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Navigating Emission Metrics: Examining the Role of Eco-Innovation, Energy Efficiency, and Institutional Quality in OECD Countries

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ABSTRACT

Purpose: Main purpose of this paper is to compare and contrast the factors affecting consumption-based emissions (CCO_2) and production-based emissions (PCO_2) accounting approaches by considering role of eco innovation, energy efficiency, imports, exports and institutional quality under Environment Kuznets Curve (EKC) hypothesis for OECD countries.

Design/Methodology/Approach: This study investigated research models based on EKC hypothesis and Porter's hypothesis (PH) by utilizing the data set of 1996 to 2020. This study utilized second generation econometric techniques (Cross sectional dependence and slope heterogeneity tests). Set of regressions and models were estimated by using sys-GMM technique to get robust results after applying the panel unit root test by using E-views.

Findings: Result of sys-GMM, supporting the presence of EKC for production-based emissions but EKC doesn't exist for consumption-based emissions. Secondly, the impact of imports and exports is divergent across emission calculation approaches. Imports are significant for CCO_2 but have no effect on PCO_2. Impact of exports is significant and negative on both emission approaches. Coefficients of eco-innovation (EI) and Energy efficiency (EE) are significant and negative, yet quality of institutions (INQ) have moderating role for enhancing eco-innovation performance in OECD countries.

Implications/Originality/Value: Empirical findings of study provided useful insight for policy makers and researchers that both emission calculation approaches (PCO_2 and CCO_2) have their respective importance depending on the nature of the analysis. In the case of OECD countries, $CCO_2$is more relevant because in OECD countries emission is more related to consumption patterns than production activities. Further, these countries must emphasize synergistic relationship between EI and INQ for enhancing, energy efficiency and eco-innovation performance.

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1. Introduction

The upsurge in human consumption, production and trade practices has enhanced the environmental load of economic activities by imposing a huge environmental cost, especially after economic openness which has far-reaching consequences through interconnected global corridors. The environmental load factor of economic activities has imbalanced global heat balance by emitting a huge number of heat-absorbing gases (Solomon et al., 2017). According to the global climate report and global emission statistics (2020), the years 2015 and onward are recorded as the hottest years, ever in the history of the globe. The World Bank (2018) reported a 68% rise in global emissions as compared to the last six decades, with a yearly average growth rate of 1.5%. the issue of emissions originating within and beyond borders is still seeking the attention of researchers and policymakers to look into the responsible factors and actions taken to conserve the environment. In the current decade, substantial linkages have been observed between trade flows, economic growth and environmental sustainability (Dong et al., 2018).

Trade flows and economic activities are major global environmental hazards in the global economic system and their impact on environmental quality is not uniform, depending on the nature of emissions because a wide-ranging phenomenon has multiple dimensions with heterogeneous consequences. A growth-emission relationship has become a challenging phenomenon, especially in developed countries. The conflicting EKC hypothesis is often used to explore the relationship between environmental degradation and economic growth (Torrace & Boyce., 1998). Economic progress degrades environmental quality by inducing a climate war (Hasanov et al., 2019). The upsurge associated with economic growth is the increase in demand for energy-intensive products, i.e. vehicles, bigger homes and home appliances. Now emissions have become an issue of developed countries, which are responsible for one-third of total emissions. In developed countries, the trade-emission nexus has turned in the direction of emission, as emission in developed countries is more of a consumption-based phenomenon than production.

Emission analysis is incomplete without regarding trade flows because trade and climate are complex and interconnected with deep roots pivoted in each other. There is no unanimous outcome of exports and imports on carbon emissions (PCO_2 & CCO_2). The ultimate impact of trade flows on the environment of any economy is uncertain (Yang, et al., 2018). Trade involves both direct emissions related to transportation and indirectly, it affects environmental performance through the relative strength of composition, scale and technological components (Antweiler et al., 2001; Cole and Elliott, 2003). There is a paradigm shift in the traditional facts about the trade emission nexus. In the current century, the picture is changing especially in developed countries.

To erode the consequences of interconnected ecological destructive activities associated with trade flows, consumption, and production processes, environmental researchers and policymakers found several factors that can significantly reduce environmental load, with a particular focus on eco-innovation (EI) and energy efficiency (EE) as key drivers of pollution reduction. EE and EI are a cornerstone of sustainability in OECD countries. OECD countries are among the leading world economies with high growth, high energy demand (IEA, 2020) and increasing trade volume. EE and EI reduce environmental costs and improve environmental performance, which in turn improves economic growth via productivity and competitiveness channels (Costantini et al, 2017; Cai and Li, 2018).

Environmental dynamics are not homogeneous across countries; depend on country specific conditions (Shahbaz et al., 2017). EI is useless until and unless the host country does not design proper policies and a stable environment for the absorption of externalities. The quality of institutions improves regulations, the structure of the economy, economic performance and trade patterns (Ahmed & Wyckoff., 2003). So, INQ, EI, and EE result in a synergistic relationship in nations belonging to the OECD when there is a strong presence of technological innovation and effective governance structures, which indicates that EI has a notable impact on enhancing environment quality, especially when combined with high-quality institutional frameworks.

After realizing the fact that aggregate trade openness measures do not reveal the direction of environmental policies, this study used imports and exports for a clear understanding of which variable to target. Moreover, for the adaptation of environment-related technologies, the role of complementary factors of the host country's policies, such as institutional quality is included that has not been addressed in the previous literature. Further, aggregate measures of CO_2 emissions do not explain real facts about environmental degradation, whether countries are facing domestic emissions or emissions are imported through traded goods. That's why both PCO_2 & CCO_2 emission accounting are employed for investigating the distinct factors. To the best of my knowledge, only a few studies have made comparison of factors affecting PCO_2 & CCO_2 (Liddle, 2018; Hansove et al, 2018; Khan et al, 2020) but none of these studies employed complementary role of institutional quality with EI. Lastly, to control the heterogeneity across panel data, this endeavor employed second-generation panel data techniques to obtain more robust results for further policy formulation.

The objective of the study is to explore the effect of eco-innovations, energy efficiency, economic growth, imports, exports and institutional quality on PCO_2 & CCO_2 across selected countries. Further this piece of work also checks the validity of the EKC by comparing, CCO and PCO_2 emission accounting approaches, which are less studied in previous literature. Further, complementary role of institutional quality is investigated to explore the channels that could enhance eco-innovation capacity because technology alone is nothing; it's the complementary factors that provide channels for diffusion and adaptation of environmentally friendly technologies.

The remainder of the paper is structured as: section 2 contains brief literature on affecting environmental performance; section 3 is describing model specification; section 4 is providing detail of variables and data sources; section 5 reported the analytical frame work and findings of study; section 6 and 7 are presenting conclusion, policy recommendations.

2. Literature on Factors Affecting Environmental Performance

Numerous variables contributing to environmental degradation have been examined in literature, such as per capita income (Zhang & Zhou, 2015), economic conditions and stages of development (Gao et al., 2021), financial progress (Safi et al., 2021, Ozturk & Ilhan 2013; Dong et al., 2018), financial development, labor market characteristics, infrastructure development and governance (Chang et al., 2012), energy structure (Shahbaz et al., 2017), urbanization (Ali et al., 2017), stage of industrial development (Al Mulali et al., 2015), political regime (Yao et al., 2021). The impact of all these factors on environment is hotly debated in the literature but these studies have not explored the possible direction of specific factors with special reference to PCO_2 and CCO2.

Production and consumption-based emission accounting are the two most popular accounting systems for analyzing carbon emission allocation responsibility. In the literature, generally, both accounting approaches are used, the traditional production-based accounting approach that does not account for the impact of imported consumption through trade flows and the recently developed consumption-based accounting approach (Petres et al, 2011). Literature suggests that most of the data on emissions and climate policy is based on a PCO_2 approach that could be misleading (Karakay et al., 2019) because PCO_2ignores environmental aspects of consumption emissions produced abroad or produced domestically and exported abroad (Petres et al., 2011). To better analyses the composition of global emission contributions, it's better to use a consumption-based emission accounting approach that involves all types of emissions indirectly reaching consumers (Petras et al., 2016; Grasso, 2017).

Previous literature (Ali et al., 2014; Zhang et al., 2017; Zhao et al., 2015; Shahbaz et al., 2018) suggests that only production activities are responsible for environmental degradation, but recent literature review emphasizes that consumption activities of importing countries are responsible for international carbon emissions, and their findings suggest a significant effect of imports and exports on carbon emissions, supporting the phenomenon of emissions originating outside countries (Knight & Socher., 2014; Afionis et al., 2017; Liddle, 2018; Hansove et al., 2018; Khan

et al., 2020). Import and export-oriented decisions are important for determining the path of economic growth and environmental degradation. Exports enhance capital flows, competitiveness, and market share via the international trade flow channel. Exports of a country are based on a comparative advantage that is cost-effective (Tyler, 1981). If exports are carbon-intensive products they can reduce emissions in the domestic country by being transferred to another country or region. The role of imports is also important for climate protection if imports are embodied with technology-driven products (Feder, 1983) rather than emission-embodied. Khan et al. (2020) investigated factors effecting CBA in G-7 countries and found that exports and eco-innovation as abating factors for CBA, whereas, economic growth and imports are sources of enhancing consumption-based carbon emissions.

Al-Mulali et al. (2015) examined the influence of GDP, financial development; urbanization and trade openness on PCO_2 by using panel FMOLS. Empirical analysis of 23 European countries found a negative link between PCO_2 and trade openness, whereas, financial development, economic growth and urbanization enhance production-based emission in the case of European countries.

Recent literature emphasizes that production activities alone are not responsible for carbon emissions; consumption activities also add carbon emissions to the atmosphere. Peters et al (2011b) put the responsibility of global gas emissions on consumption activities in developed countries. In most recent literature, especially in developed countries, consumption-based carbon emissions are emphasized (Akram et al, 2022; Azam & Khan., 2016; Jorden et al.). Ding et al. (2021) filled the literature gap by analyzing the impact of trade, eco-innovation, and REC on G-7 countries by utilizing the data set 1990–2018. Findings suggest a significant impact of the above-mentioned variables on consumption-based carbon emissions. Eco-innovation and more use of renewable energy are better than a reduction in energy use in developed countries. Moreover, imports and exports both have a significant impact on carbon emissions in the case of G-7 countries.

Traditional production-based carbon calculation techniques do not provide a clear understanding of the responsibility of trade-related emissions (Mózner, et al, 2013). Saifi et al (2021) investigated the influence of exports, imports, eco-innovation, and financial stability in case of E-7 countries by employing CCO_2. By using advanced second-generation panel integration analysis of emerging countries, it is suggested that financial stability, exports and REC reduce CCO_2. Acheampang (2019) investigated the impact of exports and imports on 169 countries and found that exports are adding to production based (PBE) emissions whereas; Wahab et al. (2021) found that exports reduce CCO_2Results depict that the impact of exports on CCO_2 and P CO_2 is not the similar.

Mózner (2013) analyzed trading activities with special reference to consumption-based emissions. Comparative analyses of Germany, the UK, the Netherlands, and the United States provoked the importance of CCO_2 or better policy formulation by concluding that it is important to investigate whether it is production or trading activities that are causing particular carbon emissions. Most of the traditional literature employs production-based carbon emission accounting that does not account for embodied emissions in trade. Aggregation of emission calculation accounting does not explain real facts about countries emission contributions (Peters et al., 2011).

Growth and emission relationship is a challenging phenomenon in developed countries because of direction of emission. Literature has revealed the presence of inverted u shaped EKC in developed countries (Halkos & Tzeremes, 2009; Seldon & Song, 1994; Torrace & Boyce, 1998). Yet, in some developed countries, EKC is "N"-shaped instead of inverted "U"-shaped (Webber & Allen, 2010; Beak, 2015). An N-shaped environment Kuznets curve was observed in Finland, Norway and Australia showing that even after threshold level emissions decreased but in the long run it resumed again because of an upsurge in consumption activities. Allard et al (2018) found the N-shaped EKC for countries with heterogeneous income levels. There is no definite and single outcome for growth and environment quality in developed economies. In short, the growth of developed countries has an uncertain

outcome on environmental performance across both emission calculation approaches and EKC has different graphical shapes besides the traditional inverted U shape.

The concept of eco-innovation has transformed the climate related literature to address environmental performance issues (Zhang et al., 2017; Ali et al., 2021; Ahmad et al., 2016; Mehsah et al., 2018; Ding et al., 2021; Wang et al., 2021). Initially, eco-innovation was considered a costly and burdensome strategy to combat the emission reduction challenge (Wally and Whitehead, 1994). The cost of a patent application would shift domestic capital abroad instead of improving production technology (Kiefer et al., 2019) towards less restricted countries. After a long journey, Porter and Linde (1995) argued that eco-innovation can outweigh the cost of environmental regulation if furnished with proper policies.

Ali et al. (2016) explored the relationship between eco-innovation (EI) and environment for Malaysian economy and found that EI reduces carbon emission. Ahmad et al. (2016) found similar results for European countries. Navarro et al. (2017) explored the role of eco-innovation in Spain and France and found emission reduction effects through improved resource allocation. Mehsah et al. (2018) investigated the impact of EI in 28 OECD countries and found a noteworthy influence on environmental quality. Findings of the study also highlighted that the extent of EI on environmental quality varies across countries depending on countries policies and EI adaptation strategies.

Though eco-innovation is considered a vital factor for a clean and green environment without hurting economic growth, it requires some complementary conditions. Impact of eco-innovation is significant on environmental quality, yet the outcome is not homogeneous across countries. Innovations are the strategic factors for reducing carbon emissions, and the role of institutions is to ensure the effectiveness of innovation on environmental quality (Ibrahim & Law, 2015). The character of institutional quality in affecting carbon neutrality targets has been explored in the literature (Li et al., 2014; Ibrahim & Law, 2015; Dean et al., 2009; Ozturk, 2015; Ali et al., 2021) but not investigated with special reference to eco-innovation. Only efficient and well-functioning institutions help improve environmental quality because institutions ensure technological innovation by directing investment in clean and green technologies. Moreover, well-established institutions encourage citizens to invest in or innovate in environmentally friendly technologies (Acemoglu, 2012). In the wake of attaining carbon neutrality and sustainable growth targets, energy efficiency has become the center of emission reduction efforts to combating current global environmental problems (Machiba., 2010). Energy saving is a cost-saving strategy that deals with global emission issues very carefully (Danish et al., 2020). Most industrialized and developed nations are investing in energy-efficient technology to cope with the dual challenges of the environment and economic performance (UNEP, 2016). The concept of energy efficiency has become the standard for emission reduction strategies in the current decade.

Literature revealed that only few studies made comparison of factors affecting carbon emissions by comparing two emission calculation approaches (Liddle, 2018; Hansove et al, 2018; Knight and schor, 2014). Knight and schor (2014) investigated high income countries. Liddle, 2018) considered 102 countries including both OECD and non-OECD countries. Hansov et al (2018) investigated a group of oil exporting countries. No study has made comparison of factor affecting PBA and CBA for OECD countries by considering eco-innovation, energy efficiency and complementary role of institutional quality for eco-innovation performance.

3. Description of Data and Model specification

The sample of this study is composed of 35 OECD countries over the period of 1996 to 2020. This study analyzed the variables selected from the OECD that are highly developed countries[1]. Most of the OECD economies are dominant economies in the world, with the highest share of trade and growth in global trade and occupying high positions on energy efficiency and eco-innovation scoreboards. The study used data taken from the Global Carbon

1The list of countries is presented in Appendix 2.

Atlas (GSA, 2020), the OECD, 2020)2, World Bank data from World Development Indicators (WDI), from World Economic Outlook, the IEA, and the International Monetary Fund (IMF, 2020).

CCO_2 include both emissions produced domestically and emissions embodied in imports. CCO_2 is slightly higher than PCO_2 in OECD countries (OECD, 2019. Data is obtained from the Global Carbon Atlas (GSA). Metric tons of carbon emissions are used as a unit for measuring CCO_2. Secondly, PCO_2 include emissions resulting from domestic activities. Goods produced domestically, either used within the country or exported abroad, are both included PCO_2. This study used data on PCO_2 variables collected from the Global Carbon Atlas (GSA). Literature suggests that data on this variable will be measured in metric tons of carbon emissions. Data on imports and exports is obtained from World Development Indicators (WDI, 2020) as a percentage of GDP. Data on energy use and GDP is obtained from the World Development Indicators Data Base 2020 and International Energy Agency statistics.

The word "eco-innovation" pertains to the advancement and implementation of novel concepts, technologies, processes and practices that provide favorable outcomes for the environment. Data on Environment-Related Technological Innovation (Eco-Innovation) is obtained from the OECD (2020) database. Data on growth variables is obtained from the World Development Indicators database (WDI, 2020). The concept of "Renewable Energy Consumption" (REC) pertains to the measurement of the proportion or quantity of energy obtained from renewable sources within the total energy consumed within a specific geographical area, sector or operation.

The notion of "institutional quality" (INQ) pertains to the overall efficiency, transparency, and resilience of a country's institutions. This encompasses the legal systems, regulatory frameworks, governance structures, and adherence to the rule of law inside the nation. The concept of Institutional Quality (INQ) pertains to the evaluation of the overall health and effectiveness of a country's institutions. The INQ is assessed by using additional indices, such as the World Governance Indicators (WGI), the Worldwide Governance Indicators of the World Bank, or the Transparency International Corruption Perceptions Index.

4. Model specification

In light of goals of this piece of research; to compare and contrast the factors that affect carbon emission on PCO_2 and CCO_2 in the green gas emission accounting system under eco-innovation, energy efficiency, exports, imports and economic growth, following Hasanov et al. (2018) and Liddle (2018) the equation form of the model of this analysis is given as:

$$PCO_{2,i,t} = \beta_1 GDP_{i,t} + \beta_2 GDP^2_{i,t} + \beta_3 IM_{i,t} + \beta_4 EX_{i,t} + \beta_5 X_{i,t} + \varepsilon_{i,t} \quad (1)$$

PCO_2 is for production-based carbon emissions, EX is for exports and IMP is for imports, $\varepsilon_{i,t}$ for error term and $X_{i,t}$ is for controlled variables to avoid omitting any important variable. Economic activities result in increased emissions and increased imports and exports also effects carbon emissions. Whereas, the square of GDP shows that after a threshold level, further increases in GDP will help to control carbon emissions by checking the presence and absence of the environmental Kuznet curve and the pollution haven hypothesis (PHH). Imports are considered a cradle of knowledge and technology transfer, but if imports are carbon-embodied, especially consumption-based appliances that are pollution-intensive, then they can affect the host country's environment negatively through the consumption channel. Moreover, transportation-associated emissions are also trade-associated emissions. Exports are a source of emission reduction in developed countries because of technology-based production. Expected sign of economic performance, imports and exports are ambiguous a priori.

2OECD data base (2020)

Production-based emission calculations don't consider the impact of products produced domestically but consumed abroad (Halicioglu, 2009) as well as imported products from abroad that are consumed domestically. After realizing this fact that production-based emissions do not account for imported and exported emissions this study also examined in a parallel model for CCO_2 another aspect of carbon emissions, to see whether the effect of EI, EE GDP, imports and exports remains the same across both proxies of carbon emissions.

$$CCO_{2,i,t} = \beta_1 GDP_{i,t} + \beta_2 GDP^2{}_{i,t} + \beta_3 IM_{i,t} + \beta_4 EX_{i,t} + \beta_5 X_{i,t} + \varepsilon_{i,t} \quad (2)$$

In the next step, following Hasanov et al. (2018), Mensah et al. (2018) and Khan et al. (2019), this study includes environment-specific technological innovation and energy efficiency in the empirical model. The extended models are given as:

$$PCO_{2,i,t} = \beta_1 GDP_{i,t} + \beta_2 GDP^2{}_{i,t} + \beta_3 IM_{i,t} + \beta_4 EX_{i,t} + \beta_5 EE_{i,t} + \beta_6 EI_{i,t} + \beta_7 X_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$CCO_{2,i,t} = \beta_1 GDP_{i,t} + \beta_2 GDP^2{}_{i,t} + \beta_3 IM_{i,t} + \beta_4 EX_{i,t} + \beta_5 EE_{i,t} + \beta_6 EI_{i,t} + \beta_7 X_{i,t} + \varepsilon_{i,t} \quad (4)$$

Whereas, EE is for energy efficiency and EI stands for eco-innovation. X includes other control variables such as institutional quality, human capital and renewable energy consumption. This study acquaint with an interaction term (EI*INS) in the model. The basic purpose of including the interaction term is to gauge whether institutional quality moderates the relationship between eco-innovation and CO_2 emissions.

The extended models are given as:

$$CCO_{2,i,t} = \beta_1 GDP_{i,t} + \beta_2 GDP^2{}_{i,t} + \beta_3 IM_{i,t} + \beta_4 EX_{i,t} + \beta_5 EE_{i,t} + \beta_6 EI_{i,t} + \beta_7 X_{i,t} + \beta_8 EI * INS_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$PCO_{2,i,t} = \beta_1 GDP_{i,t} + \beta_2 GDP^2{}_{i,t} + \beta_3 IM_{i,t} + \beta_4 EX_{i,t} + \beta_5 EE_{i,t} + \beta_6 EI_{i,t} + \beta_7 X_{i,t} + \beta_8 EI * INS_{i,t} + \varepsilon_{i,t} \quad (6)$$

EI exerts a positive impact on the environment by reducing the environmental load of production and consumption activities, but its outcome may be divergent on account of the regulatory framework of economies. Implementation of rules related to the environment is the main contributor to enhancing eco-innovation performance. Institutions act as mediators for EI to improve environmental quality by reducing the burden of economic activities.

5. Analytical Framework and Findings of study

Most of the panel data is characterized by cross-sectional dependency issues. Before estimating the models, this study examined the slope heterogeneity and cross-section dependency (CSD) test developed by Pesaran (2004). Moreover, this study employed second-generation unit root tests to check the stability of the data series. Since OECD countries are integrated economically, politically, and socially with each other, that's why country-specific variables cannot be independent of each other. After applying the Sergan test, Arellano-Bond/Bullendek Bond-sys-GMM is used. This study has tackled the problem of endogenity by applying the Sys-GMM econometric technique. Moreover, keeping in view the existence of substantial bias and size distortions when cross-section dependency is ignored, this study employs cross-section independence using the CSD tests proposed by Pesaran (2015) and Pesaran (2008).

Table 5.1

Results of Cross Section Dependence Test

Variable	Pesaran (2015) CD test	Pesaran (2008) CD-test	Correlation
CCO2	16.427*(0.000)	19.116*(0.000)	0.431
PCO2	13.611*(0.000)	16.261*(0.000)	0.447
GDP	11.218*(0.000)	14.833*(0.000)	0.375

EXP	14.181*(0.000)	17.117*(0.000)	0.472
IMP	13.719*(0.000)	14.187*(0.000)	0.565
EI	18.638*(0.000)	17.072*(0.000)	0.611
REC	11.402*(0.000)	12.171*(0.000)	0.461
INSQ	9.624*(0.000)	10.054*(0.000)	0.399
EE	11.419*(0.000)	14.086*(0.000)	0.466

Table 5.2

Results of Slope Heterogeneity Test

Models	$\tilde{\Delta}$	$\tilde{\Delta}_{Adjusted}$
Model-1. A PCO_2=f (Y, IMP, EXP, EI, EE, INQ, INQ*EI, X)	11.437***	10.528***
Model-1. B CCO_2=f (Y, IMP, EXP, EI, EE, INQ*EI, X)	9.731***	10.301***

* Represents significant at 1 percent level, ** represents significant at 5 percent level and * **represents significant at 10 percent level.

The findings of CD illustrated that the sample countries are not completely independent of one another. Results are given in Table 5.1. Next, this study checks the slope heterogeneity in the models by employing Pesaran and Yamagata (2008) slope heterogeneity test. Results given in table 5.2 are showing that values of delta adjusted and delta are statistically significant, depicting that slope heterogeneity exist in models. Results presented in tables 5.1 and 5.2 confirm the presence of cross-sectional dependency (CSD) and slope heterogeneity because of integration among countries. Due to the presence of cross-sectional dependency (CSD), this study is limited to second-generation panel unit root tests because traditional unit root tests in the presence of cross-sectional dependency provide biased estimates. This piece of research used the Cross-Sensationally Augmented Im, Pesaran, and Shin (CIPS) unit root test developed by Pesaran (2007) that accounts for cross-sectional dependency (CSD). The results presented in Table 5.3 imply that all variables, CCO2, PCO2, REC, GDP, EI, IMP, EXP, EE, INQ are stationary at level.

Table 5.3

Results of Panel Unit Root tests

Variables	**CIPS** Intercept and Trend	**Integrated Order**
CCO2	-3.154*(0.000)	I (0)
PCO2	-2.325**(0.020)	I (0)
GDP	-3.116*(0.000)	I (0)
EXP	-3.417*(0.000)	I (0)
IMP	-2.172*(0.000)	I (0)
EI	-3.811*(0.000)	I (0)
REC	-2.164*(0.000)	I (0)
INQ	-2.734**(0.040)	I (0)
EE	-2.814*(0.000)	I (0)
HC	-2.482*(0.000)	I (0)

Note: * represents significant at 1% level of significance

To investigate the long-run coefficients, this study employed the Sys-GMM technique since all the variables are stationary at level. The system GMM is an appropriate technique that itself handles the problems of endogeneity, serial correlation, and heteroscedasticity (Chaabouni & Saidi, 2017). This study estimates model 1 and 2, where the variable environmental degradation CCO_2 and PCO_2 is regressed over income, exports, imports, eco-innovation, energy efficiency, and other control variables. Table 5.4 and 5.5 demonstrated several interesting facts about determinants of CCO_2 & PCO_2 emissions with special reference to EI and EE.

Coefficient of GDP is significant for both models. First, the results verify the absence of an environment Kuznets curve (EKC) hypothesis for CCO_2 as the coefficient of income is positive ($\beta_1 > 0$) and significant, whereas the squared term of income is also positive ($\beta_2^2 > 0$), depicting the absence of a hump-shaped relation between income and trade-adjusted CO_2. The logic behind is that, in OECD economies an increase in income enhanced demand for consumer goods that are energy-intensive imported products directly affects carbon emissions. Empirical findings of the study are in line with the work of (Dong et al., 2016 and Liu et al., 2020), who found that increase in income promotes consumption activities that put pressure on more energy use (fossil fuel) which is the greatest cause of environmental burden in OECD countries. On the contrary, the results of Table 5.5 are consistent with the theoretical foundations of the EKC hypothesis for PCO_2. The effects of GDP first increase emissions, but after some threshold level, GDP leads to emission reduction. The logic behind traditional inverted U-shaped EKC is the increased income is associated with high income, which effects productivity factors through research and development in the production process. The finding of economic performance on environmental performance is in line with (Akadiri et al., 2020).

This study empirically investigated the separate impact of IMP and EXP. The results show interesting facts that impact of exports and imports is varying on CCO_2 and PCO_2. The results illustrated that the coefficient of export is significant and negative for CCO_2, showing a negative relation between exports and CCO_2. Findings are in line with Khan et al. (2020) and Hansove et al. (2018), who discovered an inverse association between exports and CCO_2. The reason for the inverse relationship of exports on CCO_2 is that these countries export goods produced domestically with environmentally friendly technology. Emission reduction efforts in OECD countries have transformed production units into environment-friendly production processes.

Impact of exports on PCO_2 is also significant. Exports from sample countries are leading to environmental degradation, but their contribution is as small as 0.009 in Model 1.9 is showing that 1 unit increase in exports leads to a 0.009 unit increase in carbon emissions. The logic behind is that advanced countries have stringent environment-related policies with strict regulations for efficient allocation of resources in production. Exports from developed countries are technology-driven, with higher productivity and better management practices (Wanger, 2012). Better management practices in production encourage environmentally friendly means of production (Cole et al. 2006).

The second part of the trade flow variable is imports as a percentage of GDP. The coefficient of import variable is positive and significant for CCO_2. The logic behind the positive association of imports with carbon emissions is that OECD countries are developed countries with the highest per capita income and have higher demand, and increased demand for goods and services leads to increased energy consumption and higher embodied emissions. The impact of imports on CCO_2 follows the results of Liddle (2018) and Khan et al. (2020) and supports the positive relation between carbon emissions and imports as reported by the above studies. Another possible reason for the positive import-emission relationship is that leading OECD countries are importers of fossil fuel energy that is consumed in the transport sector. The energy sector is the main cause of emissions in OECD countries. Further, the use of home appliances is another major cause. An empirical investigation explained that the impact of imports is insignificant for PCO_2, indicating that IMP is not affecting traditional PCO_2 that includes only domestic production-based emissions.

To investigate the performance of EI adaptation, which is the leading strategy of OECD countries to combat environmental challenges, this study regressed EI on CCO_2 and PCO_2. Empirical results illustrated the negative and significant impact of EI in all five models estimated for robust results. The positive impact of EI performance on environmental performance is aligned with the outcomes of (Zhang et al,.2017: Wahab et al. 2020 and Alvarez & Herranz., 2017) who found that EI reduces environmental burden due to the paradigm shift in production procedures (recycling, end-to-pipe, use of wind and solar energy), clean production technology.

The baseline model is extended by the interaction term (Model 1.5) to find the complementary role of EI with INQ. Hence, in the last column of Table 6.4, the interaction term of EI with INQ is included in the model. The coefficients of EI and cross-term are negative, which implies that eco-innovation is positively associated with emission reduction and the INSQ further enhances this positive impact. Results specifying the hypothesis that eco-innovation helps to reduce carbon emissions in selected OECD economies and proper legislation and regulatory framework through quality institutions promote the role of eco-innovation to combat environmental challenges. The negative interaction term (EI*INSQ) confirms that the degree of institutional quality is a complementary factor for improving eco-innovation performance that abates CO_2 emissions, especially in industrialized economies. This result confirms the hypothesis that countries with developed institutions get more advantage from eco-innovation strategies (Porter hypothesis).

Table 5.4

Factor effecting CCO_2

Core Variable	**Model1.1**	**Model 1.2**	**Model 1.3**	**Model 1.4**	**Model 1.5**
GDP	-0.0006* (0.0001)	2.1510* (0.0022)	0.0044* (0.0003)	0.0135* (0.0014)	0.0047* (0.0003)
GDP^2	---	2.2776* (0.000)	2.5768* (0.0001)	4.1234 (0.0000)	2.7798* (0.0000)
EXP *Export as percentage of GDP)*	-0.581* (0.1008)	-2.16* (0.0000)	-0.5870* (0.1957)	-0.4100* (0.2394)	-0.3749*** (0.2230)
IMP *Export as percentage of GDP)*	1.535* (0.1258)	2.0273* (0.1471)	1.0148** (0.2261)	0.6141* (0.2040)	0.8633* (0.2077)
EI *Eco Innovation*	-0.0501* (1.5305)	-0.03012* ((0.0000)	-0.02112* (0.0001)	-0.03010 (0.0001)	-0.0322* (0.0001)
REC *Renewable energy Consumption*	-3.1275* (0.1537)	-2.2468* (0.3996)	-3.4643* (0.2455))	---	-3.6560* (0.1892)
HC *Human Capital*	---	-0.9210* (0.0757)	---	---	---
INSQ *Institutional Quality*	-0.3538* (0.014)	---	-0.4270* (0.0129)	-0.1361* (0.0417)	-0.3429* (0.0387)
EE *Energy Efficiency*	---	---	---	-0.0571* (0.0013)	
EI*INSQ	---	---	---		-0.511* (0.0001)
Number of Countries	35	35	35	35	35
Sargan test	25.60	29.40	28.05	28.57	30.22
Prob.	0.59	0.39	0.46	0.38	0.30
AR (1)	0.00	0.00	0.00	0.00	0.00
AR (2)	0.25	0.24	0.47	0.32	0.41

Dependent Variable: CCO2 emissions. *, ** and *** indicates p-value less than 1, 5 and 10 percent. The values in the parentheses are standard errors.

EE is an important determinant for both PCO_2 and CCO_2. The coefficient of EE is highly significant, with an expected sign. The negative coefficient of EE depicts its pivotal role in attaining carbon neutrality targets. Increasing demand for REC is important because it shows growing demand for cleaner production input. The variable of REC is vital to include in the analysis because renewable energy demand is a major focus in developed countries. The coefficient of REC is significant and negatively linked with environmental quality. Empirical findings of the REC impact support the presence of the de carbonization hypothesis related to the energy transition. REC (solar energy, wind

energy, and bio fuel) promotes clean and green production and growth by abating carbon emissions in production. Empirical findings of this model are supporting the outcome of Khan et al. (2020). HC is also an important factor that could reduce emissions by enhancing the absorption capacity of countries. The estimate of human capital is significant and the sign is negative on PCO2. Showing that besides the external factors, internal factors such as human capital and institutions are important factors that direct the path of the environmental destination.

Table 5.5

Factors affecting PCO_2

Core Variable	Model 1.6	Model 1.7	Model 1.8	Model 1.9	Model 1.10
GDP	-0.0009* (0.0000)	1.3524* (0.0000)	0.0046* (0.0002)	0.0116* (0.0015)	0.0046* (0.0002)
GDP^2	---	-4.6200* (0.0000)	-2.8400* (0.0000)	-5.0800* (0.0000)	-2.8200* (0.0000)
EXP *Export as percentage of GDP)*	0.0728* (0.0708)	-1.04275* (0.0000)	0.1338* (0.0810)	0.0065* (0.1344)	0.1361 (0.1414)
IMP *Export as percentage of GDP)*	0.9876* (0.0721)	1.4745* (0.0665)	0.2810*** (0.0826)	0.2278* (0.1513)	0.2755* (0.0914)
EI *Eco Innovation*	-0.5082* (0.0000)	-0.2013* (0.0000)	-0.2022* (0.0000)	-0.2011* (0.0000)	-0.2315* (0.0000)
REC *Renewable energy Consumption*	-2.8060* 0.1423	-2.3580* (0.1691)	-3.3122* (0.3191)		-3.2883* (0.2702)
INSQ *Institutional Quality*	0.1613* 0.0035		0.2221* (0.0077)	-0.1409* (0.0201)	0.2216* (0.0114)
EE *Energy Efficiency*				-0.0058* (0.0007)	---
EI*INSQ	---		---		-3.3500 (0.0000)
Number of Countries	35		35	35	35
Sargan test	30.14	30.01	26.76	27.83	29.85
Prob	0.35	0.36	0.53	0.41	0.32
AR (1)	0.00	0.00	0.00	0.00	0.00
AR (2)	0.36	0.38	0.41	0.37	0.31

Dependent Variable: TCO2 emissions. *, ** and *** indicates p-value less than 1, 5 and 10 percent. The values in the parentheses are standard errors.

6. Conclusion

After realizing the environmental consequences of greenhouse gas emissions and their impact on economic activities, developed countries, especially OECD countries, emphasized eco-innovation and efficient energy utilization to combat global emissions. Eco-innovation (EI) and energy efficiency (EE) are key strategies adopted by OECD countries in line with sustainable development goals. Realizing the importance of institutional quality (INQ), this variable is added as a complementary factor for EI performance. The coefficient of interaction term of INQ with EI is also negative with enhanced magnitude. Strong institutions provide a framework for addressing the carbon emission management issue related to growing human activities both in PCO_2 and CCO_2 because strong institutions spur technology-related research and development in production. Implement rules and laws to control pollution havens through environmental legislation. Adaptation of carbon-abating technologies can outweigh the negative effect of trade on the environment by controlling the carbon leakage phenomenon. EE and EI both have

significant and negative coefficients across both emission calculation approaches. The impact of EI is more vulnerable to emission reduction as compared to EE.

According to the EI Action Plan Report (2012), most of the OECD members are EI leaders and rank higher on the eco-innovation scoreboard. The introduction of efficient institutions with environment-related technological innovation supports Porter's hypothesis in OECD countries. Strong institution by reducing carbon emissions suggesting that effective governance and quality intuitions are important factors for achieving carbon neutrality targets by controlling carbon transfer phenomena. REC and HC are introduced as control variables. The impact of renewable energy consumption REC and HC is also significant and negative on both carbon emissions. The logic behind the significant relationship between trade-adjusted carbon emissions is that REC is associated with production and consumption activities that reduce environmental burden by adapting environmentally friendly clean and green energy practices

7. Policy Recommendations and Limitation of study

The sustainability of OECD countries lies in policy frameworks that have the potential to reduce environmental load by enhancing resource efficiencies, especially energy-based inputs, which are the main cause of GHG emissions. According to the Energy Commission report (IEA, 2020), energy and material use are the largest emitting sectors in OECD countries. For environmental security, EI is a powerful tool of rich economies that underpins global commitments by considering environmental, economic, and energy dimensions. Policies should pay special attention to minimizing GHG concentration in environments that have a hazardous impact on the climate because of their long-life span. Carbon emissions once produced remain almost twenty years in the atmosphere. OECD countries should invest in carbon-neutralizing technology through the eco-innovation channel.

The impact of EI, EE, IMP, EXP, GDP, and INQ is divergent across emission calculation approaches (CCO_2, PCO_2). The importance of both approaches is related to their policy targets, depending on country-specific conditions and policy targets for emission reduction. If a country is a net exporter of emissions, it should adopt policies to control it PCO_2. On the contrary, if a country is a net importer, its policy targets for a carbon-free economy should be in line with CCO_2 reduction targets, such as a high tax on dirty products that will discourage dirty production inside and outside. In case of OECD countries consumption-based emission is more vulnerable to imports and economic growth. OECD countries must overlook their trade and emission structures. The role of imports and economic growth has a detrimental effect on consumption-based emissions. Exports do not have any hazardous impact on emissions. OECD countries should align their trade policies with environmental policies by considering the role of EI and EE. Export diversification by OECD economies can alter global emission outcomes through global value chains, as clean and green exports will transfer technology to other regions, which will improve the quality of traded goods globally.

In OECD countries, CCO_2 is more relevant than PCO_2because increased income has prompted consumer domestic demand as well as imported demand, which is a major cause of emissions. It is obvious that in OECD countries, climate change is a behavior problem that can be resolved through citizen awareness through proper legislation. Promoting the use of common transport, energy-efficient technologies, environmentally friendly home appliances, and renewable energy all depends on environment-related innovation. Efficient institutions can help eco-innovation achieve the target of climate stabilization. The government should collaborate with the private and public sectors to enhance eco-innovation improvement efforts through pollution control laws, regulations, and campaigns.

This study tried to provide a comprehensive, dynamic analysis of possible factors in the environmental challenge debate. Yet there is ample space for further investigation in this area. The results of this study are confined to the OECD region. The outcome of the relationship on the variable under analysis may be different for other countries

or regions depending on the cross-country factor. That may alter the outcome of eco-innovation, trade, energy efficiency, and economic growth on environmental, economic, and energy performance. Moreover, eco-innovation efficiency and adaptation can be different among different income groups. The financial sector, institutions, trade, and growth patterns vary from country to country, which can alter the EI outcome. This study is confined to the complementary role of institutions and can be extended to other complementary factors that affect EI efficiency.

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Appendix 1

List of Countries

1.Austria	19.Latvia
2. Australia	20.Lithuania
3.Belgium	21. Luxembourg
4.Canada	22. Mexico
5.chile	23. Netherlands
6.czech Republic	24. New Zealand
7. Denmark	25. Norway
8.Estonia	26. Poland
9.Finland	27.Portugal
10. France	28.Slovakia
11.Germany	29.Slovenia
12.Greece	30.Spain
13.Hungry	31. Sweden
14. Ireland	32.Switzerland
15.Israel	33.Turkey
16.Italy	34.Uk
17.Japan	35.USA
18.Korea	

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