The impact of fiscal decentralization, green energy, and economic policy uncertainty on sustainable environment: a new perspective from ecological footprint in five OECD countries

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Abstract
The paper explores the short-run and long-run asymmetric impact of fiscal decentralization, green energy, and economic policy uncertainty on environmental sustainability proxied by ecological footprint. Using the Nonlinear Autoregressive Distributed lag (NARDL) approach in selected five OECD countries, we find that ecological footprint responds to positive and negative fiscal decentralization asymmetrically in the long run and short run. However, the nature of the response varies significantly across countries. The result also suggests that green energy is a major factor in reducing the ecological footprint in all countries except Canada. Finally, economic policy uncertainty plays a negative and significant role in the ecological footprint in the UK, USA, and Germany while insignificant in Australia and Canada. Implications for effective environmental policies are discussed.

Keywords Fiscal decentralization · Green energy · Economic policy uncertainty · OECD · Environmental sustainability · Asymmetric

Introduction
Since the World Earth Summit in Kyoto, Japan, in 1997, creating a sustainable environment has become a significant world issue in the global context. The summit initiated the need to protect our planet from the global environmental crisis. Approximately 80% of the world’s population lives in a country plagued by major ecological issues. Human living standards and well-being have risen dramatically in recent decades because of significant economic expansion and prosperity (Majeed et al. 2021). This puts strain on the ecosystem, resulting in emissions, biodiversity loss, and environmental imbalance (Ahmed and Wang 2019; Lin et al. 2015). Therefore, formulating and achieving sustainable environmental objectives becomes a top priority agenda to be addressed globally.

Scholars recently have introduced several factors that can contribute to a sustainable environment; which include fiscal decentralization (H. Chen et al. 2018; Hao et al. 2020; Ji et al. 2021; Shi et al. 2018), green energy (Adams et al. 2020; Charfeddine and Kahia 2019; de Souza et al. 2018; Majeed and Luni 2019; Öztürk et al. 2020; Rasoulinezhad and Saboori 2018; Riti and Shu 2016), and reducing economic policy uncertainty (Adedoyin and Zakari 2020; Anser et al. 2021b; Pirgaip and Dinçer gök 2020; Ulucak and Khan 2020; Q. Wang et al. 2020a, b; Yu et al. 2021) as an important factor to preserve our planet and thereby creating a sustainable environment.

Fiscal decentralization has occupied a central place in international economic patterns (L. Wang and Lei 2016). It is a process of decentralization or power delegation to local political authorities to consider controlling important political and economic decisions in the best interest of economic objectives (Hao et al. 2020). There are two approaches responsible for this contradictory association between fiscal decentralization and environmental sustainability. One is the “Race to Bottom” hypothesis, and the other one is the “Race
to Top” hypothesis. Fiscal decentralization is a major determinant of environmental degradation (X. Liu et al. 2017; Que et al. 2018), and the “Race to Bottom” hypothesis is responsible for the positive association where governments encourage the relaxation of environmental regulatory norms, resulting in a reduction in environmental sustainability (X. Chen and Chang 2020; L. Liu et al. 2019; K. Zhang et al. 2017a, b). On the contrary, Hao et al. (2020), S. Cheng et al. (2020), and K. Li et al. (2020) believe that the “Race to the Top” hypothesis is responsible for the positive association between fiscal decentralization and environmental sustainability. Accordingly, we hypothesize the relationship between fiscal decentralization and environmental sustainability is asymmetrical. The effect of the negative and positive changes in fiscal decentralization on environmental sustainability may not be similar. Sustainability maybe more affected by fiscal decentralization negative change than positive changes due to the cyclicality of expenditures in fiscal systems (Rodden and Wibbels, 2010). This asymmetric impact of fiscal decentralization has been confirmed in previous studies (Li et al. 2021). Other than that, Sacchi and Salotti (2014) argued that asymmetry is intrinsic to fiscal decentralization and suggest both empirical and theoretical contributions would benefit by taking into account the asymmetric nature of fiscal decentralization.

Green energy is an essential factor in evaluating environmental sustainability. The gradual shift from non-renewable to green energy solutions leads to continuous improvement in environmental sustainability. In order to achieve economic and environmental goals and objectives, to enhance the use of renewable energy is a need of hour (Charfeddine and Kahia 2019; de Souza et al. 2018; Lau et al. 2018; Ridzuan et al. 2020; Riti and Shu, 2016; Samuel Asumadu Sarkodie et al. 2020; Sharif et al. 2020; Z. Wang et al. 2018; K. Zhang et al. 2017a, b).

Apart from the role of fiscal decentralization and green energy, economic policy uncertainty has gained the central position in economic-cum-environmental objectives (Baker et al. 2016). Thus, the ambiguity surrounding governmental policies, particularly fiscal and monetary policies, that affects the economic environment in which businesses operate is called (EPU) economic policy uncertainty (Pirgaip and Dinçergök 2020). However, COVID-19 has recently produced a great deal of economic uncertainty worldwide (Altig et al., 2020). Literature shows the positive association between environmental degradation and monetary policy uncertainty and determines that economic policy uncertainty is a significant and positive determinant of ecological degradation (Adams et al. 2020; Jiang et al. 2019; Q. Wang et al. 2020a, b).

However, the current literature can be criticized for failing to capture the whole aspects of a sustainable environment because of the extensive use of CO2 emission as a proxy. This proxy has recently been questioned because it is not comprehensive as the individual impact on the environment is not considered. As a result, the focus has switched to ecological footprint as a superior proxy (Ahmed et al. 2020; Alola et al. 2019; Alola et al. 2019; Alola et al. 2019; Baccini and Brunner. 2012; Barrett and Scott, 2003; Bello et al. 2018; Charfeddine and Mrabet 2017; Dogan et al. 2019; Wang et al. 2019; Zahra et al. 2021). The ecological footprint combines the two concepts to address the damage caused by human activities at the ground level and the damage caused by the unreturned use of all of the Earth’s natural resources. Moreover, the ecological footprint is also regarded as a measure of environmental sustainability (Destek and Sinha, 2020).

The core objective of this study is to empirically investigate the impact of green energy, economic policy uncertainty, and asymmetric effects of fiscal decentralization on the ecological footprint in the USA, UK, Germany, Australia, and Canada, the OECD countries, as explained in Fig. 1. These countries are highly decentralized OECD countries in which Germany, Australia, and Canada, during the last three decades, shifted from centralized to highly decentralized status. Even these three countries are included in the top seven decentralized countries, which have an average fiscal decentralization ratio of more than 58% in 2018, greater than the average ratio of fiscal decentralization of the rest of the world (Shan et al. 2021). Secondly, these developed countries can achieve SDGs to bring forward socio-political and environmental economic objectives and synergy (Destek and Sinha 2020). These reasons create room to investigate the association between fiscal decentralization, green energy, economic policy uncertainty, and environmental sustainability in these five selected OECD countries.

Keeping the contradiction in the literature about the impact of fiscal decentralization on environmental sustainability in form of either “Race to Top” hypothesis or “Race to Bottom” hypothesis, it is crucial to investigate the impact of fiscal expenditure decentralization on environmental sustainability. Similarly, many studies have attempted to assess the effectiveness of renewable and non-renewable energy sources in terms of environmental sustainability. Some studies on green energy revealed eco-friendly behavior (Shao et al. 2021; Sharif et al. 2020), while others revealed the contrary (Adams and Nsiah 2019). In addition to this, there is also a laudable contradiction about the role of economic policy uncertainty on environmental sustainability. Some studies suggest the negative relationship between environmental sustainability and economic policy uncertainty (Pirgaip and Dinçergök 2020; Ulucak and Khan 2020; Q. Wang et al. 2020a, b) while Adedoyin and Zakari (2020) has contradictory results. However, in most of the previous studies, CO2 is regarded as an environmental proxy, while in Ecological Footprint, it is a relatively more comprehensive
proxy to measure the performance of environmental sustainability (Zahra et al. 2021). Keeping this contradiction in view in the literature about the role of fiscal decentralization, renewable energy and economic policy uncertainty on environmental sustainability, this study explores the impact of fiscal decentralization, renewable energy and economic policy uncertainty on ecological footprint in selected OECD countries.

The current study adds to the previous literature in two ways. First, most research in the literature has analyzed the symmetrical empirical association between fiscal decentralization and the environment, using variables such as fiscal expenditure decentralization and fiscal revenue decentralization, and environmental emissions. The present study fills the existing gap by determining the asymmetric or nonlinear impact of fiscal expenditure decentralization on environmental sustainability for selected OECD countries. Secondly, most previous research studies employed CO₂ emissions as a proxy for environmental degradation; this study approximates the ecological footprint to measure environmental sustainability.

Moreover, policymakers, environmentalists, and government officials will benefit from the results of this study, which provide a deeper understanding and critical information, consequences, and evidence for environmental sustainability. The literature on fiscal decentralization, green energy, and economic policy uncertainty concerning their impact on the environment is briefly examined in the “Literature review” section. We cover the model, data, and methodology in the “Research and methodology” section. Empirical findings and their interpretation will be discussed in the “Model estimation and result analysis” section. Finally, we conclude the results and policy implications in the “Conclusion and policy implications” section.

**Literature review**

**Fiscal decentralization and environmental sustainability**

Theoretically, fiscal decentralization and ecological sustainability are interlinked (L. Liu and Li 2019). Fiscal decentralization, according to first-generation fiscal federalism (FGFF), is beneficial to environmental sustainability. According to this theory, public decision-makers are benefit maximizers of social welfare who deliver public goods and services equally (Rubinfeld, 1987). Local governments exceed the federal government in providing public goods and services and matching local preferences and requirements when there are no externalities (Tiebout, 1956); thus, fiscal decentralization improves the quality of environmental sustainability (L. Liu and Li 2019). Second-generation fiscal federalism (SGFF), while based on first-generation...
fiscal federalism, assumes that public officials’ priorities are influenced by political institutions that frequently divert from maximizing citizen benefit (Oates, 2005); thus, fiscal decentralization, in this case, is counterproductive for environmental sustainability (L. Liu and Li 2019).

Fiscal decentralization is a practice in which regional or provincial governments are given allocated authority or control over the regional economic activity (Hao et al. 2020; L. Liu et al. 2019). Therefore, fiscal decentralization has been documented as a global trend during the past several decades (L. Wang and Lei 2016). Furthermore, studies indicate that fiscal decentralization can, directly and indirectly, impact environmental sustainability (Li et al. 2021). The research shows as fiscal decentralization draw its impact on economic growth and development, which in return draws its influence on environmental sustainability and thus cause environmental degradation. Thus there is an indirect correlation between environmental sustainability and fiscal decentralization. Contrary, the literature also demonstrates that fiscal decentralization directly impacts environmental sustainability and quality. Shi et al. (2018); L. Wang and Lei (2016), and H. Chen et al. (2018) positively associate fiscal decentralization with environmental degradation and determine fiscal decentralization decline environmental sustainability. Similarly, C. He et al. (2012), Sigman (2007), J. Liu et al. (2017), Que et al. (2018), Kuai et al. (2019), Esty (1996), Ljungwall and Linde-Rahr (2005), Kunce and Shogren (2008), Taguchi and Murofushi (2010), Batterbury and Fernando (2006), Sigman (2014), and Fell and Kaffine (2014) empirically investigated that fiscal decentralization is a major factor for demoting environmental sustainability.

There is no consensus in the literature about the association between fiscal decentralization and environmental sustainability. K. Zhang et al. (2017a, b) and X. Chen and Chang (2020) have opined that the “Race to the Bottom” hypothesis is responsible for a positive association between environmental degradation and fiscal decentralization. On the contrary, Hao et al. (2020), S. Cheng et al. (2020), and K. Li et al. (2021) believe that the “Race to the Top” hypothesis is responsible for the negative association between fiscal decentralization and environmental degradation. As a result, investigating the influence of nonlinear fiscal decentralization on environmental sustainability is required to develop a strong policy framework (Shan et al. 2021).

Green energy and environmental sustainability

Countries around the world are keen to increase the capacity production of renewable energy as their sources are environmentally friendly and maintain environmental sustainability. Keeping the one of important SDGs in view that is to achieve the zero-carbon level by 2030, renewable energy production is given importance (Shen et al. 2021). Many empirical studies show how an increase in renewable energy production and consumption enhances environmental sustainability.

The gradual shift to green energy solutions leads to continuous improvement in ecological sustainability. Ozturk et al. (2016), Esso and Keho (2016), Bekhet et al. (2017), (Baloch et al. 2019a, b), Charfeddine and Mrabet (2017), Baloch et al. (2019a, b), Ozcan et al. (2020), and C.-Z. Chen and Lin (2008) empirically investigated a positive relationship between non-renewable energy consumption and ecological footprint as it is the major determinant responsible for increasing environmental footprint. Similarly, B. Chen et al. (2007) for China between 1981 and 2001, Caviglia-Harris et al. (2009) for selected 146 countries between 1961 and 2000, and Al-Mulali et al. (2016) for selected 144 countries in 1988 until 2008 determine that primary energy or non-renewable energy consumption is the major determinant of ecological footprint. Considering the importance of green energy in the arena of ecological footprint, certain studies also investigate the importance of green energy consumption to control the burden on ecological footprint. Sarkodie et al. (2020), Destek and Sarkodie (2019), Dogan et al. (2019), Ozcan et al. (2018), Bello et al. (2018), and Destek et al. (2018) empirically investigated that green energy is a significant determinant to reduce the ecological footprint and thus promote environmental sustainability. Similarly, Destek and Sinha (2020) for twenty-four OECD countries empirically investigated that increasing green energy reduces pressure on ecological footprint and vice versa. Similarly, Pata (2021) for BRICS countries between time period of 1971 and 2016 determines that green energy consumption reduces ecological footprint. Similarly, Usman et al. (2020) by using ARDL model for quarterly data from 1985:Q1 to 2014:Q4 determines for USA that green energy exerts negative pressure on increase in ecological footprint. On the contrary; Nathaniel et al. (2020) for MENA countries in time span of 1990 to 2016 empirically investigated that green energy does not contribute to the environmental sustainability.

Economic policy uncertainty and environmental sustainability

Jiang et al. (2019) and Anser et al. (2021a) theoretically explain that economic policy uncertainty influences environmental sustainability through direct policy adjustment effect and indirect demand effect. Prior explains how a high level of economic policy uncertainty divers the attention of policymakers, thus reducing the conducive circumstances for environmental sustainability, the later one, on contrary, effects energy consumption patterns through economic conditions and decision-making, thus influencing environmental sustainability. Economic Policy Uncertainty may have environmental consequences in addition to its financial products.
EPU may compel producers to use inefficient and environmentally damaging production methods, hence increasing CO₂ emissions. Furthermore, EPU may impact consumption and investment, resulting in lower CO₂ emissions (Anser et al. 2021b). Pieces of literature such as Pirgaip and Dinçergök (2020), Q. Wang et al. (2020a, b), Uluçak and Khan (2020), Yu et al. (2021), and Anser et al. (2021b) show the positive association between environmental degradation and economic policy uncertainty and determine that economic policy uncertainty is major and positive determinant environmental degradation. Similarly, Jiang et al. (2019) investigated that economic policy uncertainty in the USA is an economic problem that diverts Government attention from environmental burning concerns and thus causes indirect degradation to the environment and reduces environmental sustainability. In addition Adams et al. (2020) by replacing Economic Policy Uncertainty with World Uncertainty Index as a proxy of uncertainty empirically investigated that it is the major determinant responsible to escalate environment deterioration and CO₂ emission. On the other hand, Adegoyin and Zakari (2020) depicts that economic policy uncertainty increases environmental sustainability in the short run and then ultimately ecological degradation in the long run.

The current study adds to the previous literature in two ways. First, most research in the literature has analyzed the symmetrical empirical association between fiscal decentralization and the environment, using variables such as fiscal expenditure decentralization and fiscal revenue decentralization, and environmental emissions. Secondly, most previous research studies employed CO₂ emissions as a proxy for environmental degradation; this study approximates the ecological footprint to measure environmental sustainability and determines the asymmetric impact of fiscal decentralization, renewable energy, and economic policy uncertainty on the ecological footprint in OECD countries and also compares and contrasts the difference in empirical results for selected five OECD countries.

Research methodology

The model

The paper aims to empirically investigate the asymmetric impact of fiscal decentralization on ecological footprint. We exhibit the ecological footprint as a function of fiscal decentralization, green energy, and economic policy uncertainty as given below:

\[ EFP = f(FED, GE, EPU) \]  

(1)

where EFP is ecological footprint, FED is fiscal expenditure decentralization, GE is green or renewable energy, and EPU is economic policy uncertainty. Then we convert this function into a regression equation shown as Eq. 2, which determines the mathematical relationship uncertainty between dependent and presumed determinants to check their relationship.

Mathematically:

\[ EFP_t = \alpha_0 + \alpha_1 FED_t + \alpha_2 GE_t + \alpha_3 EPU_t + \epsilon_t \]  

(2)

where \( t \) shows each quarter of the selected data as subscripts and \( \alpha_0 \ldots \alpha_3 \) are respective parameter coefficients. The dependent variable is anticipated to respond to both increases and decreases of each independent variable in the traditional cointegration (Badeeb and Lean 2018). Linear Unrestricted Error Correction Model (UECM) without asymmetry or nonlinear impact, both in the long run and short run, is shown in Eq. 3 with \( \alpha_i \) and \( \beta_i \) as short run and long-run parameters, respectively. On the other hand, \( \epsilon_t \) shows the residual term with mean is equal to zero and constant variance.

\[ \Delta EFP_t = \alpha_0 + \sum_{i=1}^{m} \alpha_i \Delta EFP_{t-i} + \sum_{i=0}^{m} \alpha_i \Delta FED_{t-i} + \sum_{i=0}^{m} \alpha_i \Delta GE_{t-i} + \sum_{i=0}^{m} \alpha_i \Delta EPU_{t-i} + \epsilon_t \]  

(3)

The methodology

The rapid response of ecological footprint concerning fluctuations in fiscal expenditure decentralization in selected OECD countries could be a hint of asymmetric relationship in the short term, while fluctuation may cause consistent impact in the long run. Following Shin et al. (2014) through asymmetric modification in linear long-run and short-run empirical analysis, \( FED_t \) is decomposed into partial sum of two new time series variables of each of the variable. As it is noted that there is a contradiction about the role of fiscal decentralization in improving environmental sustainability, particularly as “Race to the Top” hypothesis and “Race to the Bottom” hypothesis; there is an asymmetric association between environmental sustainability and fiscal decentralization (Li et al. 2021). More specifically, one determines the partial sum of positive changes in FED that is \( FED_t^+ \) and another one is \( FED_t^- \) as partial sum of negative fluctuations in Fiscal Expenditure Decentralization. The specification is given below in Eqs. 4 and 5.

\[ FED_t^+ = \sum_{m=1}^{t} \Delta FED_t^+ = \sum_{m=1}^{t} \max(FED_t^+, 0) \]  

(4)
\[ FED_t^+ = \sum_{m=1}^{t} \Delta FED_t^+ = \sum_{m=1}^{t} \max(FED_t^+, 0) \quad (5) \]

Equation 6 shows the Asymmetric Error Correction Model (AECM), which inserts partial sum of positive and negative fluctuations of fiscal expenditure decentralization as \( FED_t^+ \) and \( FED_t^- \) to determine the long-run and short-run asymmetric or nonlinear impact of fiscal decentralization of expenditures on the ecological footprint in selected OECD countries.

\[ \Delta EFP_t = a_0 + \sum_{k=1}^{m} a_k \Delta EFP_{t-k} + \sum_{k=0}^{m} \left[ a_k^* \Delta FED_{t-k} + a_k^* \Delta FED_{t-k}^- \right] \sum_{k=0}^{m} 1 \Delta GE_{t-k} + \sum_{k=0}^{m} a_k \Delta EPU_{t-k} + \beta_1 EFP_{t-1} + \beta_2 FED_{t-1}^- + \beta_3 GE_{t-1} + \beta_4 EPU_{t-1} + \epsilon \quad (6) \]

The Wald test can be used to test the long-run symmetry in the model (Badeeb and Lean 2018; Li et al. 2021) where the null hypothesis is \( \beta_2 = \beta_3 \). The short-run positive and negative fluctuations or shocks in FED are shown by the coefficient \( a_k^* \) and \( a_k^- \), respectively. The Wald test can also be used to determine the short-run asymmetric impact with the null hypothesis of \( a_k^* = a_k^- \) (Atil et al. 2014; Badeeb and Lean 2018; Li et al. 2021).

It is important to note that Eq. 3 interprets linear short-run and long-run determinants of ecological footprint (ARDL model) while Eq. 6 determines asymmetric or nonlinear short-run and long-run determinants of ecological footprint in selected five OECD countries. It determines NARDL (nonlinear ARDL) as it includes the model’s short-run and long-run partial sum of positive and negative fluctuations.

Finally, appropriate diagnostic tests are used to determine the reliability, stability, and predictability of NARDL coefficients of the model. The Breusch-Godfrey LM test (Breusch, 1978; Godfrey, 1978) was used to verify the residuals autocorrelation and serial correlation. Ramsey’s RESET test (Ramsey, 1969) was used to verify the normal distribution of the residual terms and the appropriate functional form of the model. Auto-correlation and ARCH, i.e., Autoregressive Conditional Heteroscedasticity (Engle, 1982), are used to check the residuals.

**Data description**

Annual time series data for the variables of this study has been taken from 1998 to 2017 and is converted to quarterly time-series data by using the quadratic match sum method. The quadratic match sum method for converting the data from low frequency to high frequency is a good and widely accepted technique to reduce variations in the data and thus solves the problems related to seasonal variations (M. Cheng et al. 2012; Faisal et al. 2018; Türsoy and Faisal 2018); moreover, it also enhances the long-run relationship investigation between exogenous variables and dependent variable (Kisswani et al. 2020). A time series quarterly data has been taken from 1998 quarter one to 2017 quarter four. All variables are subjected to the natural logarithm. Total three exogenous variables are examined to explore their impact on ecological footprint, which are further explained in Table 1.

Fiscal expenditure decentralization is an important measure to determine the political risk (Su et al. 2021), which is a ratio of provincial expenditures to general government expenditure (Su et al. 2021; K.-H. Wang et al. 2021). However, the environmental impact of political decentralization has remained an important factor (Hao et al. 2020) where local and provincial governments are given the authority to control the economic activities in the allocated area (Farzanegan and Mennel 2012; Hao et al. 2020; L. Liu et al. 2019). Green energy collected from renewable energy resources such as wind, waves, geothermal, solar, heat, and rain is also called green energy. Green energy is environment friendly and has significant economic benefits, energy security, and reducing climate change (Zandi and Haseeb 2019). Green energy consumption as a percentage of total final energy consumption is another exogenous variable of this study to determine the impact on the ecological footprint in selected OECD countries. Economic policy uncertainty is unpredictably linked with regulatory authorities, fiscal and monetary policies, which can affect economic short-run and long targets and also has sustainable environmental consequences (Adedoyin and Zakari 2020). The economic policy uncertainty in this research paper is news-based economic policy uncertainty. Baker et al. (2016) developed news-based economic policy uncertainty by calculating the proportion of news articles showing policy uncertainty about fiscal and monetary policies, health care facilities, laws and order situation, trade policy, debt, and currency uncertainty (Azqueta-Gavaldón, 2017). These measures concern newspaper credibility, impartiality, biasness, and consistency when measuring policy uncertainty (Amin and Dogan 2021).

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1 We focus on the expenditure side as it provides more information about the efficiency of decentralized fiscal policy. The key assumption is that local governments face budget constraints in allocating their choices or preferences for spending. Thus, under a rational expectation theory, local governments are to maximize the utilization of fiscal resources to benefit their respective regions (Tirtosuharto, 2017). Therefore, allocation of fiscal expenditure becomes a proxy of quality of local governments. Other than that, Barbiero and Courrède (2013) argued that OECD countries are substantially more spending—than revenue—decentralized. This suggest that using government expenditure is the best measure for OECD countries.
Model estimation and result analysis

Unit root

The pre-requisite to using NARDL to investigate the asymmetric impact of exogenous variables on ecological footprint is to test the time series data for stationarity. It is important to note that NARDL models are employed after checking whether all the variables are stationarity at level or first difference or the mixture of I(0) and I(1). However; if any independent variable is found stationary at the second difference I(2) or higher difference order, the NARDL is not an appropriate choice to empirically investigate the asymmetric relationship between exogenous and dependent variables of the model; in other words, it will give spurious results (Badeeb et al. 2021; Ibrahim, 2015). In this study, Clemente et al. (1998) structural break unit root is used to check the unit root in the data with one structural breakpoint. The test follows two models: an additive outlier (AO) and an innovative outlier (IO). The first model, the additive outlier model, covers abrupt changes or fluctuations. In contrast, the second one covers the gradual or incremental changes in the mean of the variables in the model. In this case, the AO model prefers to judge the stationary decision because of sudden or abrupt structural changes rather than gradual or show fluctuations. Table 2 shows the outcomes of Clemente et al. (1998) unit root test and determines that none of the variables is stationary at the second difference, which satisfies the pre-requisite condition to use the NARDL model for further analysis.

Wald test and model selection criteria

It is important to note that the choice of lag order is receptive to selecting the optimal lag length for the NARDL model. There are different selection measures used to determine the most suitable lag length. Due to the limited number of observations, lag length can be imposed to an appropriate, limited number (Badeeb et al., 2020). Here, we assess three lags of each of the first differences of the variables. The Wald test is used to judge the presence of the long-run and short-run symmetric and asymmetric relationship between an exogenous variable and ecological footprint (Badeeb and Lean 2018; Jafri et al. 2021; Li et al. 2021). Table 3 exhibits long-run asymmetric relationship in Australia and USA, short-run asymmetric relationship in Canada and Germany, and symmetric relationship in the UK both in the long run and short run between fiscal expenditure decentralization and ecological footprint for the respective countries.

Main results and discussion

Empirical results

As indicated in Table 4, the analysis empirically discusses these countries’ long- and short-run dynamics one by one.

Australia  Wald test supports a long-run asymmetric and short-run symmetric relationship by depicting the long-run positive relationship between the partial sum of positive changes in fiscal expenditure decentralization and ecological footprint. At the same time, the partial sum of negative changes is not a substantial determinant of ecological footprint in the long run. At the same time, green energy is the negative determinant of an ecological footprint both in the long and short run. Contrary, the economic policy uncertainty is not a substantial factor in an ecological footprint both in the long and short run.

Canada  The result depicts a short-run, negative, but significant relationship between the partial sum of positive changes in fiscal expenditure decentralization and ecological footprint in Canada. On the contrary, there is a long-run positive and symmetric relationship between these two variables. Unlike Australia, in this country, green energy is neither a significant factor of ecological footprint in the long run nor in the short run. Likewise, economic policy uncertainty is not a substantial factor in an ecological footprint both in the long and short run.

Germany  Table 4 suggests that the partial sum of adverse changes in fiscal expenditure decentralization is the positive short-run determinant of an ecological footprint as the Wald

| Variables | Description | Source |
|-----------|-------------|--------|
| EP        | Ecological Footprint in million gha | Global Footprint Network |
| FED       | The ratio of own spending to general government expenditures | International Monetary Funds |
| GE        | Renewable energy consumption % of total final energy consumption | WDI 2020 |
| EPU       | Quarter-wise arithmetic mean of \( EPU_M \) \( \text{where} \quad EPU_M = \frac{3CGPU_{c-2} + 2CGPU_{c-1} + CGPU_c}{6} \) \( \text{CGPU} = \text{Monthly Economic Policy Uncertainty} \) | Economic Policy Uncertainty Index www.policyuncertainty.com |
test determines the short-run asymmetry between them. Likewise, fiscal expenditure decentralization has a negative but symmetric relationship with the ecological footprint in the long run. On the other hand, green energy is only a long-run negative determinant that suggests replacing green energy with non-renewable energy in the long run to increase environmental sustainability in the country. Moreover, economic policy uncertainty is a negative but significant factor of an ecological footprint both in the long and short run.

**UK** As per the Wald test and ARDL model, a symmetric, significant, and positive relationship is found between fiscal expenditure decentralization and ecological footprint in the long and short run. Contrary, green energy is neither a significant variable of ecological footprint in the long run nor the short run. On the other hand, economic policy uncertainty is a negative but significant determinant of ecological footprint in the long run only.
USA Like Australia, the Wald test confirms long-run asymmetry between fiscal expenditure decentralization and ecological footprint in the USA. Positive changes in expenditure decentralization are positive long-term determinants of ecological footprint; contrary, with no influence in the short run. Moreover, green energy is the negative determinant of ecological footprint in the short run and the long run. Therefore, the USA as in green energy for production and consumption purpose is suggested to reduce the ecological pressure. While economic policy uncertainty is a negative but significant determinant of an ecological footprint both in the long and short run. While economic policy uncertainty is a negative but significant factor or determinant of an ecological footprint both in the long and short run.

Discussion

Fiscal decentralization and environmental sustainability A partial sum of positive changes in expenditure decentralization increases the ecological footprint in Australia and USA in the long run. These results are also in-line with those of Li et al. (2021) at a 5% level of significance used as an environmental proxy. Li et al. (2021) suggested that in the long run, positive changes of fiscal expenditure decentralization have a positive association with environmental sustainability for Pakistan between 1984 and 2018. On the contrary, Yan and Zhong (2012) and K. Zhang et al. (2017a, b) argued that fiscal decentralization could not help control emissions. You et al. (2019) suggested that “Race to Bottom” is the major reason for a positive relationship between fiscal expenditure decentralization and environmental footprint in the long run. Most high-profit enterprises are attracted by decentralized governments that do not impose strong environmental regulations, leading to “Race to Bottom” (You et al., 2019).

On the other hand, Du and Sun (2021) regarded capital competition and biased and partial technological development as a major cause of a nonlinear but positive association between fiscal decentralization and environmental degradation. However, the negative changes in expenditure decentralization are not a significant variable of ecological footprint but also positively associated with an ecological footprint in both countries in the long run. Likewise, Q. He (2015) and Li et al. (2021) investigated the positive but insignificant relationship between fiscal expenditure decentralization and environmental degradation in the long run.

As Table 3 suggests, the symmetric long-run relationship between fiscal expenditure decentralization and ecological footprint in Canada, Germany, and UK. In Canada and the UK, fiscal expenditure decentralization is positively interlinked with an ecological footprint in the long run. These results are also in line with previous literature such as L. Liu and Li (2019), You et al. (2019), Du and Sun (2021), Li et al. (2021), Shan et al. (2021), and Y. Cheng et al. (2021) as these studies show a positive relationship between fiscal decentralization and environmental degradation in the long run. Shan et al. (2021) confirm the typical inverted U-shaped relationship between environmental degradation and fiscal decentralization for seven selected OECD countries. The potential reason is local or decentralized governments while keeping GDP growth in mind, attract relatively cheaper and easily accessible resources for production function to stimulate higher profit industries but on the expenses of environment sustainability. Therefore this “Race to Bottom Hypothesis” is the major cause of positive relationship between environmental degradation and fiscal expenditure decentralization.

The short-run analysis depicts quite interesting output, as shown in Table 4. In Germany, the short-run asymmetric relationship between fiscal expenditure decentralization and ecological footprint is in line with S. Cheng et al. (2020), who determines the nonlinear relationship between fiscal expenditure decentralization and environmental degradation in China. According to S. Cheng et al. (2020), an increase in per capita fiscal expenditure decentralization will reduce CO₂ emissions in China. On the contrary, Li et al. (2021) exert a positive short-run relationship between fiscal expenditure decentralization and ecological footprint in Pakistan. It is interesting to note that Shan et al. (2021) depict both positive and negative short-run relationships between environmental degradation proxy that is CO₂ emission and fiscal decentralization in different provinces of China. The research has concluded that the sign of relation coefficient between environment and fiscal decentralization depends on technological progress and energy consumption methods. Therefore fiscal decentralization coupled with technological progress can reduce carbon emission (Shan et al., 2021).

Table 4 shows both short-run and long-run symmetric, significant, and positive relationships between fiscal expenditure decentralization and ecological footprint in the UK. These results are supported by previous literature. According to L. Liu and Li (2019), the possible explanation is that...
Table 4 Nonlinear ARDL estimation results

|                      | Australia                  | Canada                     | Germany                    |
|----------------------|----------------------------|----------------------------|----------------------------|
| NARDL with LR asymmetry |                            | NARDL with SR asymmetry | NARDL with SR asymmetry |
| $FED_{t-1}^+$        | 3.66** (2.04)              | $FED_t$                    | 0.83*** (1.80)            | $FED_{t-1}$                    | $-3.96^{**}$ (−2.14) |
| $FED_{t-1}^-$        | 2.92 (1.9)                 | –                         | –                         | –                            | –                |
| $GE_t$               | 0.033* (−2.52)             | $GE_{t-1}$                 | −0.0008 (−0.05)           | $GE_{t-1}$                    | 0.0003 (0.07)    |
| $EPU_t$              | −0.0035 (−0.78)            | $EPU_{t-1}$                | −0.006 (−1.26)            | $EPU_{t-1}$                    | −0.013* (−2.76)  |
| $\Delta FED_t$       | −2.55 (−0.80)              | $\Delta FED_{t-1}^+$      | −18.05* (2.85)            | $\Delta FED_{t-1}^+$          | −1.61 (0.32)     |
| $\Delta FED_{t-1}$   | 2.60 (0.63)                | –                         | –                         | –                            | 3.18 (0.69)      |
|                      |                            | $\Delta FED_{t-1}^+$      | 8.52 (0.81)               | $\Delta FED_{t-1}^+$          | 9.21 (1.50)      |
|                      |                            | $\Delta FED_{t-1}^-$      | 5.47 (0.5)                | $\Delta FED_{t-1}^-$          | 16.13** (2.24)   |
| $\Delta GE_t$        | −0.11** (−2.34)            | $\Delta GE_{t-1}$         | −0.004 (−1.26)            | $\Delta GE_{t-1}$             | −0.09* (−3.73)   |
|                      |                            | $\Delta GE_{t-1}$         | −0.0034 (−0.81)           | $\Delta GE_{t-1}$             | −0.09* (−3.73)   |
| $\Delta EPU_t$       | 0.0004 (0.08)              | $\Delta EPU_{t-1}$        | −0.004 (−1.26)            | $\Delta EPU_{t-1}$            | −0.0084** (−1.95) |
|                      |                            | –                         | –                         | –                            |                  |
| Constant             | 1.78* (2.87)               | Constant                   | 3.04* (3.57)              | Constant                     | 5.9* (5.27)      |
| Long-run coefficient |                            |                            |                            | NARDL with LR Asymmetry       |                  |
| $LFED^+$             | 35.56***                   | LFED                       | 4.95*                     | LFED                         | −12.46**         |
| $LFED^−$             | −28.57                     | –                         | –                         | –                            |                  |
| UK                   |                            |                            |                            | NARDL with LR Asymmetry       |                  |
| $FED_{t-1}$          | 1.82*** (1.73)             | $FED_{t-1}^+$             | 1.53*** (1.70)            | $FED_{t-1}^+$                | −0.44 (−0.76)    |
| $GE_{t-1}$           | 0.0023 (0.46)              | $GE_{t-1}$                 | −0.038* (−3.18)           | $GE_{t-1}$                    | −0.089* (−2.40)  |
| $EPU_{t-1}$          | 0.0067** (−2.26)           | $EPU_{t-1}$                | −0.021* (−3.97)           | $EPU_{t-1}$                   | −0.0099* (−2.02) |
| $\Delta FED$         | 7.04* (2.81)               | $\Delta FED_{t-1}$        | 0.37 (1.54)               | $\Delta FED_{t-1}$            |                  |
|                      |                            | $\Delta GE_t$              | −0.03 (−0.64)             | $\Delta GE_{t-1}$             | −0.089* (−2.40)  |
| $\Delta GE_{t-1}$    | 0.04 (0.82)                | –                         | −                         | –                            |                  |
| $\Delta EPU$         | −0.003 (−0.96)             | $\Delta EPU_{t}$          | 0.0099 (2.02)             | $\Delta EPU_{t}$              |                  |
| Constant             | 1.51* (3.10)               | Constant                   | 4.3 (4.86)                | Constant                     |                  |
| LFED                 | 1.82**                     | $LFED^+$                   | 7.25**                    | $LFED^+$                     | 2.09             |

*, **, and *** denote 1%, 5%, and 10% level of significance, t-statistics are in parenthesis. Long run coefficient effect (- and +) refers to a permanent change in exogenous variables by (-1 and +1) respectively as fiscal decentralization (expenditure decentralization) increases, local governments seeking to maximize their
CO₂ emissions also have a significant negative externality; conversely, de-carbonization has a significant positive externality. Local governments are interested in free rides to maximize regional economic growth, resulting in a steady increase in carbon emissions. Yang et al. (2020) also investigated the same positive correlation between fiscal expenditure decentralization and environmental degradation for China. It is suggested that local governments avoid the “Free Riding” of resources to boost economic output on the expenses of environmental sustainability. Similarly, L. Liu et al. (2019) and Hao et al. (2020) empirically supported these results. They investigated the positive relationship between fiscal decentralization and environmental footprint or environmental degradation at the first stage, empirically proving an inverted U-shape relationship between them. These studies have concluded that there is “Race to Bottom Hypothesis” prevailing, which is responsible for deteriorating environmental sustainability at local level.

Result suggests fiscal expenditure decentralization is not the major or significant determinant of ecological footprint in the short run in Australia and the USA. These results are also in-line with S. Cheng et al. (2020), who did not find any significant relationship between fiscal expenditure decentralization and environmental degradation in China between 1995 and 2010. To better comprehend, Table 5 has summarized these results.

| FED impact       | Australia | Canada | Germany | UK   | USA  |
|------------------|-----------|--------|---------|------|------|
| Long run Increase in FED | +         | (+)    | [-]     | (+)  | +    |
| Decrease in FED  | NS        |        |         |      | NS   |
| Short run Increase in FED | {NS}      | -      | NS      | (+)  | [-]  |
| Decrease in FED  | NS        | +      |         |      |      |

NS represents not significant, {} shows symmetric, + and – show positive and negative relationships respectively.

Energy-incentive inputs can increase growth, sustainability, and quality (Majeed and Taqir, 2020; Zhao et al. 2013). However, non-renewable energy resources deteriorate environmental sustainability (Baloch, 2018; Baloch and Suad, 2018; Baz et al. 2020; Majeed and Luni 2019; Munir and Riaz 2020; Pao and Tsai, 2010, 2011). Similarly, S. Wang et al. (2011), Saboori and Sulaiman (2013), Shahbaz et al. (2012), OzTurk and Acaravci (2013), Ahmad et al. (2016), (Bekhet et al. 2017; Esso and Keho, 2016), Ozturk et al. (2016), Solarin et al. (2017), Mrabet and Alsamarra (2017), Atasoy (2017), B. Zhang et al. (2017a, b), Alvarado et al. (2018), S. Chen et al. (2019), Sohail et al. (2021), and Majeed and Taqir (2020) also investigated the positive relationship between non-renewable energy consumption and environmental degradation, on the contrary, the use of green energy resources or green energy has thus decreased CO₂ emission to a certain extend (Majeed and Luni 2019; Ozturk et al. 2016; Z. Wang et al. 2018; Zhang et al. 2018). Along with these findings Charfeddine (2017), Baloch et al. (2019a, b), (Ozcan et al. 2020), Majeed et al. (2021), and Charfeddine and Mrabet (2017) have explored non-renewable that an increase in non-renewable energy resource exploitation increases the extent of ecological footprint. On the contrary, Sarkodie et al. (2020), Alola et al. (2019), Baloch et al. (2019a, b), Dogan and Seker (2016), Dogan and Ozturk (2017), Zaidi et al. (2018), Khan et al. (2020), Vural-Yavaş (2021), Swain and Karimu (2020), Chu and Le (2021), Amin and Dogan (2021), Z. Wang et al. (2020a, b), Adams and Acheampong (2019), and Chu and Le (2021) found the solution for this problem and empirically investigated that the use of green energy helps to not only control and alleviates CO₂ emission but also reduce ecological footprint.

Green energy and environmental sustainability Table 4 shows green energy consumption is a major determinant of ecological footprint in Australia and the USA both in the short run and long run. The result also determines the long-run and short-run negative relationship between green energy consumption and ecological footprint in both countries. On the other hand, in the UK and Canada, green energy consumption is not a major determinant of an ecological footprint both in the short-run and long-run and draws no significant influence on ecological footprint. On the contrary, green energy is a negative determinant of ecological footprint in Germany in the short run but not a significant variable in the long run. Energy-incentive inputs can increase growth, sustainability, and quality (Majeed and Taqir, 2020; Zhao et al. 2013). However, non-renewable energy resources deteriorate environmental sustainability (Baloch, 2018; Baloch and Suad, 2018; Baz et al. 2020; Majeed and Luni 2019; Munir and Riaz 2020; Pao and Tsai, 2010, 2011). Similarly, S. Wang et al. (2011), Saboori and Sulaiman (2013), Shahbaz et al. (2012), OzTurk and Acaravci (2013), Ahmad et al. (2016), (Bekhet et al. 2017; Esso and Keho, 2016), Ozturk et al. (2016), Solarin et al. (2017), Mrabet and Alsamarra (2017), Atasoy (2017), B. Zhang et al. (2017a, b), Alvarado et al. (2018), S. Chen et al. (2019), Sohail et al. (2021), and Majeed and Taqir (2020) also investigated the positive relationship between non-renewable energy consumption and environmental degradation, on the contrary, the use of green energy resources or green energy has thus decreased CO₂ emission to a certain extend (Majeed and Luni 2019; Ozturk et al. 2016; Z. Wang et al. 2018; Zhang et al. 2018). Along with these findings Charfeddine (2017), Baloch et al. (2019a, b), (Ozcan et al. 2020), Majeed et al. (2021), and Charfeddine and Mrabet (2017) have explored non-renewable that an increase in non-renewable energy resource exploitation increases the extent of ecological footprint. On the contrary, Sarkodie et al. (2020), Alola et al. (2019), Baloch et al. (2019a, b), Dogan and Seker (2016), Dogan and Ozturk (2017), Zaidi et al. (2018), Khan et al. (2020), Vural-Yavaş (2021), Swain and Karimu (2020), Chu and Le (2021), Amin and Dogan (2021), Z. Wang et al. (2020a, b), Adams and Acheampong (2019), and Chu and Le (2021) found the solution for this problem and empirically investigated that the use of green energy helps to not only control and alleviates CO₂ emission but also reduce ecological footprint.

Economic policy uncertainty and environmental sustainability In the long run, in the case of Germany, the UK, and the USA, economic policy uncertainty is a negative but significant factor or determinant of ecological footprint, while in the short run, it is significant in Germany and USA only. These results also align with those of Chu and Le (2021) and Adedoyin and Zakari (2020),
who empirically investigated the negative relationship between economic policy uncertainty and environmental degradation. This negative relationship is if EPU draws an effect on volume and pattern of consumption that will surely reduce CO$_2$ emission and ultimately environmental degradation and ecological footprint. To compensate for the low revenue induced by EPU, manufacturers utilize low-cost energy sources in their production methods. As a result, when revenue grows, they use environmentally friendly production methods in such industries, resulting in lower CO$_2$ emissions (Amin and Dogan 2021). Similarly, Syed and Bouri (2021) exhibit that EPU increases CO$_2$ emissions in the short run, implying that high EPU is responsible for short-term environmental damage. However, EPU reduces CO$_2$ emissions in the long run, interpreting that a high EPU improves environmental sustainability. Given the evidence of a trade-off between EPU and CO$_2$ emissions, authorities should take immediate steps to minimize EPU to improve environmental sustainability. In the long run, if policymakers want to limit EPU and CO$_2$ emissions simultaneously, they should look for alternative strategies to offset CO$_2$ emissions (for example, green energy consumption). On the contrary, Amin and Dogan (2021), Pirgaip and Dinçergök (2020), Adams et al. (2020), Q. Wang et al. (2020a, b), Ulucak and Khan (2020), Yu et al. (2021), Anser et al. (2021b), Zakari et al. (2021), and Adedoyin et al. (2021) empirically investigated that economic policy uncertainty adversely influences the environmental sustainability and enhance environmental degradation by escalating CO$_2$ emission. The current study further shows that there is a negative relationship between economic policy uncertainty and ecological footprint both in Germany and the USA. While in the case of Australia and Canada, economic policy uncertainty is not the major determinant of ecological footprint both in the short run and long run. Jiang et al. (2019) also empirically concluded that in commercial sector EPU is not the major determinant of CO$_2$ emission.

**Diagnostic tests**

Finally, different diagnostic tests are applied to confirm whether the coefficients of the selected nonlinear ARDL model are reliable, stable, and predictable or not. The results of the Breusch-Godfrey LM test (Breusch, 1978; Godfrey, 1978) confirmed that the specified nonlinear ARDL model is free from serial correlation problems, as the probability value of $X^2$ statistical is insignificant at the significance level of 5%. The results of Ramsey’s RESET test (Ramsey, 1969) verified the normal distribution of the residual terms, as the probability value of $X^2$ statistical is insignificant at the significance level of 5%. Similarly, the ARCH test suggests that the selected data for all five OECD selected countries are homoscedastic and no evidence of heteroscedaticity is found at 5% level of significance. Findings of diagnostic tests are given in Table 6.

### Table 6: Findings of diagnostic tests

| Test                      | Australia | Canada | Germany | UK    | USA    |
|---------------------------|-----------|--------|---------|-------|--------|
| Breusch-Pagan-Godfrey LM  | 0.32      | 0.21   | 0.02    | 0.92  | 0.02   |
| Ramsey’s RESET test       | 2.88      | 0.023  | 0.09    | 0.36  | 0.15   |
| ARCH Test                 | 0.15      | 0.35   | 0.55    | 0.75  | 0.92   |

**Cumulative effects of fiscal decentralization, green energy, and economic policy uncertainty on ecological footprint.**

The graphical presentation is given in Fig. 2, Fig. 3, Fig. 4, Fig. 5, and Fig. 6 showing the cumulative effect of fiscal decentralization, green energy, and economic policy uncertainty on the ecological footprint for Australia, Canada, Germany, UK, and the USA, respectively, by determining the positive changes, negative changes, and asymmetry in the data. The green dotted line shows positive changes, the red dotted line shows the negative changes while the blue line shows the extend of asymmetry for the selected variables with respect to the ecological footprint in respective models for each of the countries.

**Conclusion and policy implications**

The main objective of this study is to empirically investigate the asymmetric or nonlinear relationship between fiscal expenditure decentralization and ecological footprint as a proxy of environmental sustainability both in the short-run and long-run in five selected OECD countries, namely, Australia, Canada, Germany, UK, and the USA. This study also explains the empirical symmetric relationship between green energy, economic policy uncertainty, and ecological footprint for these five OECD countries. The results show that fiscal decentralization is asymmetrically correlated with an ecological footprint in the long run only in the case of the USA and Australia, while in the short run, in both of these countries, these variables are symmetrically associated. On the contrary, in the UK, the asymmetric relationship between
fiscal expenditure decentralization and ecological footprint is neither found in the long run nor in the short run. On the other hand, in the case of Canada and Germany, fiscal decentralization is asymmetrically interlinked with an ecological footprint in the short run only, while in the long run, there is a linear relationship between these two variables.

Empirical evidence also shows that in the case of Australia and the USA, green energy is a major determinant of an ecological footprint both in the long run and short run. On the contrary, it is neither a long-run nor a short-run determinant of ecological footprint in Canada and the UK. In Germany, green energy is a major determinant of ecological footprint in the short run only, but not in the long run. Looking into another assumed determinant of ecological footprint and its long-run and short-run significant relationships, economic policy uncertainty is neither a significant variable of ecological footprint in long run nor in the short run in Australia and Canada. On the contrary, it is a major determinant of
an ecological footprint both in the long run and short run in Germany and USA while in the UK, it is a major determinant of ecological footprint in long run but not in the short run.

There are certain policy implications that are arising from this research study. Firstly, the powers should be delegated and distributed to institutions at a lower level to allow them to design environmental policies in favor to promote environmental sustainability. Moreover, central governments should allocate more powers to local governments to further strengthen the fiscal expenditure decentralization and enhance the projects for green energy to control environmental degradation. Along with this, increasing the fiscal expenditures ratio both in current and development spheres to improve environmental sustainability is an effective tool to apply (Hao et al., 2020). Thus, this is also suggested for the selected OECD countries. Similarly, the “Free Riding” behavior of local governments and the industrial sector, fiscal decentralization, should be curtailed by bounding carbon
shares in environmental degradation both in the short run and long run. Setting special autonomous bodies at local and provincial levels to monitor the institutional qualities to guard environmental concerns can play an influential role in this regard. It is also suggested to implement the carbon tax at the very root of provincial and local authority levels, which will play an effective role like a two-way sword, which will not only surge government revenue thus will prompt fiscal revenue decentralization and control environmental degradation, and upgrade climate sustainability. Similarly, delegating more power to the provincial government to manipulate the policies in favor of paradigm shift from extensive economic growth-oriented models to low environmental degradation developmental models, especially low carbon economic growth models to achieve sustainability concerning environmental perspective, will be favorite.

The subsequent policy implication for these countries is to focus on a paradigm shift related to energy portfolio by accumulating the share of green energy in the total sphere of energy consumption. Similarly, proper planning for technological advancements and enhancements in the power sector to enhance carbon capture and storage is the need of the hour to subdue environmental degradation. Therefore it is indispensable to increase green investment to promote environmental sustainability. Another suggestion is to devise different credit or green credit mechanisms or systems to allow varying interest rates for industries depending on their parts into environmental degradation and carbon emission. The more polluting industries may offer credit at higher interest rates and vice versa, which will compel industries to innovate green or renewable energy production at their potential level. Likewise, industries with low carbon emissions should be given an incentive in the form of a low tax rate or tax exemptions. In parallel, importers should be given subsidies to import green energy products. These suggestions exhibit the collaboration of three crucial goals of Sustainable Development Goals (SDGs), which are to enhance economic growth (SDG no 8), with considering the problem of environmental degradation and to uplift the ecological quality (SDGs no 13) in addition to providing masses affordable green energy (SDG no 7). The role of renewable energy in environmental sustainability cannot be denied. Therefore, it is suggested to increase green investment to migrate from traditional methods of energy production to enhance and modernize green energy production techniques. More focus should be given to increase geothermal, nuclear, and wind energy production. The scope and volume of green finances to promote renewable energy production should be enlarged in selected OECD countries.

Another vital recommendation to control economic policy uncertainty is implying very fair and transparent economic policies so that government authorities and officials can analyze the economic policy uncertainty transparently and diagnose economic illness and thus treat it properly and timely. At the global level, economic organizations such as World Trade Organization, United Nations Organizations, International Monetary Funds, and World Bank must campaign to shrink economic policy uncertainty both at the global and country-wise level. Governments should assess all of the different ways that Economic Policy Uncertainty and other emission-causing factors could affect environmental sustainability. They should concentrate on controlling...
Economic Policy Uncertainty while also stimulating the deployment of renewable energy, energy-efficient technology, and knowledge production and transfer.

Apart from these findings, there are certain limitations. Firstly, future studies may focus on finding the threshold level of fiscal decentralization to optimize economic growth with sustainable environmental goals, which is the very soul of SDGs. Secondly, World Uncertainty Index can be a relatively better proxy for monetary policy uncertainty which can be used in future studies for better policy suggestions. Thirdly, this research study assumes the impact of green energy on ecological footprint; however, energy segregation paves the way for future researchers to dissect the energy consumption role in enhancing ecological footprint with particular reference to fiscal decentralization and economic policy uncertainty. Fourthly, this research study assumes fiscal expenditure decentralization as a proxy to fiscal decentralization. However, future studies can develop an index to aggregate the impact of both dimensions of fiscal decentralization, namely, fiscal revenue decentralization and fiscal expenditure decentralization.

Author contribution Samia Zahra: Conceptualization, methodology, formal analysis, investigation, writing—review and editing. Ramez Abubakr Badeeb: methodology, reviews, and supervision.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate I am free to contact any of the people involved in the research to seek further clarification and information.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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