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RESEARCH ARTICLE

Pathways to securing environmentally sustainable economic growth through efficient use of energy: a bootstrapped ARDL analysis

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Abstract

Oman has traditionally relied upon natural gas and oil for meeting its domestic energy demand. As a result, despite growing economically, the level of carbon dioxide emissions in Oman has persistently surged; consequently, the nation has failed to ensure environmentally sustainable economic growth. Against this background, this current study aims to explore the impacts of energy consumption, energy efficiency, and financial development on Oman's prospects of attaining environmentally sustainable growth over the 1972–2019 period. The estimation strategy is designed to take into account the structural break issues in the data. Using the carbon productivity level as an indicator of environmentally sustainable economic growth, we find long-run associations amid the study variables. Besides, higher energy consumption and greater financial development are found to impede carbon productivity while improving energy efficiency is observed to boost carbon productivity in Oman. Therefore, it is pertinent for Oman to consume low-carbon and energy-efficient fossil fuels, improve energy efficiency levels, and green its financial sector to achieve environmentally sustainable growth.

Keywords Energy consumption · Energy efficiency · Financial development · Environmentally sustainable growth · Carbon productivity

Introduction

Greater globalization has led to a surge in economic activities whereby the level of energy consumption has grown manifolds. As a result, energy has played a critically important role in driving the growth of global economies. Although achieving economic growth is the core objective of all nations, it has strings attached to it in the form of environmental degradation. Hence, the world economies must emphasize on achieving growth in an environmentally sustainable way (Murshed 2020, 2021; Li et al. 2021). Although in the past, the complementarity between economic growth and environmental pollution was not opposed, the ratification of the Paris Agreement has necessitated the adoption and implementation of decoupling strategies worldwide (Wang and Zhang 2020; Wang et al. 2022). However, the decoupling task is relatively more cumbersome across nations that are predominantly fossil fuel-dependent and have limited scopes of undergoing renewable energy transition. In such circumstances, considering the limitations, it is important for these countries to come up with other relevant and interim solutions that can enable them to achieve environmentally sustainable growth.

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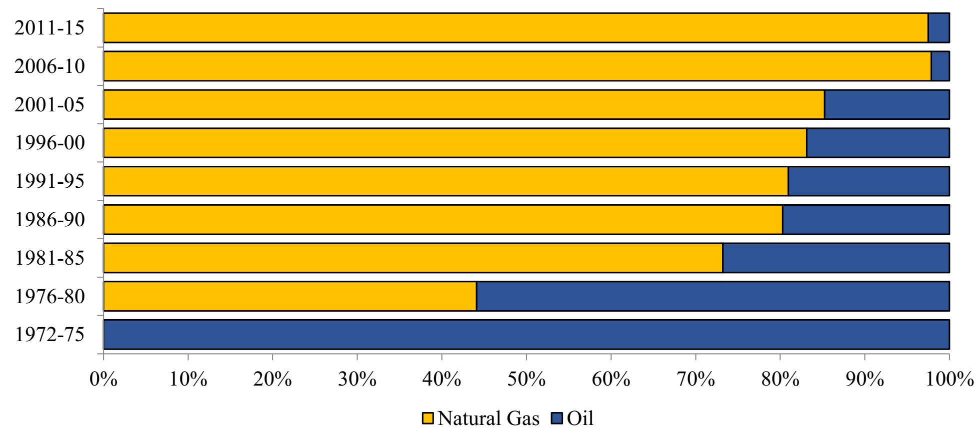

Fig. 1 Fossil fuel dependency in Oman. Notes: The figures are average shares (within the corresponding period) of natural gas and oil in the total electricity output of Oman. Source: World Development Indicators (World Bank 2022)

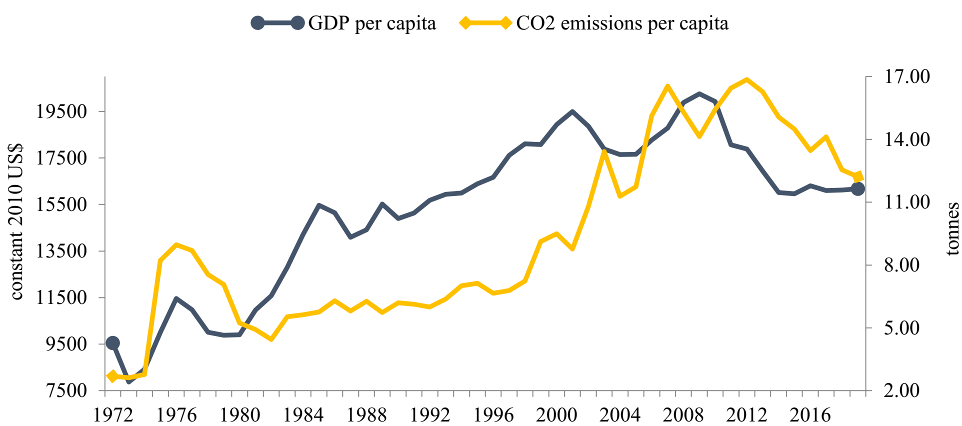

Fig. 2 The per capita GDP and CO2 emission trends in Oman. Notes: The annual per capita GDP figures are shown along the primary axis (i.e., left axis) while the per capita CO2 emission figures are shown along the secondary axis (i.e., right axis). Source: World Development Indicators (World Bank 2022) and Andrew and Peters (2021)

Similar issues are faced by the Gulf Co-operation Council (GCC) member nations that are fossil fuel-dependent to a large extent. These countries account for around one-third and one-fifth of the global crude oil and gas reserves, respectively (British Petroleum 2022). Among the GCC nation, Oman is believed to be the most climate change-vulnerable one courtesy of its insufficient water resources; whereby climate change-induced droughts are likely to jeopardize the entire economy (World Health Organization 2015; Charabi et al. 2020; Hamid et al. 2021). On the other hand, Oman meets its entire energy demand using fossil fuels. As depicted in Fig. 1, it can be observed that although initially being totally dependent on oil, the oil dependency within the Omani electricity sector has drastically declined over time while the reliance on natural gas has steadily surged. Figure 1 also illustrates the chronic fossil fuel dependency of the nation that can be held responsible for the economic growth-environmental pollution trade-offs in Oman.

Figure 2 presents a picture of this scenario. It can be seen that the annual per capita levels of Oman's real Gross Domestic Product (GDP) and carbon dioxide (CO2) emissions have projected identical trends. Thus, it can be assumed that Oman's economic growth strategies have conventionally impeded the nation's potential of safeguarding environmental welfare in Oman. Hence, from the perspective of achieving environmentally sustainable growth, it is important to increase the output level per unit of CO2 emitted. However, if we look into the trends in the annual level of Oman's output per unit of CO2-emitted figures over the 1972–2019 period (as shown in Fig. 3), we can observe that from 1982 onwards, this ratio has gradually declined which further certifies that the economic activities in Oman have traditionally been environmentally-unfriendly.

Among the relevant factors, achieving environmentally sustainable economic growth is said to be conditional on energy use (Zaman and Kalirajan 2019). This is because combusting energy resources simultaneously drives economic growth (Bhattacharya et al. 2016; Ozcan and Ozturk 2019) and influences the environmental quality as well (Bilgili et al. 2016a, b; Salahuddin et al. 2018). For instance, fossil fuel consumption-led economic growth is likely to result in high emissions of CO2 (Kanat et al. 2022) while achieving economic growth by employing renewable energy can be assumed to curb these emissions (Murshed et al. 2021a; Fell et al. 2022). Consequently, diversifying the energy mix by reducing and increasing non-renewable and renewable energy shares, respectively,

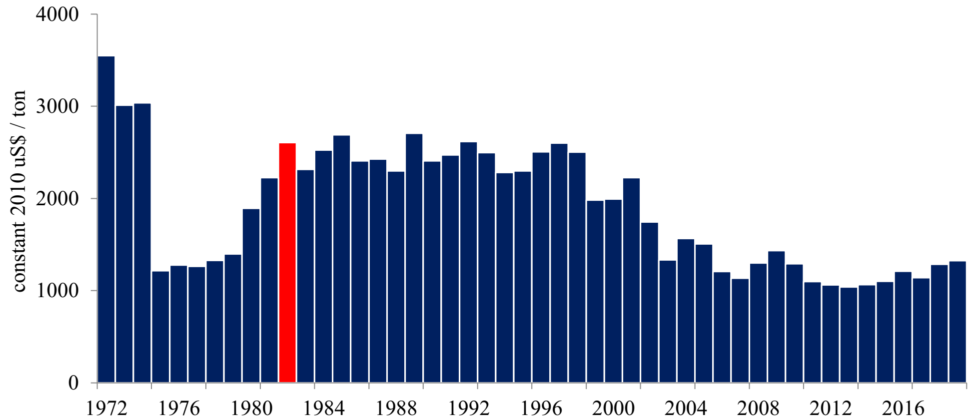

Fig. 3 The trends in the GDP-CO2 emissions ratio in Oman. Notes: The figures are the annual per capita real GDP-CO2 emissions ratio. Source: World Development Indicators (World Bank 2022) and Andrew and Peters (2021)

can be hypothesized to facilitate environmentally sustainable growth (Shakib et al. 2022; Mahmood et al. 2022). However, this cannot be a universal and immediate solution, especially across countries with limited or no scope for undergoing a renewable energy transition.[1] Therefore, for these particular nations, environmentally sustainable economic growth can either be achieved by using relatively less unclean fossil fuels (Murshed et al. 2021b; Rej et al. 2021) or by improving the efficiency of energy use (Alsaedi et al. 2022; Hassan et al. 2022).

Furthermore, concerning the switch from traditionally utilized unclean fossil fuel sources to relatively less unclean alternatives, financial development is said to play a crucial role in driving this energy transition. For instance, a developed financial sector can be expected to enhance credit access to the private sector whereby it can be assumed to make the relatively clean and expensive energy sources affordable. On the other hand, it can also stimulate investment in research and development for technological advancement regarding the production of modern cleaner fossil fuels at cheaper rates. Under such circumstances, financial development can be associated with environmentally-friendly growth. However, on the flip side, financial development can also inhibit low-carbon economic growth attainment. This is because, with greater access to private sector credit, the demand for energy may go up whereby higher energy consumption can be anticipated to surge higher emissions of CO2 (Abbasi et al. 2022). Accordingly, financial development has been recognized in past studies to inflict equivocal environmental consequences (Khan and Ozturk 2021; Shahbaz et al. 2013; Farhani and Ozturk 2015).

[1] Renewable energy transition emphasizes on the simultaneous decline in non-renewable energy use and increases in renewable energy use. For a more in-depth understanding of this process, see Murshed (2022), Fraser et al. (2022), and Murshed et al. (2022).

Against this background, this study assesses the effects of energy use, energy efficiency, and financial development on environmentally sustainable economic growth in Oman over the 1972–2019 period. This study is important from the perspective that Oman has finite possibilities of undergoing renewable energy transition whereby the nation has to make changes in its patterns of energy consumption to achieve higher economic growth in exchange for lower CO2 emissions. Besides, this study is also important from the perspective that Oman and the other GCC nations are currently working to collaborate for energy efficiency improvement and conservation. In this regard, Oman had initiated a Master Plan for Energy Efficiency and Conservation (EE&C) in collaboration with Japan International Cooperation Agency (JICA) in the year 2013. Presently, Oman is making the Energy Master Plan 2040 intending to meet around 30% of its demand for electricity from renewable energy resources by 2030. Besides, for energy conservation, Oman's Supreme Council for Planning has established a board in 2016 to develop an inclusive green design code to cater to the needs of the planned unified GCC Building Code. It was permitted by the Council of Financial Affairs and Energy Resources in September 2017. However, unless the nation is infrastructurally sound in facilitating renewable energy transition, energy efficiency improvement can be expected to be effective in curbing CO2 emissions generated from the production processes. As a result, assessing the impacts of energy efficiency gains on environmentally sustainable economic growth is of paramount importance from Oman's point of view.

This current study differs from the preceding ones in the following manner. First, the macroeconomic determinants of economic growth in Oman have received limited mentions in the literature. On top of that, none of the previous studies has emphasized the relevance of unearthing factors that can enable Oman to achieve environmentally sustainable (low-carbon) economic growth. Therefore, this study models the effects of energy use, energy efficiency, and financial development on environmentally sustainable economic growth in

Oman. This study considers the nation's carbon productivity level, which shows the amount of national output generated per unit of CO2 emitted, as a proxy for green growth. It is assumed that higher (lower) carbon productivity indicates low-carbon (high-carbon) economic growth. Second, this is the seminal study that not only evaluates the impacts of energy use on Oman's prospects of achieving low-carbon growth but also assesses the corresponding impacts associated with energy efficiency improvement. It is extremely relevant and important to probe into the energy efficiency-economic growth nexus in the context of Oman because the nation has always been totally dependent on non-renewable energy and is yet to utilize renewable energy to meet its energy requirement (World Bank 2022). Therefore, unless the nation is sufficiently empowered to undergo the renewable energy transition, it can be hypothesized that by utilizing less energy to produce its national output Oman can manage to curb its energy-use-related emissions.

Literature review

Initially, the theoretical framework of the study is briefly analyzed followed by the summary of empirical literature that has shed light on the issues related to the objectives of this current study.

Theoretical underpinnings

The nexus between energy consumption and economic growth can be understood from four perspectives. Firstly, the growth hypothesis classifies economic growth as a function of energy consumption (Magazzino 2017). As per this notion, economies follow energy use-led growth strategies whereby energy resources are combusted to produce the national output. Secondly, the conservative hypothesis emphasizes that economic growth influences energy consumption levels and therefore advocates in favor of conserving energy resources for future use (Murshed and Alam 2021). This hypothesis tends to glorify the importance of energy efficiency improvement to save energy for future consumption. Thirdly, the feedback hypothesis states that economic growth and energy consumption are interdependent whereby reverse causation between these variables can be evidenced (Menegaki 2011). Lastly, the neutrality hypothesis nullifies any sort of relationship between energy consumption and economic growth (Antonakakis et al. 2017).

Although these four hypotheses explain the relationships between economic growth and energy use, they do not comment on the influence of energy on the quality of growth. Therefore, it is necessary to isolate the effects of different energy resources on the degree of environmental damage caused during the utilization of the energy resources in the production processes. Since fossil fuels are composed of hydrocarbons, combusting these for output generation purposes is likely to stimulate higher CO2 emissions and result in environmental quality-inhibiting growth (Ibrahiem and Hanafy 2020). On the contrary, since renewable energy resources are hydrocarbon-free, employing these can be assumed to impede CO2 emissions to facilitate environmental quality-improving growth (Sinha et al. 2019). Hence, considering these contrasting impacts, it can be hypothesized that since Oman is entirely dependent on natural gas and oil, energy consumption is likely to reduce the nation's carbon productivity level.

Even though higher consumption of unclean energy is unfavorable for attaining low-carbon growth, the adverse impacts can possibly be reduced by enhancing the rate of efficiency at which energy is utilized (Wang and Wang 2020a). Following an improvement in the energy efficiency level, it can be assumed that the quantity of unclean energy utilized to produce a certain amount of output would go down; consequently, the associated CO2 emissions can be assumed to decline as well. As a result, energy efficiency improvement can contribute to improving the carbon productivity level and enable Oman to attain environmentally sustainable economic growth. However, improving energy efficiency can also induce an energy rebound syndrome whereby instead of declining, the energy consumption level and the associated CO2 emissions can go up. Under such a circumstance, energy efficiency improvement may not guarantee the achievement of environmentally sustainable growth.

Now turning to the financial development-clean economic growth nexus, it is believed that financial development imposes dual environmental impacts whereby its effect on environmentally sustainable growth can display ambiguity. The level of financial development is commonly proxied by the share of private sector credit in the national value-added (Ozturk and Acaravci 2013; Al-Mulali et al. 2015). The higher (lower) the share the more developed (underdeveloped) the financial sector (Salahuddin et al. 2015; Shahbaz et al. 2020). Hence, as the financial sector develops, it can increase private sector investments whereby the energy demand can go up; consequently, CO2 emissions can go up to eventually reduce carbon productivity. In contrast, if private sector borrowing is assumed to be invested in energy improvement technology development projects, then financial sector development can be anticipated to facilitate environmentally sustainable economic growth by improving the carbon productivity level.

Empirical evidence

The majority of the preceding studies have examined the effects of energy use on both economic growth (Ozturk et al. 2010; Bhattacharya et al. 2016; Wang and Wang 2020b) and CO2 emissions (Ahmed et al. 2020a, b). However, these studies have overlooked the impacts of energy use on environmentally sustainable economic growth. Similarly, focusing on the separate effects of financial development on economic growth (Ibrahim and Alagidede 2018) and CO2 emissions (Kihombo et al. 2021; Chishti et al. 2021), an additional literature gap can be identified whereby the impacts of financial development on environmentally sustainable economic growth has largely been ignored. Therefore, this section summarizes the previous studies that have shed insights on the economic and environmental impacts associated with energy use and financial development. Hence, linking the findings documented in these studies would provide an understanding of whether energy use and the development of the financial sector can contribute to higher environmentally sustainable economic growth in Oman.

The literature on the nexus between energy use and economic growth

Though the study by Kraft and Kraft (1978) is believed to be the seminal contribution to the energy use-economic growth narrative, Al-Iriani (2006) conducted and published the first study that checked the association between consumption of energy and growth of the economy in the context of the GCC countries. A total of six GCC states were analyzed using a data set spanning from 1971 to 2002. The results supported the conservative hypothesis since the causality analysis unearthed a one-way causal association running from economic growth towards consumption of energy. In another study on the GCC countries between 1975 and 2012, Osman et al. (2016) found evidence of the feedback causal association between electricity consumption and economic growth; thus, the feedback hypothesis was verified in this study. Besides, using time series analysis, Mezghani and Haddad (2017) opined that electricity consumption shocks and volatility affects economic growth in Saudi Arabia. On the other hand, economic growth volatility was also evidenced to increase the energy consumption level. Hamdi et al. (2014), using the Cobb–Douglas production function, found that electricity consumption is a key contributor to economic growth in Bahrain.

Similarly, Wasti and Zaidi (2020) also found energy consumption to be effective in positively influencing the growth of the economy of Kuwait. In another relevant study on oil-exporting nations including Kuwait, Saudi Arabia, and Iran, Mehrara (2007) claimed that the conservative hypothesis was valid for Iran and Kuwait while for Saudi Arabia, the growth hypothesis was validated. A plethora of other existing studies has also shed light on the energy consumption-economic growth nexus for the GCC nations (AlKhars et al. 2020). Therefore, it is evident that the energy use-economic growth nexus in the context of Oman has not attracted much attention in the literature. Other than the GCC countries, Usman et al. (2021) remarked that higher energy consumption is associated with higher economic growth in Bangladesh, India, and Pakistan in the short run and for India and Pakistan in the long run. Ha and Ngoc (2021) validated the feedback hypothesis concerning the petroleum consumption-economic growth relationship in the context of Vietnam. Likewise, the importance of energy consumption in securing higher economic growth in Pakistan was affirmed by Yasmeen et al. (2021). In contrast, using data from emerging countries across Asia, Sharma et al. (2021) reported that energy consumption eventually dampens economic growth in the long run.

Apart from energy consumption, a few studies have explored the effects of energy efficiency on economic growth. Using data from 5 African countries, Adom et al. (2021) opined that improving the level of energy use efficiency, under the seventh Sustainable Development Goal, is pertinent in boosting economic growth across Africa. Akram et al. (2021) found that energy efficiency improvement is a crucial factor for stimulating economic growth in the BRICS[2] nations. Besides, the authors also found evidence of bidirectional causal relationships between energy efficiency and economic growth. Similarly, Bataille and Melton (2017) conducted a computational general equilibrium analysis and found evidence of energy efficiency gains resulting in higher economic growth in Canada between the 2002–2012 period. On the other hand, Rajbhandari and Zhang (2018) remarked that lowering energy intensity levels (similar to improvement in energy efficiency) was evidenced to generate economic growth-enhancing impacts across selected high- and middle-income countries. Although empirical studies related to the energy efficiency-economic growth nexus have not been conducted for the GCC countries, Krarti et al. (2019), in recognition of the importance of energy efficiency improvement within buildings, stated that installation of retrofits in existing buildings can enhance energy use efficiency which, in turn, can be expected to contribute to the development of the economic sectors in the associated countries.

The literature on the nexus between energy use and CO2 emissions

Abdul-Wahab et al. (2015) pointed out that energy consumption, especially natural gas, is the leading cause of CO2 and other greenhouse gas emissions. However, empirical evaluation of the energy consumption-CO2 emission nexus has not attracted attention among researchers. However, several studies have assessed the impacts of energy use on CO2

[2] BRICS abbreviates for Brazil, Russia, India, China, and South Africa.

emissions in the context of the panel of GCC nations. Baydoun and Aga (2021), controlling for cross-sectional dependency and slope heterogeneity, concluded that higher energy consumption results in greater emissions of CO2 both in the short and long run. Besides, evidence of one-way causality running from energy use to CO2 emissions was also highlighted in the study. Similarly, the positive correlation between energy consumption and CO2 emissions for the GCC countries was portrayed in the study by Salahuddin and Gow (2014). However, the authors also found evidence of bidirectional causal associations between these variables. In another study on Qatar, Salahuddin and Gow (2019) showed that marginal positive shocks to the energy use level boost CO2 emissions in the short run but not in the long run. In the context of Saudi Arabia, Mahmood et al. (2019) stated that a rise in the per capita level of energy consumption is responsible for higher CO2 emissions both in the short and long run. Regarding the electricity use-CO2 emissions nexus, Charfeddine and Khediri (2016) found that electricity consumption results in higher CO2 emissions in the short and long run in the United Arab Emirates.

Among the related studies on non-GCC nations, Dong et al. (2017) concluded that natural gas and renewable energy consumption help to curb CO2 emissions in the BRICS nations. On the other hand, Wang et al. (2016) asserted that energy consumption causally influences CO2 emissions in China. In another study on 17 OECD nations, Bilgili et al. (2016a, b) found evidence of renewable energy being favorable for the environment since higher renewable energy consumption was evidenced to curb CO2 emissions. Using data from India, China, Indonesia, and Brazil, Alam et al. (2016) documented evidence of higher energy consumption boosting CO2 emissions both in the short and long run. Besides, the results revealed that compared with India, China, and Indonesia, the CO2 emission-stimulation impact associated with energy consumption is relatively higher in Brazil. Shao et al. (2021) recently opined that renewable energy and green technological innovation help to curb the CO2 emission figure of the Next Eleven countries.

Regarding the impacts of energy efficiency on CO2 emissions, the GCC countries have remained overlooked in the empirical literature. However, considering the case of Qatar, it has been estimated that improving the rate of energy efficiency in buildings can save more than 4700 GWh of electricity and more than 2 million tons of CO2 in the next 10 years (Kamal et al. 2019). For the non-GCC nations, Lin and Xu (2018) used provincial data of 30 Chinese provinces and found evidence of energy efficiency gains inhibit agriculture sector-based CO2 emissions. In a recent study on 25 European nations, Neagu (2019) found that higher energy intensity level (synonymous with lower energy efficiency) accounts for higher CO2 emissions in 14 of these countries while only in the case of Greece higher energy intensity was found to curb CO2 emissions. Danish et al. (2020) also found that higher energy intensity stimulates higher CO2 emissions in the United States of America.

The literature on the nexus between financial development, economic growth, and CO2 emissions

Financial development is more often than not considered as a driver of economic growth whereby a wide pool of the existing studies has explored the nexus between these macroeconomic variables. However, no significant contribution can be found in this regard for the cases of the GCC nations. Among the studies featuring economies that are not members of the GCC, Ibrahim and Alagidede (2018) stated that financial development supports the economic growth of the Sub-Saharan African nations provided the private sector credits are not invested in risky projects. On the other hand, Asteriou and Spanos (2019) asserted that developing the financial sector complements the economic growth policies in Europe provided there is no economic crisis; however, in the presence of economic crisis, financial development was found to dampen economic growth. Although most studies have supported the view of financial development being associated with higher economic growth, Cheng et al. (2021) used data from 72 global countries and found financial development to inflict economic growth-inhibiting effects.

On the other hand, regarding the financial development-CO2 emissions nexus concerning the GCC countries, Gazdar et al. (2019) found that financial development not only boosts CO2 emissions but also reinforces the adverse environmental impacts associated with the growth of the GCC nations. In another study featuring Oman, Saudi Arabia, Qatar, and Bahrain, Bekhet et al. (2017) also showed that developing the financial sector accompanies the risk of surging the CO2 emission levels of these GCC countries. Similarly, for selected East and South Asian countries, Batool et al. (2022) concluded that financial development degrades environmental quality by surging the CO2 emissions figures in the long run but not in the short run. Considering data of 18 African nations, Mesagan and Olunkwa (2022) also explored the relationship between financial development and CO2 emissions. The results confirmed that the development of the financial sector boosts CO2 emissions in the short run but abates emissions in the long run.

Research design

Model and data

Using the theoretical underpinnings discussed in the previous section, we model carbon productivity (proxy for environmentally sustainable growth) as a linear function of

Table 1 Descriptive statistics and data sources

Descriptive stat	lnCP	lnEC	lnEE	FD
Min	6.947	4.718	0.913	4.704
Max	8.174	8.820	4.444	76.494
Mean	7.489	7.667	1.943	32.078
St. dev	0.361	1.097	0.882	18.014
Skewness	−0.027	−1.085	1.014	0.997
Kurtosis	1.514	2.158	2.603	2.515
Jarque–Bera (probability)	2.620 (0.300)	3.150 (0.211)	4.140 (0.120)	2.145 (0.390)
Data source	Authors' own	World Bank (2022)	Authors' own	World Bank (2022)

energy consumption and financial development. This underlying model can be expressed as:

$$\text{Model1}: \ln CP_t = \varphi_0 + \varphi_1 \ln EC_t + \varphi_2 FD_t + \omega_t \quad (1)$$

where t refers to the period, φ_0 is the intercept parameter, φ_1 and φ_2 are the elasticity parameters, and ω_t is the error-term. The dependent variable lnCP refers to the natural logarithm of the annual carbon productivity level which is measured as the ratio between national output and CO2 emissions (measured in terms of constant 2015 US$ per ton of CO2). This variable can be considered as an indicator of the quality of economic growth in relation to its corresponding effect on the environment. A rise in the carbon productivity level implies a rise in the value of output generated per unit of CO2 emitted; consequently, higher carbon productivity is synonymous with the attainment of environmentally sustainable growth.

Among the independent variables, lnEC stands for the natural logarithm of the annual per capita energy consumption level (measured in terms of kilograms of oil equivalent). Since Oman is dependent on natural gas and oil, it can be assumed that a positive shock to the per capita energy consumption level would facilitate economic growth but also release high volumes of CO2 into the atmosphere; as a result, higher energy consumption is likely to lower the level of carbon productivity in Oman. Under such circumstances, the sign of φ_1 can be expected to be negative. The variable FD abbreviates for financial development which is proxied using the share of private sector credit in the total value added (measured in terms of percentage of GDP). Since Oman is fossil fuel-dependent, it can be assumed that borrowed funds are utilized from consumption and production processes whereby the energy demand would go up; consequently, the economic output and energy-related CO2 emissions would simultaneously go up. As a result, the carbon productivity level can be anticipated to decline whereby the sign of φ_2 is likely to be negative.

Since Oman is yet to utilize renewable energy to meet its energy demand, it can be assumed that the nation should focus on reducing its energy consumption level in order to abate the associated emissions. However, reducing energy use is not rational since it dampens the economic output level. Therefore, enhancing the energy efficiency level could be a more rational option whereby neither the economic output level has to be reduced nor the higher CO2 emission problems have to be accepted. Hence, we replace energy consumption in Model 1 with the energy efficiency level which can be shown as:

$$\text{Model2}: \ln CP_t = \varphi_0 + \varphi_3 \ln EE_t + \varphi_2 FD_t + \omega_t \quad (2)$$

where the variable lnEE stands for the natural logarithm of the energy efficiency level which is given by the ratio of the value of national output that is generated per unit of energy consumed (measured in terms of constant 2015 US$ per kilogram of oil equivalent). For a given output level, a rise in the energy efficiency level would implicate lower use of energy and therefore the carbon productivity level can be assumed to go up. As a result, the sign of φ_3 is likely to be positive.

Annual data spanning from 1972 to 2019[3] is utilized in this study. Table 1 reports the descriptive statistics and the data sources of the variables. The platykurtic property of all variables is ensured from the kurtosis values of the respective variable. We also observe parity in terms of the

Table 2 Correlation matrix

Correlation	lnCP	lnEC	lnEE	FD
lnCP	1.000			
lnEC	−0.514	1.000		
lnEE	0.556	−0.999	1.000	
FD	−0.566	0.357	−0.656	1.000

[3] The missing data points are filled using the linear interpolation technique.

Table 3 Variance inflation factor analysis outcomes

Model	Variable	VIF	Mean VIF	1/VIF
1	**lnEC**	2.34	2.45	0.427
1	**FD**	2.56		0.391
2	**lnEE**	2.47	2.49	0.405
2	**FD**	2.50		0.400

A mean VIF score of less than 5 indicates no multicollinearity concerning the respective model

The outcomes show that the variables lnCP, lnEC, and lnEE are stationary at the first difference since the predicted *t* statistics are statistically significant at the 1% level of significance. However, the variable FD is found to be stationary at the level which is affirmed by the statistical significance of the predicted test statistic at the 5% level of significance. Therefore, the findings unearth a mixed order of integration among the variables. Once the unit root properties have been identified, we proceed to the cointegration analysis.

Considering the structural break concerns, the Gregory-Hansen (GH) cointegration analysis (Gregory and Hansen 1996) is conducted. This method predicts three test statistics (ADF, Zt, and Za) or each model considering the null hypothesis of non-cointegration among the variables. The results from the GH cointegration analysis, as presented in Table 5, confirm cointegration among the variables of concern for both models. The statistical significance of the predicted test statistics, at the 1% level of significance, affirms this claim. In light of these findings, we can claim that there are long-run relationships between carbon productivity, energy consumption, energy efficiency, and financial

Table 4 Results from ZA (Zivot and Andrews 2002) unit root analysis

Variable	Trend	Intercept	Both	Variable	Trend	Intercept	Both	Decision
lnCP	−4.471 (1980)	−3.868 (1980)	−3.878 (1980)	ΔlnCP	−7.060[a] (1983)	−7.930[a] (1983)	−8.533[a] (1983)	I(1)
lnEC	−3.827 (1990)	−3.531 (1991)	−3.492 (1990)	ΔlnEC	−8.798[a] (1981)	−9.051[a] (1982)	−9.010[a] (1979)	I(1)
lnEE	3.967 (1990)	−3.579 (1990)	−4.530 (1989)	ΔlnEE	−9.0.594[a] (1981)	−9.340[a] (1981)	−9.958[a] (1981)	I(1)
FD	−3.341 (2012)	−4.693[b] (2011)	−4.970[b] (2011)	ΔFD	−5.741[a] (2009)	−5.684[a] (2009)	−6.014[a] (2009)	I(0)

The *t* statistics are reported; the locations of the structural breaks are presented within the parentheses; the optimal lag selection method is Akaike Information Criterion (AIC); Δ denotes first difference; I(0) and I(1) refer to stationarity at the level and first difference, respectively; a and b refer to statistical significance at 1% and 5% level, respectively

skewness of the variables; lnCP and lnEC are negatively skewed while lnEE and FD are positively skewed. Moreover, the statistical insignificance of the Jarque–Bera statistics affirms the normality of the distributions of the respective variable. Besides, the correlations amid the variables are presented in Table 2. Furthermore, for checking possible multicollinearity issues, the variance inflation factor (VIF) analysis is conducted. The VIF outcomes, as shown in Table 3, confirm that there is no multicollinearity problem in both models since the individual VIF values are below 5 while the mean VIF value is below 10.

Econometric methods

One of the major data concerns in the time-series analysis is the problem of a structural break in the data. This is because if structural breaks are not controlled for within the analysis, then the outcomes generated are likely to be biased (Khan et al. 2022). Therefore, we employ econometric techniques which are efficient in identifying and handling structural break issues. Firstly, the Zivot-Andrews (ZA) unit root analysis with a structural break (Zivot and Andrews 2002) is employed. This technique identifies the location of a structural break for each series by predicting a *t* statistic under the null hypothesis of non-stationarity. This technique allows the structural break to be in the intercept, trend, or both. The results from the ZA test are presented in Table 4.

Table 5 Results from GH (Gregory and Hansen 1996) cointegration analysis

Model	Test statistic	Value	Break date
Model 1 {lnCP = f(lnEC, FD)}	**ADF**	−10.20[a]	1983
	Z_t	−9.51[a]	1980
	Z_a	−87.29[a]	1980
Model 2 {lnCP = f(lnEE, FD)}	**ADF**	−10.20[a]	1983
	Z_t	−9.51[a]	1980
	Z_a	−87.29[a]	1980

The test statistics are predicted considering breaks in the regime and trend; The optimal lag selection method is AIC; a refers to statistical significance at 1% level; The critical values at 1% level for the ADF, Zt, and Za statistics are −5.80, −5.80, and −64.77, respectively development levels in Oman. Besides, the locations of structural break dates are also identified. Corresponding to the ADF test statistic, the structural break for Models 1 and 2 is estimated at the year 1983. Hence, we control for this structural break issue by including structural break year dummies for the year 1983 within the empirical models. The unit root and cointegration analyses are followed by the regression analysis.

We employ the recently developed Bootstrapped Autoregressive Distributed Lag (BARDL) model approach for cointegration and regression. This method was developed by McNown et al. (2018) to account for the limitations of the conventional Autoregressive Distributed Lag (ARDL) technique of Pesaran et al. (2001). The BARDL method is a bootstrapped version of the ARDL method. In the bounds test for cointegration under the traditional ARDL approach, a *F* statistic and a *t* statistic are predicted to test cointegration among the variables (Pesaran et al. 2001). The *F* statistic is predicted from an Error-Correction Model (ECM) using lagged levels of both dependent and independent variables while the *t* statistic is estimated from an ECM using lagged level of the dependent variable. In addition, the BARDL approach introduces an additional *F* statistic (abbreviated as *F* independent) which is derived from an ECM using lagged levels of the independent variables. All these three test statistics are predicted under the null hypothesis of non-cointegration. Hence, there is evidence of cointegration among the variables if the predicted values of all three test statistics (under the BARDL method) are larger than the bootstrapped critical values.

In the next step, the short- and long-run elasticity estimates are predicted which would give an indication of the marginal impacts of positive shocks to the independent variables (energy consumption, energy efficiency, and financial development) on the dependent variable (carbon productivity). In relation to our first model (i.e., Model 1), the ECM for the BARDL analysis can be represented as follows:

$$lnCP_t = \delta_0 + \sum_{f=1}^{M} \alpha_{1f} \Delta lnCP_{t-i} + \sum_{f=1}^{N} \alpha_{2f} \Delta lnEC_{t-i} + \sum_{f=1}^{O} \alpha_{3f} \Delta FD_{t-i} + \sum_{f=1}^{P} \alpha_{4f} \Delta DBY_{t-i} + \beta_1 lnCP_{t-1} + \beta_2 lnEC_{t-1} + \beta_3 FD_{t-1} + \beta_4 DBY_{t-1} + \varepsilon_t \quad (3)$$

where *M*, *N*, *O*, and *P* are the optimal lags for the respective variable; these optimal lags can differ and are derived using the AIC. Δ symbolizes the difference operator. The variable DBY is the structural break year dummy variable that is predicted from the ADF test statistic under the GH cointegration test. From Eq. (3), the short-run model can be extracted as follows:

Table 6 Results from the BARDL cointegration analysis

Model	Test statistic	Value	Bootstrapped critical values		
			1%	5%	10%
Model 1	***F* statistic**	3.95[b]	4.20	3.10	2.60
	***t* dependent**	−3.20[a]	−3.15	−2.50	−2.13
	***F* independent**	5.35[a]	4.90	3.50	3.00
Model 2	***F* statistic**	5.12[a]	5.10	3.25	2.60
	***t* dependent**	−3.45[a]	−3.38	−2.40	−2.20
	***F* independent**	6.12[a]	5.67	3.70	2.95

The test statistics are predicted using 10,000 bootstrapped replications; optimal lag selection is based on AIC; a and b denote statistical significance at 1% and 5% significance level, respectively

$$lnCP_t = \delta_0 + \sum_{f=1}^{M} \alpha_{1f} \Delta lnCP_{t-i} + \sum_{f=1}^{N} \alpha_{2f} \Delta lnEC_{t-i} + \sum_{f=1}^{O} \alpha_{3f} \Delta FD_{t-i} + \sum_{f=1}^{P} \alpha_{4f} \Delta DBY_{t-i} + \alpha_5 ECT_{t-1} + \theta_t \quad (4)$$

where ECT refers to the one-period lagged error-correction term which shows the speed of convergence from disequilibrium to equilibrium. From Eq. (3), the long-run model can be extracted as:

$$\mathrm{lnCP_t} = \delta_0 + \beta_1 \mathrm{lnCP_{t-1}} + \beta_2 \mathrm{lnEC_{t-1}} + \beta_3 \mathrm{FD_{t-1}} + \beta_4 \mathrm{DBY_{t-1}} + \rho_t \quad (5)$$

For robustness check of the estimates, we also utilize the Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS) regression techniques, proposed by Phillips and Hansen (1990) and Stock and Watson (1993), respectively, to estimate the empirical models.

Results and discussion

This section reports and discusses the findings from the BARDL analysis. Firstly, the BARDL cointegration outcomes are reported inTable 6.[4] Since all three test statistics (*F* statistic, *t* dependent statistic, and *F* independent statistic) are found to be statistically significant, at the 1% and 5% significance levels, we can claim that there is cointegration among the variables in both models. Hence, the BARDL cointegration test results provide support to the findings from the GH cointegration analysis presented in Table 5.

Table 7 reports the elasticity outcomes derived from the BARDL analysis for both the short and long run. In the context of Model 1, it can be observed that higher consumption

[4] In both models 1 and 2, we have included the structural break year dummy variable for the year 1983 as identified from the BH cointegration analysis.

Table 7 The short- and long-run elasticity estimates from the BARDL analysis

Dependent variable: lnCP				
	Model 1		Model 2	
Regressors	Short run	Long run	Short run	Long run
lnEC	−0.259[b] (0.119)	−0.888[a] (0.207)	-	-
lnEE	-	-	0.151[b] (0.076)	0.350[b] (0.155)
FD	−0.274 (0.235)	−0.266[a] (0.072)	−0.230 (0.249)	−0.340[a] (0.100)
DBY	−0.150[a] (0.032)	0.478[b] (0.236)	−0.222[b] (0.110)	0.513[b] (0.250)
Constant	1.501[c] (0.784)	-	1.984[a] (0.340)	-
ECT_{t-1}	−0.204[b] (0.088)	-	−0.315[a] (0.101)	-
R^2-adj	0.785	-	0.690	-
Diagnostics	**Value**	**Probability**	**Value**	**Probability**
Serial correlation	0.103	0.790	0.140	0.765
Functional form	0.165	0.800	0.170	0.772
Normality	0.075	0.994	0.105	0.650
Heteroscedasticity	0.065	0.850	0.050	0.885
CUSUM	Stable		Stable	
CUSUMSQ	Stable		Stable	

The robust standard errors are reported within the parentheses; a, b, and c denote statistical significance at 1%, 5%, and 10% significance levels, respectively

of energy is associated with lower carbon productivity both in the short and long run. These imply that energy consumption is a barrier towards the attainment of environmentally sustainable growth in Oman. Besides, the carbon productivity-inhibiting impacts associated with energy use seem to surge with time since the relative magnitude of the estimated long-run energy use elasticity of carbon productivity is smaller than the corresponding short-run elasticity estimate. A rise in the per capita energy consumption level in Oman is seen to trigger declines in the energy carbon productivity level by 0.25% and 0.89% in the short and long run, respectively. This finding supports the hypothesis that since Oman is highly dependent on natural gas and oil, the energy use-associated CO2 emissions are to expectedly rise as more energy is utilized to generate the national output. Besides, during the period of analysis (1972–2019), the average annual growth rate in per capita CO2 emissions in Oman has been more than five times the corresponding average rate of growth in the per capita GDP level of the nation (World Bank 2022). As a result, the finding of the negative correlation between energy consumption and carbon productivity is justified. Similar to the findings in this study, Wasti and Zaidi (2020) found energy consumption to promote economic growth in Kuwait while Abdul-Wahab et al. (2015) remarked that natural gas consumption triggers higher emissions of CO2 into the atmosphere. Likewise, it can be assumed that energy consumption inflicts similar impacts on the economy and environment of Oman.

On the other hand, the results related to Model 1 also reveal that financial development also exerts carbon productivity-dampening impacts only in the long run. Hence, it can be asserted that financial development does not facilitate environmentally sustainable economic growth in Oman. A 1% rise in the financial development level (i.e., a 1% rise in the share of private sector credit in the GDP) is seen to reduce the carbon productivity level by 0.27% in the long run. This finding indicates that private sector investments, in particular, in Oman have mostly been undertaken within the dirty industries whereby the nation's carbon productivity level is pinned down. Gazdar et al. (2019) also pointed out the CO2 emission-stimulating effects associated with financial development with the GCC countries. Besides, the authors also claimed that financial development reinforces the adverse environmental impacts related to economic growth in the GCC nations. Therefore, it can be said that financial development policies in Oman and other GCC countries have not monitored the mechanism in which the private sector credits are utilized; consequently, the financial development policies were not aligned with the objective of facilitating environmentally sustainable growth in these countries. On the contrary, if this alignment could be ensured, the development of the financial sector can be anticipated to boost carbon productivity and help Oman and the other GCC nations achieve low-carbon growth.

The findings in the context of Model 2 reveal that although higher energy consumption inhibits the carbon productivity level in Oman, improving the efficiency at which energy resources are utilized can effectively enhance the nation's level of carbon productivity. Hence, this finding supports the hypothesis of energy efficiency improvement being necessary for facilitating environmentally sustainable economic growth in Oman. A rise in the

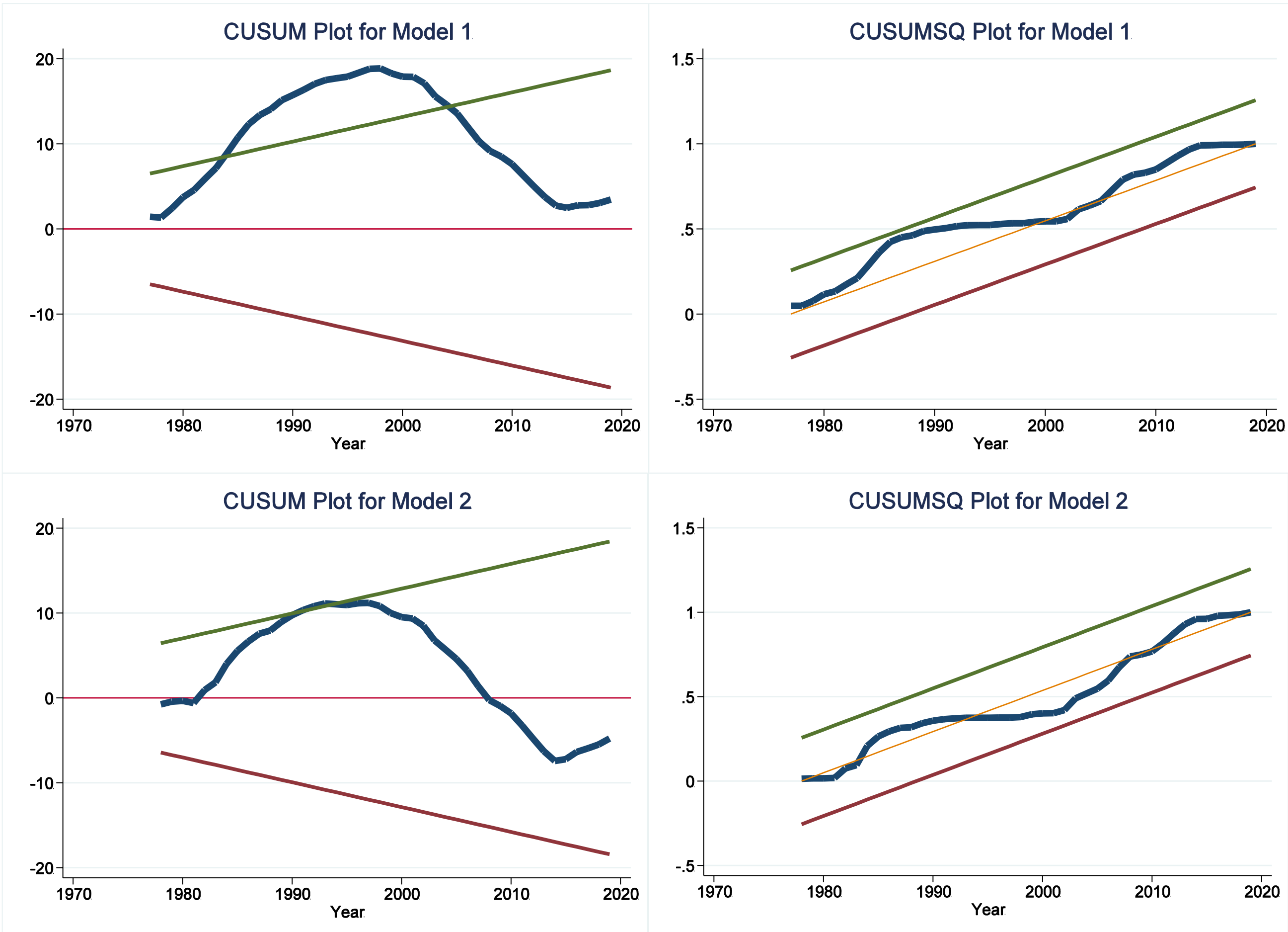

Fig. 4 The CUSUM and CUSUMSQ plots for models 1 and 2

level of energy efficiency by 1% is observed to increase the short-run carbon productivity level by 0.15% and the long-run carbon productivity level by 0.35%. Since using energy more efficiently has the potential of limiting the discharge of energy-related CO2 emissions without compromising the national output level, the finding of the positive correlation between energy efficiency and carbon productivity can be justified. This is an important finding from the perspective of Oman, a country that has never managed to reduce its monotonic dependency on fossil fuels. Besides, since the nation is also yet to undergo a renewable energy transition, enhancing energy efficiency can indirectly curb the fossil fuel dependency of Oman and complement the nation's objective of attaining environmentally sustainable economic growth. The potential role of energy efficiency improvement in curbing CO2 emissions was also highlighted in the study by Kamal et al. (2019) in which the authors asserted that improving energy efficiency in buildings can help Qatar significant volumes of electricity consumption and CO2 emissions.

On the other hand, similar to the case of Model 1, the findings from Model 2 once again confirm the negative nexus between financial development and carbon productivity in Oman. Furthermore, the parameter estimates related to the structural break dummy variables are evidenced to be statistically significant; consequently, the decision to control for the structural break issues in the data is justified.

Table 7 also presents the outcomes from several diagnostic tests that are conducted to assess the credibility of the short- and long-run estimates. The results show that there are no serial correlation, model misspecification, non-normality, and heteroscedasticity concerns in both models. Besides, the stability of parameter estimates, for both models, is affirmed from the plots of the cumulative sum of squares (CUSUM) and its squared (CUSUMSQ) shown in Fig. 4.

Table 8 reports the outcomes from the robustness analysis conducted using the FMOSL and DOLS estimators. The result shows that, despite differing in terms of the magnitude, the estimated elasticities using the FMOLS and DOLS techniques are identical to the corresponding

Table 8 The robustness analysis outcomes

Dependent variable: lnCP				
Estimator	Model 1		Model 2	
	FMOLS	DOLS	FMOLS	DOLS
Regressors				
lnEC	−0.650[a] (0.204)	−0.579[a] (0.189)	-	-
lnEE	-	-	0.290[a] (0.079)	0.350[a] (0.130)
FD	−0.365 (0.275)	−0.334[b] (0.169)	−0.219 (0.246)	−0.326[b] (0.150)
DBY	0.502[a] (0.183)	0.719[a] (0.201)	0.616[a] (0.176)	0.741[a] (0.202)
Constant	1.958 [b] (0.995)	1.444[b] (0.710)	1.716[a] (0.450)	1.675[a] (0.501)
R^2-adj	0.646	0.466	0.421	0.525

The robust standard errors are reported within the parentheses; a, b, and c denote statistical significance at 1%, 5%, and 10% significance levels, respectively

BARDL long-run outcomes in respect of the predicted signs. Therefore, the long-run regression findings can be considered robust across alternative estimation techniques.

Conclusion and policy suggestions

Achieving environmentally sustainable growth has become a concern for Oman since this nation is yet to reduce its traditional dependence on fossil fuels, especially natural gas and oil. Besides, since this nation has not undergone a renewable energy transition, it is imperative for Oman to look for efficient mechanisms through which the energy resources can be utilized to mitigate CO2 emissions without compromising the growth of the national output. Against this backdrop, this study aimed to evaluate the impacts of energy use, energy efficiency, and financial development on the potential of Oman to achieve environmentally sustainable economic growth. In this regard, this particular study innovatively proxies environmentally sustainable economic growth by Oman's annual carbon productivity level. The period of analysis spanned from 1972 to 2019 and involved the application of econometric methods that are robust to handling structural break issues in the data. The cointegration analysis confirmed long-run associations among the variables of concern. Besides, the regression analysis showed that higher energy consumption and greater financial development impeded environmentally sustainable economic growth by reducing the carbon productivity level in Oman. In contrast, energy efficiency improvement was evidenced to facilitate the environmentally sustainable economic growth objective of the nation by reducing the carbon productivity level in the short and long run.

In light of these findings, we recommend several policies for the government of Oman. Firstly, to address the carbon productivity-inhibiting impacts associated with energy use, it is pertinent for Oman to look for low-carbon fossil fuels as alternatives to the conventionally utilized natural gas and oil. Switching to these low-carbon energy resources can be assumed to limit the level of CO2 emissions without dampening the growth of the Omani economy. Besides, as part of a long-term energy policy reform, it is also important for Oman to gradually develop its renewable energy sector and eventually switch from non-renewables to renewables. In this regard, investment in research and development for improving renewable energy generation technologies is a must for Oman. At the moment, the nation does have a plan of meeting around one-third of the domestic energy demand using renewable energy by 2030. Hence, to achieve this target, it is necessary for Oman to develop its capacity to generate power using renewables; consequently, investments for renewable energy innovation can be assumed to help Oman undergo renewable energy transition and curb its carbon productivity level.

Secondly, and more importantly, Oman should emphasize on significantly enhancing its energy efficiency level since it is evident that the nation cannot instantly reduce its fossil fuel dependency nor can it undergo renewable energy transition within the next couple of years. Under such circumstances, there is no other alternative for Oman rather than utilizing the existing fossil fuels more efficiently so that less energy is consumed to generate the national output. In this regard, Oman should make use of relatively more energy-efficient fossil fuels so that the carbon-productivity-inhibiting impacts associated with energy use can be mitigated. On the other hand, Oman can also consider investing in technological development relevant to improving the level of energy efficiency. Lastly, Oman should also develop its financial sector sustainably so that greater access to credit for investment in environmentally-friendly projects can be ensured. Besides, from the consumption side channel, the financial sector of Oman should incentivize the loan borrowers to spend the funds on the consumption of energy-efficient appliances. As a result, greening the financial sector can be considered effective in reducing carbon productivity-inhibiting impacts of financial development in Oman.

The findings of this study are limited in the sense that it is appropriate for Oman but may not be totally relevant for other GCC and non-GCC countries. Thus, from the point of view of external validity, the findings from this study should be compared with similar studies on other fossil fuel-dependent countries. As part of the future research direction, this study can also be conducted using alternate indicators of economic growth and using different GCC countries.

Author contribution Md Shabbir Alam conceptualized and wrote the final manuscript. Mohammad Noor Alam analyzed the data and helped in drafting the original manuscript. Muntasir Murshed wrote the original manuscript, assisted in the literature review, methodology, analysis, and discussions. Haider Mahmood helped in discussions and analysis. Risana Alam conducted the analysis and edited the final manuscript.

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

Declarations

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References

Abbasi KR, Hussain K, Haddad AM, Salman A, Ozturk I (2022) The role of financial development and technological innovation towards sustainable development in Pakistan: fresh insights from consumption and territory-based emissions. Technol Forecast Social Change 176:121444

Abdul-Wahab SA, Charabi Y, Al-Maamari R, Al-Rawas GA, Gastli A, Chan K (2015) CO2 greenhouse emissions in Oman over the last forty-two years. Renew Sustain Energy Rev 52:1702–1712

Adom PK, Agradi M, Vezzulli A (2021) Energy efficiency-economic growth nexus: What is the role of income inequality? J Clean Prod 310:127382

Ahmed Z, Ali S, Saud S, Shahzad SJH (2020a) Transport CO2 emissions, drivers, and mitigation: an empirical investigation in India. Air Qual Atmos Health 13(11):1367–1374

Ahmed Z, Asghar MM, Malik MN, Nawaz K (2020) Moving towards a sustainable environment: the dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. Resour Polic 67:101677

Akram R, Chen F, Khalid F, Huang G, Irfan M (2021) Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: a fixed effect panel quantile regression analysis. Energy 215:119019

Alam MM, Murad MW, Noman AHM, Ozturk I (2016) Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia. Ecol Ind 70:466–479

Al-Iriani MA (2006) Energy–GDP relationship revisited: an example from GCC countries using panel causality. Ener Pol 34(17):3342–3350

AlKhars M, Miah F, Qudrat-Ullah H, Kayal A (2020) A systematic review of the relationship between energy consumption and economic growth in GCC countries. Sustainability 12(9):3845

Al-Mulali U, Ozturk I, Lean HH (2015) The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat Hazards 79(1):621–644

Alsaedi MA, Abnisa F, Alaba PA, Farouk HU (2022) Investigating the relevance of Environmental Kuznets curve hypothesis in Saudi Arabia: towards energy efficiency and minimal carbon dioxide emission. Clean Technol Environ Polic. https://doi.org/10.1007/s10098-021-02244-3

Andrew and Peters (2021) The Global Carbon Project's fossil CO2 emissions dataset. Available at https://figshare.com/articles/preprint/The_Global_Carbon_Project_s_fossil_CO2_emissions_dataset/16729084/1. Accessed 2 Feb 2022

Antonakakis N, Chatziantoniou I, Filis G (2017) Energy consumption, CO2 emissions, and economic growth: an ethical dilemma. Renew Sustain Energy Rev 68:808–824

Asteriou D, Spanos K (2019) The relationship between financial development and economic growth during the recent crisis: evidence from the EU. Financ Res Lett 28:238–245

Bataille C, Melton N (2017) Energy efficiency and economic growth: a retrospective CGE analysis for Canada from 2002 to 2012. Energy Econ 64:118–130

Batool Z, Raza SMF, Ali S, Abidin SZU (2022) ICT, renewable energy, financial development, and CO2 emissions in developing countries of East and South Asia. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-18664-7

Baydoun H, Aga M (2021) The effect of energy consumption and economic growth on environmental sustainability in the GCC countries: does financial development matter? Energies 14(18):5897

Bekhet HA, Matar A, Yasmin T (2017) CO2 emissions, energy consumption, economic growth, and financial development in GCC countries: dynamic simultaneous equation models. Renew Sustain Energy Rev 70:117–132

Bhattacharya M, Paramati SR, Ozturk I, Bhattacharya S (2016) The effect of renewable energy consumption on economic growth: evidence from top 38 countries. Appl Energy 162:733–741

Bilgili F, Koçak E, Bulut Ü (2016a) The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach. Renew Sustain Energy Rev 54:838–845

Bilgili F, Öztürk İ, Koçak E, Bulut Ü, Pamuk Y, Muğaloğlu E, Bağlıtaş HH (2016b) The influence of biomass energy consumption on CO2 emissions: a wavelet coherence approach. Environ Sci Pollut Res 23(19):19043–19061

British Petroleum. (2022). BP Statistical Review of World Energy. Available at https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/xlsx/energy-economics/statistical-review/bp-stats-review-2021-all-data.xlsx. Accessed 2 Feb 2022

Charabi Y, Al Nasiri N, Al Awadhi T, Choudri BS, Al Bimani A (2020) GHG emissions from the transport sector in Oman: trends and potential decarbonization pathways. Energy Strat Rev 32:100548

Charfeddine L, Khediri KB (2016) Financial development and environmental quality in UAE: cointegration with structural breaks. Renew Sustain Energy Rev 55:1322–1335

Cheng CY, Chien MS, Lee CC (2021) ICT diffusion, financial development, and economic growth: an international cross-country analysis. Econ Model 94:662–671

Chishti MZ, Ahmed Z, Murshed M, Namkambe HH, Ulucak R (2021) The asymmetric associations between foreign direct investment inflows, terrorism, CO2 emissions, and economic growth: a tale of two shocks. Environ Sci Pollut Res 28(48):69253–69271

Danish, Ulucak R, Khan SUD (2020) Relationship between energy intensity and CO2 emissions: does economic policy matter? Sustain Dev 28(5):1457–1464

Dong K, Sun R, Hochman G (2017) Do natural gas and renewable energy consumption lead to less CO2 emission? Empirical evidence from a panel of BRICS countries. Energy 141:1466–1478

Farhani S, Ozturk I (2015) Causal relationship between CO2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ Sci Pollut Res 22(20):15663–15676

Fell H, Gilbert A, Jenkins JD, Mildenberger M (2022) Nuclear power and renewable energy are both associated with national decarbonization. Nat Energy 7(1):25–29

Fraser T, Bancroft M, Small A, Cunningham L (2022) Leaders or networkers? the role of mayors in renewable energy transition. Environ Innov Soc Trans 42:301–316

Gazdar K, Hassan MK, Safa MF, Grassa R (2019) Oil price volatility, Islamic financial development and economic growth in Gulf Cooperation Council (GCC) countries. Borsa Istanbul Rev 19(3):197–206

Gregory AW, Hansen BE (1996) Practitioners corner: tests for cointegration in models with regime and trend shifts. Oxford Bull Econ Stat 58(3):555–560

Ha NM, Ngoc BH (2021) Revisiting the relationship between energy consumption and economic growth nexus in Vietnam: new evidence by asymmetric ARDL cointegration. Appl Econ Lett 28(12):978–984

Hamdi H, Sbia R, Shahbaz M (2014) The nexus between electricity consumption and economic growth in Bahrain. Econ Model 38:227–237

Hamid I, Alam MS, Murshed M, Jena PK, Sha N, Alam MN (2021) The roles of foreign direct investments, economic growth, and capital investments in decarbonizing the economy of Oman. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-17246-3

Hassan T, Song H, Khan Y, Kirikkaleli D (2022) Energy efficiency a source of low carbon energy sources? Evidence from 16 high-income OECD economies. Energy 243:123063

Ibrahiem DM, Hanafy SA (2020) Dynamic linkages amongst ecological footprints, fossil fuel energy consumption and globalization: an empirical analysis. Manag Environ Qual 31(6):1549–1568

Ibrahim M, Alagidede P (2018) Effect of financial development on economic growth in sub-Saharan Africa. J Polic Model 40(6):1104–1125

Kamal A, Al-Ghamdi SG, Koç M (2019) Role of energy efficiency policies on energy consumption and CO2 emissions for building stock in Qatar. J Clean Prod 235:1409–1424

Kanat O, Yan Z, Asghar MM, Ahmed Z, Mahmood H, Kirikkaleli D, Murshed M (2022) Do natural gas, oil, and coal consumption ameliorate environmental quality? Empirical evidence from Russia. Environ Sci Pollut Res 29(3):4540–4556

Khan M, Ozturk I (2021) Examining the direct and indirect effects of financial development on CO2 emissions for 88 developing countries. J Environ Manag 293:112812

Khan I, Lei H, Shah AA, Khan I, Baz K, Koondhar MA, Hatab AA (2022) Environmental quality and the asymmetrical nonlinear consequences of energy consumption, trade openness and economic development: prospects for environmental management and carbon neutrality. Environ Sci Pollut Res 29:14654–14664. https://doi.org/10.1007/s11356-021-16612-5

Kihombo S, Saud S, Ahmed Z, Chen S (2021) The effects of research and development and financial development on CO2 emissions: evidence from selected WAME economies. Environ Sci Pollut Res 28(37):51149–51159

Kraft J, Kraft A (1978) On the relationship between energy and GNP. J Energy Dev 3:401–403

Krarti M, Dubey K, Howarth N (2019) Energy productivity analysis framework for buildings: a case study of GCC region. Energy 167:1251–1265

Li R, Wang Q, Liu Y, Jiang R (2021) Per-capita carbon emissions in 147 countries: The effect of economic, energy, social, and trade structural changes. Sustain Prod Consump 27:1149–1164. https://doi.org/10.1016/j.spc.2021.02.031

Lin B, Xu B (2018) Factors affecting CO2 emissions in China's agriculture sector: a quantile regression. Renew Sustain Energy Rev 94:15–27

Magazzino C (2017) The relationship among economic growth, CO2 emissions, and energy use in the APEC countries: a panel VAR approach. Environ Syst Decis 37(3):353–366

Mahmood H, Alkhateeb TTY, Al-Qahtani MMZ, Allam Z, Ahmad N, Furqan M (2019) Agriculture development and CO2 emissions nexus in Saudi Arabia. PloS one 14(12):e0225865

Mahmood H, Adow AH, Abbas M, Iqbal A, Murshed M, Furqan M (2022) The fiscal and monetary policies and environment in GCC countries: analysis of territory and consumption-based CO2 emissions. Sustainability 14(3):1225

McNown R, Sam CY, Goh SK (2018) Bootstrapping the autoregressive distributed lag test for cointegration. Appl Econ 50(13):1509–1521

Mehrara M (2007) Energy consumption and economic growth: the case of oil exporting countries. Energy Polic 35:2939–2945

Menegaki AN (2011) Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. Energy Econ 33(2):257–263

Mesagan EP, Olunkwa CN (2022) Heterogeneous analysis of energy consumption, financial development, and pollution in Africa: the relevance of regulatory quality. Util Polic 74:101328

Mezghani I, Haddad HB (2017) Energy consumption and economic growth: an empirical study of the electricity consumption in Saudi Arabia. Renew Sustain Energy Rev 75:145–156

Murshed M (2020) An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. Environ Sci Pollut Res 27(29):36254–36281. https://doi.org/10.1007/s11356-020-09497-3

Murshed M (2021) LPG consumption and environmental Kuznets curve hypothesis in South Asia: a time-series ARDL analysis with multiple structural breaks. Environ Sci Pollut Res 28(7):8337–8372. https://doi.org/10.1007/s11356-020-10701-7

Murshed (2022) Pathways to clean cooking fuel transition in low and middle income Sub-Saharan African countries: the relevance of improving energy use efficiency. Sustain Prod Consump 30:396–412. https://doi.org/10.1016/j.spc.2021.12.016

Murshed M, Alam M (2021) Estimating the macroeconomic determinants of total, renewable, and non-renewable energy demands in Bangladesh: the role of technological innovations. Environ Sci Pollut Res 28(23):30176–30196

Murshed M, Ahmed R, Kumpamool C, Bassim M, Elheddad M (2021a) The effects of regional trade integration and renewable energy transition on environmental quality: Evidence from South Asian neighbours. Bus Strateg Environ 30:4154–4170. https://doi.org/10.1002/bse.2862

Murshed M, Alam R, Ansarin A (2021b) The environmental Kuznets curve hypothesis for Bangladesh: the importance of natural gas, liquefied petroleum gas and hydropower consumption. Environ Sci Pollut Res 28(14):17208–17227. https://doi.org/10.1007/s11356-020-11976-6

Murshed M, Nurmakhanova M, Al-Tal R, Mahmood H, Elheddad M, Ahmed R (2022) Can intra-regional trade, renewable energy use, foreign direct investments, and economic growth reduce ecological footprints in South Asia? Energy Sources B Econ Plan Polic. https://doi.org/10.1080/15567249.2022.2038730

Neagu O (2019) The link between economic complexity and carbon emissions in the European Union countries: a model based on the Environmental Kuznets Curve (EKC) approach. Sustainability 11(17):4753

Osman M, Gachino G, Hoque A (2016) Electricity consumption and economic growth in the GCC countries: panel data analysis. Energy Policy 98:318–327

Ozcan B, Ozturk I (2019) Renewable energy consumption-economic growth nexus in emerging countries: a bootstrap panel causality test. Renew Sustain Energy Rev 104:30–37

Ozturk I, Acaravci A (2013) The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Econ 36:262–267

Ozturk I, Aslan A, Kalyoncu H (2010) Energy consumption and economic growth relationship: evidence from panel data for low and middle income countries. Energy Polic 38(8):4422–4442

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Economet 16(3):289–326

Phillips PC, Hansen BE (1990) Statistical inference in instrumental variables regression with I (1) processes. Rev Econ Stud 57(1):99–125

Rajbhandari A, Zhang F (2018) Does energy efficiency promote economic growth? Evidence from a multicountry and multisectoral panel dataset. Energy Econ 69:128–139

Rej S, Bandyopadhyay A, Mahmood H, Murshed M, Mahmud S (2021) The role of liquefied petroleum gas in decarbonizing India: fresh evidence from wavelet – partial wavelet coherence approach. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-17471-w

Salahuddin M, Gow J (2014) Economic growth, energy consumption and CO2 emissions in Gulf Cooperation Council countries. Energy 73:44–58

Salahuddin M, Gow J (2019) Effects of energy consumption and economic growth on environmental quality: evidence from Qatar. Environ Sci Pollut Res 26(18):18124–18142

Salahuddin M, Gow J, Ozturk I (2015) Is the long-run relationship between economic growth, electricity consumption, carbon dioxide emissions and financial development in Gulf Cooperation Council Countries robust? Renew Sustain Energy Rev 51:317–326

Salahuddin M, Alam K, Ozturk I, Sohag K (2018) The effects of electricity consumption, economic growth, financial development and foreign direct investment on CO2 emissions in Kuwait. Renew Sustain Energy Rev 81:2002–2010

Shahbaz M, Solarin SA, Mahmood H, Arouri M (2013) Does financial development reduce CO2 emissions in Malaysian economy? A time series analysis. Econ Model 35:145–152

Shahbaz M, Haouas I, Sohag K, Ozturk I (2020) The financial development-environmental degradation nexus in the United Arab Emirates: the importance of growth, globalization and structural breaks. Environ Sci Pollut Res 27(10):10685–10699

Shakib M, Yumei H, Rauf A, Alam M, Murshed M, Mahmood H (2022) Revisiting the energy-economy-environment relationships for attaining environmental sustainability: evidence from Belt and Road Initiative countries. Environ Sci Pollut Res 29(3):3808–3825

Shao X, Zhong Y, Liu W, Li RYM (2021) Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries? Evidence from advance panel estimations. J Environ Manag 296:113189

Sharma GD, Rahman MM, Jain M, Chopra R (2021) Nexus between energy consumption, information and communications technology, and economic growth: an enquiry into emerging Asian countries. J Public Affairs 21(2):e2172

Sinha A, Gupta M, Shahbaz M, Sengupta T (2019) Impact of corruption in public sector on environmental quality: implications for sustainability in BRICS and next 11 countries. J Clean Prod 232:1379–1393

Stock JH, Watson MW (1993) A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica 61(4):783–820

Usman A, Ozturk I, Hassan A, Zafar SM, Ullah S (2021) The effect of ICT on energy consumption and economic growth in South Asian economies: an empirical analysis. Telemat Informat 58:101537

Wang Q, Wang S (2020) Preventing carbon emission retaliatory rebound post-COVID-19 requires expanding free trade and improving energy efficiency. Sci Total Environ 746:141158

Wang Q, Wang L (2020) Renewable energy consumption and economic growth in OECD countries: A nonlinear panel data analysis. Energy 207:118200

Wang Q, Zhang F (2020) Does increasing investment in research and development promote economic growth decoupling from carbon emission growth? An empirical analysis of BRICS countries. J Clean Prod 252:119853. https://doi.org/10.1016/j.jclepro.2019.119853

Wang S, Li Q, Fang C, Zhou C (2016) The relationship between economic growth, energy consumption, and CO2 emissions: empirical evidence from China. Sci Total Environ 542:360–371

Wang Q, Wang X, Li R (2022) Does urbanization redefine the environmental Kuznets curve? An empirical analysis of 134 Countries. Sustain Cities Soc 76:103382. https://doi.org/10.1016/j.scs.2021.103382

Wasti SKA, Zaidi SW (2020) An empirical investigation between CO2 emission, energy consumption, trade liberalization and economic growth: a case of Kuwait. J Build Eng 28:101104

World Bank (2022) World Development Indicators. The World Bank. Available at https://databank.worldbank.org/reports.aspx?source=2&series=IP.PAT.RESD&country=#. Accessed 2 Feb 2022

World Health Organization (2015) Climate and Health Country Profile-2015: Oman. The United Nations. Available at https://apps.who.int/iris/handle/10665/208866. Accessed 2 Feb 2022

Yasmeen H, Tan Q, Zameer H, Vo XV, Shahbaz M (2021) Discovering the relationship between natural resources, energy consumption, gross capital formation with economic growth: can lower financial openness change the curse into blessing. Resour Polic 71:102013

Zaman KAU, Kalirajan K (2019) Strengthening of energy security & low-carbon growth in Asia: Role of regional energy cooperation through trade. Energy Polic 133:110873

Zivot E, Andrews DWK (2002) Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. J Bus Econ Stat 20(1):25–44