

– Alternative energies encompass renewable energy sources such as wind, solar, hydropower, and bioenergy.

– The adoption and integration of alternative energies are expected to contribute to energy efficiency by reducing reliance on fossil fuels and decreasing greenhouse gas emissions.

– The effectiveness of alternative energies in improving energy efficiency may be influenced by factors such as technological maturity, cost competitiveness, infrastructure development, and policy frameworks.

GDP Growth:

– GDP growth represents the economic expansion and development of a country or region.

– The relationship between GDP growth and energy efficiency is complex and can exhibit both positive and negative aspects.

– Positive relationship: Economic growth can lead to increased energy consumption, but it can also drive technological advancements and innovation, which can enhance energy efficiency.

– Negative relationship: The "energy efficiency paradox" suggests that as economies grow, energy efficiency improvements may not keep pace with increased energy consumption, leading to higher overall energy use and emissions.

Energy Efficiency:

– Energy efficiency refers to the ability to use energy in a way that minimizes waste while maximizing economic and environmental benefits.

– Energy efficiency is influenced by factors such as technological advancements, consumer behavior, policy actions, and the regulatory environment.

– Improving energy efficiency is crucial for mitigating climate change, reducing carbon footprint, and achieving sustainable development goals.

Interrelationships:

– Eco-innovation, alternative energies, and GDP growth are interconnected and can influence energy efficiency both individually and collectively.

– Eco-innovation and alternative energies can complement each other in driving energy efficiency improvements.

– GDP growth can act as a mediating or moderating factor in the relationship between eco-innovation, alternative energies, and energy efficiency.

– The interplay among these variables can lead to synergies or trade-offs in achieving sustainable and efficient energy systems.

This theoretical model provides a basis for the empirical analysis by outlining the key variables, their relationships, and the factors that may influence energy efficiency. It guides the selection of appropriate econometric techniques and helps in interpreting the empirical results. By considering the interrelationships among eco-innovation, alternative energies, GDP growth, and energy efficiency, this model contributes to a comprehensive understanding of the drivers of energy efficiency and informs the formulation of effective energy policies for sustainable development.

The following hypotheses have been generated for the study:

H1: Eco innovation (EI) has a positive and significant influence on EE.

H2: AEC has a positive and significant influence on EE.

H3: GDP has a positive and significant influence on EE.

METHODOLOGY

This study investigates the influence of eco innovation, alternative energies, and GDP on EE. A survey of the pertinent literature on energy efficiency and the factors that determine it is presented here as a means of providing a theoretical foundation for this investigation. The development of energy efficiency helps to sustainable economic growth by lowering energy costs and increasing competitiveness (Zhu, B., Wang, K., & Cheong, T. S., 2019). This leads to an increase in investment and the creation of new jobs in the energy industry. This, in turn, can contribute to the creation of a more sustainable energy system and fuel future economic growth. The role of innovation in driving efficiency improvement, the benefits of alternative energies, the importance of economic growth for sustainable energy transition, and the contribution of EE to sustainable economic growth are some of the various economic concepts that are at the root of the impact that eco-innovation, alternative energies, and GDP have on energy efficiency in OECD countries. Several different economic theories and concepts can be used to explain the economic intuition that lies behind the positive impact that eco-innovation, alternative energies, and GDP have on EE in countries that are members of the OECD. Following is a theoretical framework that can be developed based on this literature review to guide

the analysis of the impact that eco innovation, alternative energies, and GDP have on environmental efficiency.

EE has received a significant amount of attention in published research and is widely regarded as an essential strategy for lowering CO_2 emissions, lessening reliance on fossil fuels, and boosting overall economic performance. The concept of "eco-innovation" refers to the creation and subsequent commercialization of new or enhanced goods, procedures, or services that have a beneficial effect on the surrounding natural environment. It has been stated that eco-innovation plays a significant part in the enhancement of EE, since it results in the production of new technologies and products that have a higher energy efficiency. It is generally believed that alternative energies are energy-efficient, and a transition toward renewables can lead to improvements in EE. The paradigm operates under the presumption that eco-innovation, alternative energies, and GDP all have a substantial impact on EE, that these variables are interdependent on one another, and that their interactions are complicated. The findings of this research will shed light on the nature of the relationships between the aforementioned factors and energy efficiency, and they will also contribute to the formulation of policies that are geared toward the enhancement of energy conservation.

The choice of variables and their measurement in the conceptual framework is based on the reviewed literature and the relevance of these variables in the context of energy efficiency. The variables chosen are eco-innovation, alternative energies, GDP growth, and energy efficiency. Eco-innovation is measured using indicators such as the number of patents related to eco-friendly technologies, investments in R&D for sustainable solutions, and the adoption of eco-labeling or certification schemes. Alternative energies are measured based on the share of renewable energy sources in the total energy mix. GDP growth is measured using GDP per capita as a measure of economic growth and development. Energy efficiency is measured using indicators such as energy intensity, energy consumption per capita, and energy savings achieved through specific energy efficiency measures or policies. These variables and their measurement align with the research objectives, are supported by the literature, and can be obtained from reliable sources. They provide a comprehensive framework for analyzing the relationships between eco-innovation, alternative energies, GDP growth, and energy efficiency in OECD countries.

Model:

The following model specification will be used to estimate the relationship between these variables:

$$EE_{i,t} = \beta_1 EI_{i,t} + \beta_2 GDP_{i,t} + \beta_3 REC_{i,t} + \beta_4 INT_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where:

EE is the dependent variable, representing energy efficiency. EI represents eco innovation, AEC represents alternative energies, GDP represents gross domestic product. β_1, β_2, and β_3 are the parameters representing the impact of eco innovation, alternative energies, and GDP on EE, respectively. This model specification is based on the assumption that eco innovation, alternative energies, and GDP have a significant impact on EE. The coefficients β_1, β_2, and β_3 represent the magnitude of the impact of each variable on EE, and they will be estimated using econometric techniques. Table 1 provides the description, sources and measurement and variables.

The data used for this study is obtained from various sources, including the World Bank database and the International Energy Agency database. The results of the CIPS unit root test and the Westerlund cointegration technique are utilized to ascertain the presence of cointegration between the variables and the most suitable econometric model to employ. On the basis of the results of the CS-ARDL model, the dynamic relationship between eco-innovation, alternative energies, and GDP on EE will be estimated. The findings will shed light on the influence of eco-innovation, alternative energies, and GDP on EE in OECD nations. The use of the CIPS unit root test and the Westerlund cointegration technique addresses potential econometric issues such as cross-sectional dependence

and heterogeneity in panel datasets. These techniques provide more accurate and reliable results, ensuring that the estimation and inference are valid for analyzing the relationships between eco-innovation, alternative energies, GDP growth, and energy efficiency in OECD countries.

Table 1: Data Description, Sources and Measurement

Symbol	Variable	Source	Unit
EE	Energy Efficiency	OECD (2021) https://stats.oecd.org.	Energy consumption per unit of real GDP
RE	Alternative energies	OECD (2021) https://stats.oecd.org.	(% of total final energy consumption)
GDP	GDP per capita	World Bank (2021)	Current US$
EI	Eco innovation technologies as percent of total technologies	OECD (2021) https://stats.oecd.org.	% of the total technologies

Source: Authors' compilation (2024)

Analytical approach:

To estimate the empirical model, we use CS-ARDL approach. To test the order of integration, we use CIPS unit root test. The CIPS's equation is:

$$\Delta Y_{i,t} = \varphi_i + \varphi_i Z_{i,t-1} + \varphi_i \bar{Y}_{t-1} + \sum_{l=0}^{p} \varphi_{il} \Delta \overline{Y_{t-l}} + \sum_{l=1}^{p} \varphi_{il} \Delta Y_{i,t-l} + \mu_{it} \quad (2)$$

The Westerlund cointegration technique is employed to check the cointegrating nexus amongst variables. The test uses the following statistics:

The test uses the following statistics:

$$G_t = \frac{1}{N} \sum_{i-1}^{N} \frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)} \quad (4)$$

$$G_\alpha = \frac{1}{N} \sum_{i-1}^{N} \frac{\mathrm{T}\acute{\alpha}_i}{\acute{\alpha}_i(1)} \quad (5)$$

$$P_T = \frac{\acute{\alpha}}{SE(\acute{\alpha})} \quad (6)$$

$$P_\alpha = \mathrm{T}\acute{\alpha} \quad (7)$$

Group mean statistics are shown in Equations 4-5, whereas panel statistics are shown in Equations 6–7. To estimate the long run estimates, we use CS-ARDL method, which is a combination of both the autoregressive and distributed lag models (Chudik & Pesaran, 2015). The CS-ARDL model allows for the estimation of association between the variables, and the estimation of the dynamic effects of the explanatory variables on the EE. The CS-ARDL's equation is given as:

$$\mathrm{EE_t} = \alpha_0 + \sum_{j=1}^{p} \lambda_{\mathrm{it}} \mathrm{EE_{i,t-j}} \mathrm{PC} + \sum_{j=0}^{p} \acute{\alpha}_{\mathrm{it}} \mathrm{X_{t-j}} + \sum_{j=0}^{3} \acute{\upsilon}_{\mathrm{it}} \bar{Z}_{\mathrm{t-j}} + \mu_{\mathrm{it}} \quad (8)$$

Where: $\bar{Z}$t = ($\Delta\overline{EE}$t, $\bar{X}$t´)´and Xit = (EIit, AECit, GDPit)´.

In overall, the process of data collection and harmonization across OECD countries involved several steps to ensure data quality and comparability.

– Data Collection: The data for the study were collected from various sources, including international organizations, government agencies, and academic publications. These sources provide comprehensive data on energy efficiency, eco-innovation, alternative energies, GDP, and other relevant variables for OECD countries.

– Missing Values: In any dataset, missing values can occur due to various reasons, such as data unavailability or reporting discrepancies. To handle missing values, several approaches can be employed. One common approach is to exclude observations with missing values from the analysis. Alternatively, imputation techniques can be used to estimate missing values based on patterns in the available data.

– Inconsistencies: Inconsistencies in the data can arise due to differences in measurement units, reporting standards, or data collection methodologies across countries. To ensure comparability, it is necessary to address these inconsistencies. This can be done through data harmonization techniques, such as converting all variables to a common unit of measurement or adjusting for differences in reporting standards.

– Variable Standardization: Cross-country comparisons require standardization of variables to account for differences in scale and units of measurement. Standardization allows for meaningful comparisons and the identification of relative differences between countries. Common methods of variable standardization include z-score normalization or min-max scaling.

– Robustness Checks: To ensure the robustness of the findings, sensitivity analyses and robustness checks can be conducted. These checks involve testing the stability of the results by varying the methodology or assumptions used. For example, alternative imputation methods or different approaches to handling missing values can be tested to assess the impact on the results.

While the study utilizes various data sources and econometric methods to analyze the relationships between eco-innovation, alternative energies, GDP growth, and energy efficiency, it is important to acknowledge the limitations and potential biases that may arise to some extent.

– *Data Limitations:* The study relies on data obtained from various sources, such as the OECD, World Bank, and International Energy Agency. These data sources may have their own limitations, including potential measurement errors or inconsistencies.

– *Endogeneity Bias:* Endogeneity bias may arise due to the potential simultaneous relationship between the variables of interest. For example, eco-innovation and alternative energies may be influenced by energy efficiency, creating a feedback loop.

– *Omitted Variable Bias:* Omitted variable bias occurs when important variables that are not included in the analysis affect the relationships between the variables of interest.

– *Generalizability:* The study focuses on OECD countries, which may limit the generalizability of the findings to other regions or countries with different socio-economic contexts.

– *Model Assumptions:* The CS-ARDL model and other econometric techniques used in the study rely on certain assumptions, such as the absence of serial correlation, homoscedasticity, and normality of errors.

RESEARCH FINDINGS AND DISCUSSION

This study applies the CIPS unit root test to analyze the time series data in order to determine the presence of unit roots, which is a prerequisite for analyzing the data in order to determine the presence of cointegration amongst variables. It starts with the authors' study on the descriptive statistics and trends in energy efficiency (EE), eco-innovation, alternative energies, and gross

domestic product (GDP) across OECD countries. This includes providing descriptive statistics such as mean, standard deviation, minimum, maximum, and quartiles for each variable, as well as analyzing trends over the study period. The next step involves conducting unit root test to assess the stationarity of the variables. Cointegration test is then conducted to determine if there are long-term relationships among the variables. Finally, the CS-ARDL estimation is performed to estimate the dynamic relationship between eco-innovation, alternative energies, GDP, and EE. The CS-ARDL estimation results include the estimated coefficients for each variable, along with their corresponding standard errors and p-values.

The findings of the CIPS unit root test are summarized in Table 2. When looking at the first difference, it is clear that EE, EI, AEC, and GDP are all stationary.

Table 2: Results of Unit Root Test

Variables	Level		At First Difference	
	Drift	Drift & Trend	Drift	Drift & Trend
EE	-0.712	-0.511	-3.412***	-3.213***
EI	-2.244	-2.582	-3.621***	-3.514***
GDP	-1.511	-1.349	-2.341***	-2.627***
AEC	-0.736	-1.611	-3.318***	-3.118***

****, ** and * imply significance at 1%, 5% and 10% correspondingly*

Source: Authors' analysis (2024)

The findings of the Westerlund test are presented in Table 3. The significant group mean and panel statistics approve the cointegration nexus among variables in the model. Hence, it is inferred that EE is cointegrated with EI, GDP, and AEC.

Table 3: Cointegration Test

Model		Gt	Ga	Pt	Pa
EE = f (EI, GDP, AEC)	Constant	-7.16***	-15.27***	-8.61***	-19.27***
	Constant and Trend	-6.31***	-18.39***	-9.11***	-16.31***

**** means significance at 1%*

Source: Authors' analysis (2024)

Table 4 presents the long-term outcomes. The results show that eco innovation (EI) has a positive and significant influence on EE. This indicates that eco-innovation is helpful in achieving EE, which lends credence to the findings of Ahmadi and Frikha (2022), Amin, Zhou and Safi (2022), Ali et al. (2021), Bashir et al. (2020), and Chen, Song and Wang (2021). The findings are also in agreement with the theoretical expectations that eco-innovation can result in the creation of new technologies and products that are better able to conserve energy. The development and application of new technologies and business models result in a low environmental degradation. It is anticipated that this investment in eco-innovation will enhance EE of manufacturing processes, hence lowering the amount of energy required for production and increasing the competitiveness of businesses. The creation and subsequent commercialization of new or enhanced goods, procedures, or services that have a beneficial effect on the surrounding natural environment. It has been agreed that eco-

innovation plays a significant part in the enhancement of EE, since it results in the production of new technologies and products that have a higher energy efficiency. It is generally true that alternative energies are more energy-efficient than fossil fuels, and a transition toward renewable energy sources can lead to improvements in energy efficiency. The coefficient for alternative energies (AEC) is positive and significant. This suggests that an increase in alternative energies is linked to an increase in EE, which lends credence to the findings of Danish and Khan (2020), Ding, Khattak and Ahmad (2021), Go et al. (2020), Gvozdenac-Urošević, B. (2010), and Hasanbeigi and colleagues (2013).

This result is consistent with the theoretical premise that alternative energy sources are generally more energy-efficient than fossil fuels, and as a result, a shift towards renewable energy can result in improvements to EE. Alternative energies are crucial driver of EE improvement, as alternative energy sources are generally considered more efficient and environmentally friendly than traditional energy sources. The increased use of alternative energies results in lower energy costs, which in turn can result in lower production costs and increased competitiveness. Alternative energies are more energy-efficient, and a transition toward renewables can lead to improvements in EE.

The coefficient for GDP is positive and significant. These findings lend credence to the conclusions reached previously by Hassan, Song, and Kirikkaleli (2022), Hassan and colleagues (2022), He, Fu, and Liao (2021), Lin and Chen (2018), and Lin and Raza (2019). The rate of growth in GDP is an important factor in determining EE since it offers the financial resources that are required to invest in environmentally friendly innovations and renewable sources of energy. The move to technologies and manufacturing processes that are more energy-efficient will require substantial funding, which can be provided by an economy that is robust and expanding. With an increase in country's GDP, the energy consumption and emissions also increase.

Table 4: CS-ARDL's Estimates

Variables	Long run Coefficients	Short-Run Coefficients
Drift	0.916*** [0.031]	0.837*** [0.041]
EI	0.413*** [0.040]	0.419*** [0.031]
GDP	0.393*** [0.004]	0.615*** [0.007]
AEC	0.216*** [0.009]	0.184*** [0.027]
ECM	-	-0.61** [0.015]

*Values in [ ] are Std. errors. Significance level of 1%, 5% and 10% are represented by ***, ** and *.*

Source: Authors' analysis (2024)

To explain these, for instance, the coefficient of 0.413 for eco-innovation implies a positive relationship with energy efficiency. This means that an increase in eco-innovation is associated with an increase in energy efficiency. The magnitude of the coefficient indicates the strength of this relationship, with a larger coefficient suggesting a stronger impact of eco-innovation on energy efficiency. The economic significance of the coefficient suggests that eco-innovation plays a significant role in improving energy efficiency. It implies that when firms or industries invest in eco-innovation practices, such as developing and adopting cleaner technologies or resource-efficient practices, it leads to improved energy efficiency. The coefficient also has policy implications, highlighting the importance of promoting and incentivizing eco-innovation to enhance energy

efficiency. Policymakers can encourage research and development activities, provide financial support, and create a favorable regulatory environment to foster eco-innovation. It is important to consider sector-specific effects, as the impact of eco-innovation on energy efficiency may vary across different sectors or industries. Overall, the coefficient of 0.413 underscores the potential of eco-innovation as a driver for improving energy efficiency and emphasizes the importance of incorporating eco-innovation strategies in energy and environmental policies.

To sum up, the results of the study, particularly the positive impact of eco-innovation and alternative energies on energy efficiency, have important policy implications for OECD countries. There certainly are some specific measures that could be taken to promote eco-innovation and alternative energies for improving energy efficiency. (1) Research and Development (R&D) Funding: Governments can increase funding for R&D in eco-innovation and alternative energy technologies. This can support the development of new and improved products, processes, and services that enhance energy efficiency. Funding can be provided through grants, subsidies, tax incentives, and public-private partnerships to encourage innovation in clean technologies; (2) Regulatory Frameworks: Governments can establish and enforce regulations that promote eco-innovation and alternative energies. This can include setting energy efficiency standards for buildings, appliances, and vehicles, as well as implementing policies that encourage the use of renewable energy sources. Clear and consistent regulations provide a supportive environment for businesses to invest in energy-efficient technologies; (3) Financial Incentives: Governments can offer financial incentives to businesses and individuals to adopt eco-innovation practices and alternative energy sources. This can include grants, low-interest loans, and feed-in tariffs for renewable energy generation. Financial incentives can help overcome the initial cost barriers associated with adopting energy-efficient technologies and encourage their widespread adoption; (4) Education and Awareness: Governments can invest in educational programs and awareness campaigns to promote the benefits of eco-innovation and alternative energies. This can include providing training and resources to businesses and individuals on energy-efficient practices, as well as raising awareness about the environmental and economic advantages of adopting clean technologies. Governments can also facilitate collaboration between industry, academia, and research institutions to foster innovation in eco-innovation and alternative energy sectors. This can involve creating platforms for knowledge sharing, promoting technology transfer, and supporting collaborative research projects. By fostering collaboration, governments can accelerate the development and adoption of energy-efficient technologies; (5) International Cooperation: OECD countries can collaborate on energy efficiency initiatives and share best practices. This can involve exchanging information on successful policies and programs, coordinating research efforts, and harmonizing energy efficiency standards. International cooperation can help accelerate the transition to a low-carbon economy and facilitate the exchange of knowledge and technologies; (6) Public Procurement: Governments can lead by example through sustainable public procurement practices. By prioritizing energy-efficient products and services in government procurement processes, governments can create a market demand for eco-innovation and alternative energy solutions. This can stimulate innovation and drive down costs, making energy-efficient technologies more accessible to businesses and individuals.

These measures, when implemented collectively, can create an enabling environment for eco-innovation and alternative energies, leading to improved energy efficiency in OECD countries. By adopting a comprehensive approach that combines regulatory, financial, educational, and collaborative strategies, governments can accelerate the transition to a sustainable and energy-efficient future.

CONCLUSION AND RECOMMENDATIONS

The specific contributions of the study to the literature and policy debates on energy EE are as follows:

Empirical evidence on the impact of eco-innovation: The study provides empirical evidence on the positive and significant influence of eco-innovation on energy efficiency. This contributes to the existing literature by highlighting the importance of eco-innovation in improving energy efficiency and reducing carbon emissions. This finding can inform policy debates on the promotion of eco-innovation as a means to enhance energy efficiency.

Insights into the role of alternative energies: The study also sheds light on the positive and significant impact of alternative energies on energy efficiency. This finding adds to the literature by emphasizing the potential of renewable energy sources in reducing energy consumption and greenhouse gas emissions. It can inform policy discussions on the adoption and promotion of alternative energies as a strategy to improve energy efficiency and mitigate climate change.

Understanding the relationship between GDP and energy efficiency: The study examines the relationship between gross domestic product (GDP) and energy efficiency. It finds that GDP has a positive and significant influence on energy efficiency. This finding contributes to the literature by highlighting the importance of economic growth for sustainable energy transition. It suggests that economic development can support energy efficiency efforts and promote a transition to sustainable energy sources. This insight can inform policy debates on the integration of energy efficiency goals into economic development strategies.

Methodological contribution: The study employs the CS-ARDL approach to estimate the relationship between eco-innovation, alternative energies, GDP, and energy efficiency. This methodological contribution provides a rigorous and comprehensive analysis of the factors influencing energy efficiency. It enhances the understanding of the complex interactions between these variables and contributes to the methodological literature on energy efficiency analysis.

The findings of the investigation offer important new perspectives on the connections that exist between the EE and these other variables. We discover that a favorable association exists between EE and alternative energies, GDP, and environmentally friendly innovations. In the countries that make up the OECD, eco-innovation has a positive impact on alternative energies and environmental economics. This demonstrates the significance of making investments in environmentally friendly innovations as a means of enhancing environmental efficacy and decreasing environmental impact. The potential for renewable energy to contribute to greater energy efficiency is illustrated by the fact that alternative energies have a positive association with EE. The fact that economic growth is positively associated with energy efficiency in OECD nations highlights the significance of economic growth for the transition to sustainable energy. This study's findings provide proof that the role of eco-innovation, alternative energies, and economic growth in driving improvements in energy efficiency in OECD countries is supported by the findings. In conclusion, the study demonstrates the potential for eco-innovation, alternative energies, and economic growth to contribute to improved EE in nations that are members of the OECD. These findings can be used as a basis for developing policies that aim to promote eco innovation, alternative energies, and sustainable economic growth as a means of lowering energy use and improving energy efficiency. This means that policies targeted at promoting eco-innovation, expanding the use of alternative fuels, and growing GDP will likely result in improvements to energy efficiency. Having said that, the findings also imply that the link between these variables and EE is a complicated one. This underlines how important it is, while establishing policy to promote EE, to take into consideration elements that are distinctive to each country.

The findings have significant repercussions for decision-making processes that are involved in the promotion of EE. In light of these, policymakers ought to give serious consideration to the various measures listed below in order to advance EE. To improve the environmental friendliness of products, processes, and services, policymakers should make investments in research and development. This can be accomplished through the implementation of financial programs, the provision of tax incentives, and various other forms of support. The development of alternative

energy technology should be encouraged by policymakers, and the usage of alternative energy sources should be encouraged as well. This is something that can be accomplished with the help of feed-in tariffs, tax credits, and other types of incentives. Because a higher GDP is positively associated with improved economic efficiency, policymakers should take measures to improve economic performance. This can be accomplished by enacting laws with the goals of fostering increased investment, enhancing existing institutions, and expanding commercial activity. In summing up, the findings of this research offer important new perspectives on the connections that exist between eco-innovation, alternative energies, GDP, and environmental efficiency. The outcomes of this study demonstrate how important it is to take into consideration the aforementioned criteria when developing legislation that aims to promote equal employment.

Moreover, it is important for countries to assess their specific energy mix, industrial structure, and technological capabilities to identify the most suitable eco-innovation and alternative energy investments for maximizing energy efficiency gains. Tailoring policies and investments to their unique circumstances can lead to more effective and impactful outcomes in terms of energy efficiency improvements. Countries with different energy mixes, industrial structures, or technological capabilities can prioritize different types of eco-innovation or alternative energy investments to maximize EE gains.

Energy Mix:

– Countries heavily reliant on fossil fuels: These countries can prioritize eco-innovation and investments in alternative energies that focus on reducing the carbon intensity of their energy mix. This can include technologies such as carbon capture and storage (CCS), clean coal technologies, or transitioning to natural gas as a transitional fuel.

– Countries with abundant renewable energy resources: These countries can prioritize eco-innovation and investments in expanding their renewable energy capacity. This can include technologies such as solar power, wind power, hydropower, or geothermal energy. By maximizing the use of their renewable energy resources, they can reduce their reliance on fossil fuels and increase their energy efficiency.

Industrial Structures:

– Manufacturing-intensive countries: These countries can prioritize eco-innovation and investments in energy-efficient manufacturing processes and technologies. This can include technologies such as advanced automation, energy-efficient machinery, or waste heat recovery systems. By improving the energy efficiency of their manufacturing sector, they can reduce energy consumption and increase overall EE.

– Service-oriented countries: These countries can prioritize eco-innovation and investments in energy-efficient buildings and infrastructure. This can include technologies such as smart buildings, energy management systems, or efficient transportation systems. By focusing on energy efficiency in the service sector, they can reduce energy consumption in areas such as buildings, transportation, and information and communication technologies.

Technological Capabilities:

– Technologically advanced countries: These countries can prioritize eco-innovation and investments in advanced energy technologies. This can include technologies such as advanced energy storage systems, smart grids, or integrated energy management systems. By leveraging their technological capabilities, they can develop and deploy cutting-edge solutions that enhance energy efficiency.

– Developing countries with limited technological capabilities: These countries can prioritize eco-innovation and investments in low-cost, scalable energy solutions. This can include technologies such as decentralized renewable energy systems, energy-efficient appliances, or energy-efficient

cooking stoves. By focusing on affordable and accessible solutions, they can improve energy efficiency in a cost-effective manner.

In conclusion, this study provides new evidence on the positive impact of eco-innovation, alternative energies, and GDP on energy efficiency in OECD countries. The findings suggest that investing in environmentally friendly technologies, promoting renewable energy sources, and fostering economic growth can contribute to improved EE and support the transition to sustainable energy systems. The results have important implications for policymakers, highlighting the need for comprehensive strategies that address the technological, economic, and institutional barriers to EE improvements.

However, the study also has some limitations that should be acknowledged and addressed in future research. The analysis relies on aggregate measures of eco-innovation, alternative energies, and EE, which may obscure important variations across sectors, technologies, and countries. The study also does not consider the potential interactions or trade-offs between the variables, such as the rebound effects of energy efficiency gains on energy consumption and economic growth. Future studies could explore these issues using more disaggregated data, alternative model specifications, and complementary qualitative methods.

Despite these limitations, the study makes a valuable contribution to the literature on energy efficiency and sustainable energy transitions. By providing empirical evidence on the key drivers of EE in OECD countries, the study can inform policy debates and guide further research on the complex challenges of mitigating climate change and promoting sustainable development. The findings underscore the importance of holistic approaches that recognize the interconnections between technological innovation, economic growth, and energy efficiency, and the need for collaborative efforts across government, industry, and society to achieve long-term sustainability goals.

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REFERENCES

Ahmadi, Z., and Frikha, W. (2022). 'Consumption-based Carbon Dioxide Emissions and Their Impact on Energy Productivity in the G7 Countries', Journal of the Knowledge Economy, 1-16.

Ali, S., Dogan, E., Chen, F., and Khan, Z. (2021). 'International trade and environmental performance in top ten-emitters countries: the role of eco-innovation and alternative energies', Sustainable Development, 29(2), 378-387. https://doi.org/10.1002/sd.2153

Amin, M., Zhou, S., and Safi, A. (2022). 'The nexus between consumption-based carbon emissions, trade, eco-innovation, and energy productivity: empirical evidence from N-11 economies', Environmental Science and Pollution Research, 29(26), 39239-39248.

Atalla, T., and Bean, P. (2017). Determinants of energy productivity in 39 countries: An empirical investigation', Energy Economics, 62, 217-229.

Bashir, M. A., Sheng, B., Doğan, B., Sarwar, S., and Shahzad, U. (2020). 'Export product diversification and energy efficiency: Empirical evidence from OECD countries', Structural Change and Economic Dynamics, 55, 232-243. https://doi.org/10.1016/j.strueco.2020.09.002

Chen, Z., Song, P., and Wang, B. (2021). 'Carbon emissions trading scheme, energy efficiency and rebound effect–Evidence from China's provincial data', Energy Policy, 157, 112507. https://doi.org/10.1016/j.enpol.2021.112507

Chudik, A., and Pesaran, M. H. (2015). 'Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors', Journal of Econometrics, 188(2), 393-420.

Danish, U. R., and Khan, S.-U.-D. (2020). 'Relationship between energy intensity and CO2 emissions: Does economic policy matter?', Sustainable Development, 28(5), 1457-1464. https://doi.org/10.1002/sd.2098

Ding, Q., Khattak, S. I., and Ahmad, M. (2021). 'Towards sustainable production and consumption: assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO2) in G-7 nations', Sustainable Production and Consumption, 27, 254-268.

Go, Y.-H., Lau, L.-S., Yii, K.-J., and Lau, W.-Y. (2020). 'Does energy efficiency affect economic growth? Evidence from aggregate and disaggregate levels', Energy and Environment, 31(6), 983-1006. https://doi.org/10.1177/0958305x19882395

Grossman, G.-M., and Krueger, A.-B. (1992). 'Environmental impacts of a North American free trade agreement'. CEPR Discussion Papers, 8, 223-250. https://doi.org/10.3386/w3914

Gvozdenac-Urošević, B. (2010). 'Energy efficiency and GDP', Thermal Science, 14(3), 799-808. https://doi.org/10.2298/TSCI100505006G

Hasanbeigi, A., Morrow, W., Sathaye, J., Masanet, E., and Xu, T. (2013). 'A bottom-up model to estimate the energy efficiency improvement and CO2 emission reduction potentials in the Chinese iron and steel industry', Energy, 50, 315-325. https://doi.org/10.1016/j.energy.2012.10.062

Hassan T, Song H, Khan Y, Kirikkaleli D. (2022). 'Energy efficiency a source of low carbon energy sources? Evidence from 16 high-income OECD economies', Energy 243:123063. https://doi.org/10.1016/J.ENERGY.2021.123063

Hassan, T., Song, H., and Kirikkaleli, D. (2022). 'International trade and consumption-based carbon emissions: Evaluating the role of composite risk for RCEP economies', Environmental Science and Pollution Research, 29(3), 3417-3437. https://doi.org/10.1007/s11356-021-15617-4

Hassan, T., Song, H., Khan, Y., and Kirikkaleli, D. (2022). 'Energy efficiency a source of low carbon energy sources? Evidence from 16 high-income OECD economies', Energy, 243, 123063.

He, Y., Fu, F., and Liao, N. (2021). 'Exploring the path of carbon emissions reduction in China's industrial sector through energy efficiency enhancement induced by RandD investment', Energy, 225, 120208. https://doi.org/10.1016/j.energy.2021.120208

Honma S, Hu JL (2008). 'Total-factor energy efficiency of regions in Japan', Energy Policy. https://doi.org/10.1016/j.enpol.2007.10.026

Honma S, Hu JL (2009). 'Total-factor energy productivity growth of regions in Japan', Energy Policy. https://doi.org/10.1016/j.enpol.2009.04.034

Hou Y, Iqbal W, Shaikh GM, Iqbal N, Solangi YA, Fatima A (2019). 'Measuring energy efficiency and environmental performance: a case of South Asia', Processes. https://doi.org/10.3390/pr7060325

Hu JL, Wang SC (2006). 'Total-factor energy efficiency of regions in China', Energy Policy. https://doi.org/10.1016/j.enpol.2005.06.015

IEA. (2021). Energy Efficiency 2021: Analysis and Outlooks to 2040. Retrieved from: https://www.iea.org/reports/energy-efficiency-2021

IPCC. (2021). 'Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change' [Masson-delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (Eds.). New York: Cambridge University Press). In Press.

Jain P, Goswami B (2021). 'Energy efficiency in South Asia: trends and determinants', Energy. 221, 119762. https://doi.org/10.1016/j.energy.2021.119762

Khraiche M, Kutlu L, Mao X (2021). 'Energy efficiencies of European countries', Applied Economics, 54(23), 2694-2706. https://doi.org/10.1080/00036846.2021.1994520

Li K, Lin B (2015). 'Metafroniter energy efficiency with CO2 emissions and its convergence analysis for China', Energy Economics, 48, 230-241. https://doi.org/10.1016/j.eneco.2015.01.006

Li MJ, He YL, Tao WQ (2017). 'Modeling a hybrid methodology for evaluating and forecasting regional energy efficiency in China', Applied Energy, Applied Energy 185, 1769–1777. https://doi.org/10.1016/j.apenergy.2015.11.082

Lin, B., and Chen, G. (2018). 'Energy efficiency and conservation in China's manufacturing industry', Journal of Cleaner Production, 174, 492–501. https://doi.org/10.1016/j.jclepro.2017.10.286

Lin, B., and Raza, Y. (2019). 'Analysis of energy related CO2 emissions in Pakistan', Journal of Cleaner Production, 219. https://doi.org/10.1016/j.jclepro.2019.02.112

Mahapatra, B., and Irfan, M. (2021). 'Asymmetric impacts of energy efficiency on carbon emissions: A comparative analysis between developed and developing economies', Energy, 227(C), 120485. https://doi.org/10.1016/j.energy.2021.120485

Masuda K (2018). 'Energy efficiency of intensive rice production in Japan: an application of data envelopment analysis', Sustainability, 10(1), 120. https://doi.org/10.3390/su10010120

Mehmood, U. (2021). Renewable-nonrenewable energy: institutional quality and environment nexus in South Asian countries. Environmental Science and Pollution Research, 28(21), 26529-26536.

Ouyang, X., Chen, J., and Du, K. (2021). 'Energy efficiency performance of the industrial sector: From the perspective of technological gap in different regions in China', Energy, 214, 118865. https://doi.org/10.1016/j.energy.2020.118865

Özbuğday, F. C., and Erbas, B. C. (2015). 'How effective are energy efficiency and renewable energy in curbing CO2 emissions in the long run? A heterogeneous panel data analysis', Energy, 82, 734-745. https://doi.org/10.1016/j.energy.2015.01.084

Patterson MG (1996). 'What is energy efficiency?, Concepts, indicators and methodological issues', Energy Policy, 24(5), 377-390. https://doi.org/10.1016/0301-4215(96)00017-1

Pei, Y., Zhu, Y., and Wang, N. (2021). 'How do corruption and energy efficiency affect the carbon emission performance of China's industrial sectors?' Environmental Science and Pollution Research, 28(24), 31403-31420. https://doi.org/10.1007/s11356-021-13032-3

Pesaran, M. H. (2007). 'A simple panel unit root test in the presence of cross-section dependence', Journal of Applied Econometrics, 22(2), 265–312. https://doi.org/10.1002/jae.951

Razzaq, A., Sharif, A., Najmi, A., Tseng, M. L., and Lim, M. K. (2021). 'Dynamic and causality interrelationships from municipal solid waste AECycling to economic growth, carbon emissions and energy efficiency using a novel bootstrapping autoregressive distributed lag',

Resources Conservation and AECycling, 1666, 105372. https://doi.org/10.1016/j.resconAEC.2020.105372

Safi, A., Chen, Y., and Zheng, L. (2022). 'The Impact of Energy Productivity and Eco-Innovation on Sustainable Environment in Emerging Seven (E-7) Countries: Does Institutional Quality Matter', Frontiers in Public Health, 10.

Safi, A., Chen, Y., Wahab, S., Ali, S., Yi, X., and Imran, M. (2021). 'Financial instability and consumption-based carbon emission in E-7 countries: The role of trade and economic growth, Sustainable Production and Consumption, 27, 383-391. https://doi.org/10.1016/j.spc.2020.10.034

Saidi, K., and Omri, A. (2020). 'The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries, Environmental Research, 186, 109567. https://doi.org/10.1016/j.envres.2020.109567

Shah WU, Hao G, Yasmeen R, Kamal MA, Khan A, Padda IU (2022a). 'Unraveling the role of China' s OFDI, institutional difference and B and R policy on energy efficiency: A Meta - frontier super - SBM approach, Environmental Science and Pollution Research, 0123456789. https://doi.org/10.1007/s11356-022-19729-3

Shah, W.U.H, Hao G, Yan H, Yasmeen R, Padda IUH, Ullah A (2022b). 'The impact of trade, financial development and government integrity on energy efficiency: An analysis from G7-Countries, Energy, 255, 124507. https://doi.org/10.1016/j.energy.2022.124507

Ali, S., Maryam, B., and Rabbi, F. (2014). 'A new economic dimension to the environmental Kuznets curve: Estimation of environmental efficiency in case of Pakistan', Asian Economic and Financial Review, 4(1), 68-79.

Ul W, Shah H, Hao G, Yan H, Yasmeen R, Jie Y (2022). 'The role of energy policy transition, regional energy efficiency, and technological advancement in the improvement of China's environmental quality', Energy Rep 8, 9846–9857. https://doi.org/10.1016/j.egyr.2022.07.161

Voigt, S., De Cian, E., Schymura, M., and Verdolini, E. (2014). 'Energy intensity developments in 40 major economies: structural change or technology improvement?' Energy Economics, 41, 47-62.

Wahab S, Zhang X, Safi A, Wahab Z, Amin M. (2020). 'Does Energy Productivity and Technological Innovation Limit Trade-Adjusted Carbon Emissions?' Instructions, 34, 1896–912. https://doi:10.1080/1331677X.2020.1860111

Wang ZH, Zeng HL, Wei YM, Zhang YX (2012). 'Regional total factor energy efficiency: an empirical analysis of industrial sector in China'. Applied Energy, 97, 115-123. https://doi.org/10.1016/j.apenergy.2011.12.071

Wang, L., Su, C.-W., Ali, S., and Chang, H.-L. (2020). 'How China is fostering sustainable growth: The interplay of green investment and production-based emission', Environmental Science and Pollution Research, 27(31), 39607-39618. https://doi.org/10.1007/s11356-020-09933-4

Westerlund, J. (2007). 'Testing for error corAECtion in panel data', Oxford Bulletin of Economics and statistics, 69(6), 709-748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Wijayatunga P, Siyambalapitiya T (2017). 'Improving energy efficiency in South Asia. ADB South Asia Working Paper Series No. 47, October 2016, Available at: https://ssrn.com/abstract=2941315 or http://dx.doi.org/10.2139/ssrn.2941315

Witajewski-Baltvilks J, Verdolini E, Tavoni M (2017). 'Induced technological change and energy efficiency improvements'. Energy Economics, 68, 17-32. https://doi.org/10.1016/j.eneco.2017.10.032

World Bank. (2021). World bank. World Dev. Indic. Retrieved from: https://databank.worldbank.org/source/world-developmentindicators

Xu T, You J, Li H, Shao L (2020). 'Energy efficiency evaluation based on data envelopment analysis: a literature review'. Energies, 13(14), 3548. https://doi.org/10.3390/en13143548

Yao X, Shah WUH, Yasmeen R, Zhang Y, Kamal MA, Khan A (2021a). 'The impact of trade on energy efficiency in the global value chain a simultaneous equation approach'. Science of Total Environment, 765:142759. https://doi.org/10.1016/j.scitotenv.2020.142759

Yu, D., and He, X. (2020). 'A bibliometric study for DEA applied to energy efficiency: Trends and future challenges', Applied Energy, 268, 115048.

Zhang N, Choi Y (2013). 'A comparative study of dynamic changes in CO2 emission performance of fossil fuel power plants in China and Korea', Energy Policy, 62, 324-332. https://doi.org/10.1016/j.enpol.2013.07.060.

Zhang, X., & Choi, Y. (2013). Determinants of energy efficiency in OECD countries: A panel data analysis. Energy Policy, 61, 731-738. https://doi:10.1016/j.enpol.2013.06.036

Zhang XP, Cheng XM, Yuan JH, Gao XJ (2011). 'Total-factor energy efficiency in developing countries. Energy Policy. https://doi.org/10.1016/j.enpol.2010.10.037

Zhu, B., Wang, K., & Cheong, T. S. (2019). Energy efficiency in OECD countries: An empirical investigation. Energy Economics, 80, 30-37. https://doi:10.1016/j.eneco.2019.01.018

Zhu W, Zhang Z, Li X, Feng W, Li J (2019). 'Assessing the effects of technological progress on energy efficiency in the construction industry: a case of China'. Journal of Cleaner Production, 238:117908