European Journal of Sustainable Development (2026), **15**, 1, 621-637 ISSN: 2239-5938
Doi: 10.14207/ejsd.2026.v15n1p621

The Cost of Growth: How OPEC Countries Navigate the Trade-Offs of Sustainable Development?

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ABSTRACT:
OPEC member countries face a persistent challenge in balancing economic growth with environmental sustainability and public health. This study investigates the interlinked dynamics among economic growth, environmental protection, and public health using a panel dataset from 1990 to 2024 and employing robust econometric methods, including stationarity tests, fixed effects estimation, and the Hausman test. Key variables analyzed include per capita GDP, capital accumulation, urbanization, education, CO_2 emissions, and adult mortality rates. The results demonstrate that while capital accumulation and urbanization significantly enhance economic growth, they do not inherently alleviate environmental pressures. The empirical rejection of the Environmental Kuznets Curve (EKC) suggests that rising income levels in OPEC countries are associated with continued environmental degradation. Public health, conversely, was found to positively influence economic growth, highlighting its role as both an outcome and a driver of development. Education emerged as a supportive factor, improving health outcomes and correlating positively with economic growth, although its environmental impact was statistically insignificant. Drawing upon these empirical results, the present study delineates focused strategies for policymaking, including increased investment in human capital, reallocation of oil revenues toward healthcare and environmental remediation, and a gradual transition toward cleaner industrial practices. These proposals aim to help OPEC countries address the negative trade-offs between industrial expansion, environmental degradation, and public health challenges on the path to sustainable development.

Keywords: Sustainable Development, Economic Growth, Environmental Protection, Public Health, Kuznets Curve hypothesis, OPEC Member Countries

1. Introduction

Over the past two decades, the accelerating pace of economic growth,particularly in resource-rich and industrializing nations, has contributed significantly to environmental degradation and public health concerns. This environmental deterioration has become a critical global issue, drawing increased attention from both national governments and international organizations (Yu *et al.*, 2022).

The tension between economic expansion and its environmental and health-related externalities has produced divergent perspectives among economists. Some emphasize the productivity and well-being benefits of growth driven by increased energy use (Agrawal *et al.*, 2024). Others argue that unchecked growth exacerbates ecological and public health risks (Pathiranage, 2024).

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Member states of the Organization of the Petroleum Exporting Countries (OPEC), which control a major share of global oil reserves and exports recorded per capita CO_2 emissions well above the global average during 2000–2020 (e.g., territorial emissions averaged ~7.2tCO_2 per capita across OPEC vs ~5.2t globally in 2020) (Crippa *et al.*, 2022). Their emissions increased substantially over this period, driven by expanding fossil fuel production and rising domestic energy consumption. Oil rents also showed a consistently positive effect on emissions in most OPEC economies (Alao *et al.*, 2022). OPEC member countries have a combined population of approximately 414.49 million and cover a total area of 9.73 million square kilometres (Figure 1), accounting for only about 5% and 7% of the world's population and land area, respectively. However, their combined gross domestic product (GDP) stands at 1.89 trillion US dollars. In terms of per capita GDP, this amounts to roughly 9,460 US dollars, about 36% below the global average (OPEC, 2024). OPEC's economic model is heavily reliant on fossil fuel exports and also incentivizes industrial expansion, including petrochemicals and heavy manufacturing, which further increases environmental pressures and exacerbates public health challenges (Saidi & Rahman, 2021; Demiral *et al.*, 2024).

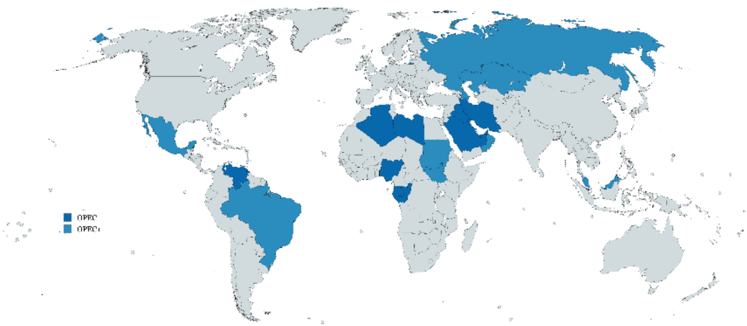

Figure 1: Distribution of OPEC Member States
Source: Caspian Delta, 2022

Moreover, governance quality and environmental regulation capacity vary widely among OPEC nations, influencing how effectively these countries manage the trade-offs between growth, environmental integrity, and population health. The dynamics governing economic growth and its interaction with environmental protection constitute a heavily scrutinized topic within the existing body of economic scholarship. From a doctrinal standpoint, the relationship between economic growth and environmental degradation is often modelled using the Environmental Kuznets Curve (EKC), which suggests an inverted-U pattern: pollution initially increases with income, then declines after a threshold (Naqvi *et al.*, 2025; Lau *et al.*, 2025). This pattern, however, remains empirically contentious, especially in oil-exporting developing countries like those in OPEC, where rent-driven growth complicates the expected trajectory. According to this theory, during the nascent phase of economic expansion, due to various factors such as the high priority given to production and employment over a clean environment, low production technology, low levels of environmental awareness, etc., economic growth will be accompanied by an increase in environmental degradation. However, after reaching a certain level of per capita income, this relationship reverses, and further economic growth leads to improvements in environmental protection. The reasons for this could be the adoption of higher production technologies, increased environmental awareness, the enactment and enforcement of stringent environmental regulations, and so on. Additionally, at higher income levels, the economic structure of countries shifts towards clean industries and technologies, as well as the emergence of the tertiary sector, which possesses the capacity to mitigate environmental degradation once higher income thresholds are attained. In most studies, CO2 emissions have been considered as the source of pollution (Lau *et al.*, 2025).

According to the human capital theory, good health not only increases individual income from a microeconomic perspective but also leads to an increase in national income and enhances labor productivity from a macroeconomic perspective (Bloom *et al.*, 2024). Furthermore, economic growth and development, followed by advancements in technology, particularly in medicine, lead to improvements in public health. The increase in per capita GDP has resulted in a significant reduction in the infant mortality rate at birth in various countries. Given these interpretations, clarifying the causal relationship between economic development and public health is essential. According to the studies conducted, per capita GDP and the infant mortality rate at birth are considered as key variables (Bloom *et al.*, 2018). The nexus of environmental pollution and public health has consistently remained a subject meriting attention and is frequently termed the health production function within the economic literature. This function considers the inputs and outputs of health, with inputs including healthcare, lifestyle, environment, and heredity, and the most important output being the mortality rate, especially among adults and infants. The environment, through the emission of polluting gases such as CO2, SO2, and PM10 particles, affects the mortality rate and impacts public health (Remoundou & Koundouri, 2009).

Many studies have examined the three-way trade-off among environmental protection and economic growth. Still, few have simultaneously addressed the intricate nexus connecting environmental protection and public health, as well as the empirical interplay among economic growth and public health. Studies related to the interlink connecting these three macro variables are divided into three categories: First, studies that focus on the relationship between economic growth and environmental pollution and thoroughly examine the hypotheses of the Environmental Kuznets Curve (Grossman & Krueger, 1995). The results of these studies indicate the confirmation of the Environmental Kuznets Curve hypotheses in various groups of countries and considering different variables (Lau *et al.*, 2025). In the second group of studies, the dynamics governing economic growth and public health was examined by investigating the causal relationship between increased income levels and improved public health in the form of mortality rates. The results support the claim that increasing the income level of society leads to a decrease in mortality rates and an improvement in public health (Bloom *et al.*, 2024). The third section of studies examines the relationship between environmental protection and public health. From a public health standpoint, the health production function, introduced by Grossman, posits that health outcomes are shaped by multiple inputs, environment, healthcare, education, and income (Grossman, 1972). Despite a vast literature on individual relationships, growth-environment, growth-health, and environment-health, there remains a critical gap in studies that integrate these three dimensions in a unified empirical framework, particularly within OPEC economies. The aspiration of OPEC member countries towards industrialization and promoting domestic production, which is based on increasing the emission of polluting gases and poses a threat to public health, has further emphasized the need for policymaking at the national and international levels (Idowu *et al.*, 2023).

Therefore, examining this relationship in the constituent entities of the OPEC alliance is essential to facilitate policymaking and improve the well-being of society. This study, reflecting the core question "The Cost of Growth: How OPEC Countries Navigate the Trade-Offs of Sustainable Development?", fills the existing gap through a rigorous investigation of the intertwined developmental trilemma in the oil-exporting states in the OPEC alliance. To this end, we construct a balanced panel dataset and apply robust econometric techniques to examine how key sustainable development drivers. Ultimately, it proposes context-specific policy applications for the trade-offs of this multifaceted interdependence in these national oil economies regions.

2. Materials and Methods

The amalgamation of longitudinal and cross-sectional observations provides a rich source of information for developing estimation methods and theoretical results. In many cases, researchers can use panel data for cases that cannot be examined solely in time series or cross-sectionally (Baltagi, 2021). The standard form for combined time series and cross-sectional models is as follows:

$$Y_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it} \qquad (1)$$

In equation (1), X_{it} represents a vector of K explanatory variables (excluding the intercept). Depending on the value of α, three cases arise: pooled OLS, fixed effects, and random effects models.

- Case 1: If there is no difference between the cross-sections, then α enters the model as the average of all cross-sections. In this case, the ordinary least squares (OLS) method will provide highly precise and asymptotically unbiased estimations of α and β if ε_{it} is homoscedastic and uncorrelated (Pooled OLS Model). The validity of this model rests on the strong assumption that the unobserved cross-sectional characteristics have zero correlation with the explanatory variables, effectively treating the entire panel as a single, large dataset (Greene, 2019).
- Case 2: If there is a difference between different cross-sections, the difference between cross-sections is shown in α_i, which are assumed to be constant over time. This method is called the fixed effects (FEM). The selected specification accounts for unobserved heterogeneity that does not fluctuate over time for each cross-sectional entity. The selection of the Fixed Effects Model (FEM) is primarily justified by its ability to mitigate potential Omitted Variable Bias (OVB) arising from unobserved heterogeneity (e.g., permanent institutional or geopolitical factors unique to each OPEC country) that is constant over time but correlated with the independent variables. By systematically filtering out this time-invariant heterogeneity, the FEM ensures consistent estimates,

thereby addressing the crucial issue of endogeneity often encountered in macro panel data analysis (Wooldridge, 2010).

- Case 3: If it is assumed that the difference between cross-sections is random and not constant over time, another method called the random effects method (REM) is used to estimate the model. Assumes that α_i are random variables drawn from a common distribution and are uncorrelated with the regressors (Eibinger *et al.*, 2024). By utilizing a Feasible Generalized Least Squares (FGLS) approach, the REM aims to maximize efficiency by incorporating the estimated variance of these random components into the estimation weights, provided the key orthogonality assumption holds (Baltagi, 2021).

To choose between the pooled data model and the fixed effects model, a model with the following assumptions is introduced:

$$\begin{aligned} &H_0: \mu_1 = \mu_2 = \cdots = \mu_{N-1} = 0 \\ &H_1: \text{There exists some } i \text{ such that } \mu_i \neq 0 \end{aligned} \qquad (2)$$

μ is the coefficient of the dummy variable in the fixed effects model. Accepting the null hypothesis H0 means that there is pooled data and the OLS estimate is used to solve the model. Rejecting it means that there is a fixed effects model, and LSDV is used to solve the model (Baltagi, 2021). Assuming the normal distribution of disturbance terms, the relevant test statistic is formally defined as:

$$F_0 = \frac{(RRSS - URSS)/(N-1)}{URSS/(NT - N - K)} \sim F_{N-1, N(T-1)-K} \qquad (3)$$

RRSS: the sum of squared residuals of the constrained model obtained from the ordinary least square’s method.

URSS: the sum of squared residuals of the unconstrained model obtained from the least square’s method with a dummy variable.

T: the number of years studied, N: the number of cross-sections, and K: the number of explanatory variables.

After the F-test validates the fixed effects specification, the choice between the fixed and random effects models is determined using the Hausman test. The key distinction lies in the assumption regarding the correlation between the cross-sectional effects and the regressors. If this correlation is absent, the random effects model is preferable for efficiency, but if the correlation exists, the fixed effects estimator is consistent, while the random effects estimator becomes inconsistent. In this test, the covariance matrix of the difference between the FE and RE coefficient vectors, that is [b-β], is used, where b is the slope in the fixed effects model and β is the slope in the random effects model (Baltagi, 2024). The statistical hypotheses underlying this test are formally articulated below:

- H0 (Null Hypothesis): The difference between the coefficients derived from the Fixed Effects (FE) and Random Effects (RE) estimators is not statistically significant. If the null hypothesis holds, the RE model is the efficient and consistent choice.
- H1 (Alternative Hypothesis): A substantial, systematic difference exists between the FE and RE estimates. If the alternative hypothesis is supported, the FE model is the consistent, preferred model (Hausman, 1978).

The Hausman test evaluates the consistency of an estimator under the null hypothesis that the preferred model (e.g., random effects) is appropriate, as compared to an alternative (e.g., fixed effects). Under the null hypothesis, the test statistic is asymptotically distributed as chi-squared (χ^2) with degrees of freedom equal to the number of regressors being tested, based on the Wald criterion (Hausman, 1978).

$$\boldsymbol{W} = \boldsymbol{\chi^2_{k-1}} = \left[\boldsymbol{b} - \widehat{\boldsymbol{\beta}}\right]^{`} \widehat{\boldsymbol{\Phi}}^{-1}\left[\boldsymbol{b} - \widehat{\boldsymbol{\beta}}\right] \qquad (4)$$

If the value of W is greater than its critical value, then the null hypothesis H0 is rejected. As a result, we accept the model with fixed effects (Baltagi, 2024).

To ensure the econometric validity and robustness of the estimated panel models, a series of post-estimation diagnostic tests is employed. First, the Modified Wald test for groupwise heteroskedasticity is conducted to detect the presence of heteroskedasticity across panels (Greene, 2019).

Given the time dimension of the data, the Wooldridge test for serial correlation is applied to examine autocorrelation in the idiosyncratic errors, which could lead to biased standard errors if ignored. To assess the potential problem of multicollinearity among regressors, Variance Inflation Factors (VIFs) are computed. Moreover, to confirm the stationarity of the panel variables, several panel unit root tests, including Levin–Lin–Chu (LLC), Im–Pesaran–Shin (IPS), and Fisher-type ADF and PP tests, are applied before model estimation (Levin *et al.*, 2002). Where evidence of autocorrelation or heteroskedasticity is detected, robust (clustered) standard errors are used to obtain efficient and unbiased inference. Furthermore, given the likelihood of cross-sectional dependence in macro-panel data, arising from global shocks, commodity price fluctuations, and region-wide institutional similarities, Driscoll–Kraay heteroskedasticity- and autocorrelation-consistent (HAC) standard errors were employed. These standard errors remain robust in the presence of heteroskedasticity, serial correlation, and cross-sectional dependence when T is sufficiently large (Driscoll & Kraay 1995).

Finally, to assess the structural stability of the model over time and across cross-sections, CUSUM and CUSUMSQ tests are applied. These comprehensive diagnostics ensure that the final estimated models are robust, reliable, and econometrically sound for inference (Baltagi, 2024).

To empirically evaluate the theoretical relationships discussed, it is essential to develop a set of econometric models that can capture both the direct and indirect effects among the key variables. These models are designed to reflect the complex interplay between economic growth, environmental degradation, and public health within the context of OPEC member countries. Considering the numerous studies mentioned, explaining the logic of the connection linking economic growth, environmental pollution, and public health is only possible through an investigation into the causality linking the variables affecting each area. By structuring these interactions into a system of equations, the study aims to quantify the underlying causal pathways and assess the mediating role of variables such as education, capital formation, and urbanization. Accordingly, the following empirical model is constructed to test these interdependencies.

Therefore, to achieve the objectives of the study and the theoretical foundations of the subject, which are based on examining the Environmental Kuznets Curve hypothesis (Grossman & Krueger, 1995), and forming the health production function in the form of causal relationships between the effective variables, the general research model is formulated as follows:

$$\boldsymbol{Ln\,Y_{it} = \alpha_0 + \alpha_1 LnI_{it} + \alpha_2 U_{it} + \alpha_3 LnE_{it} + \alpha_4 H_{it} + \alpha_5 EDU_{it} + \varepsilon_{it}} \quad (5)$$

$$Ln\,E_{it} = \beta_0 + \beta_1 LnY_{it} + \beta_2 (Ln\,Y_{it})^2 + \beta_3 R_{it} + \beta_4 SR_{it} + \mu_{it} \quad (6)$$

$$H_{it} = \gamma_0 + \gamma_1 LnY_{it} + \gamma_2 LnE_{it} + \gamma_3 LnS_{it} + \gamma_4 EDU_{it} + \varepsilon_{it} \quad (7)$$

Where:

- $\ln Y_{it}$: per capita gross domestic product
- $\ln I_{it}$: per capita capital accumulation
- U_{it}: urbanization rate
- $\ln E_{it}$: environmental protection index (1/per capita CO2 emissions)
- H_{it}: public health index (1/adult mortality rate)
- EDU_{it}: education index (average years of schooling)
- R_{it}: share of health expenditures from the total budget
- SR_{it}: share of industry value added from total GDP
- $\ln S_{it}$: per capita public health care expenditures
- $\ln D_{it}$: number of physicians per 10,000 people

Except for variables that are in the form of shares, all variables are logarithmic. Also, β_2 captures the turning point of the EKC. Information on the above variables for the member states of the Organization of the Petroleum Exporting Countries (covering 13 OPEC countries, Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, Venezuela, and Gabon, which represent the core group of member states with consistent data availability over the 1990–2024 period.) were obtained from multiple authoritative and internationally recognized sources to ensure consistency, reliability, and comparability across countries and years. These sources include the OPEC Annual Statistical Bulletins (for country-specific oil production, export revenues, and economic indicators), the World Bank's World Development Indicators (WDI) database (for macroeconomic, demographic, and environmental variables such as GDP per capita, gross capital formation, urbanization rates, and CO_2 emissions), and the World Health Organization's Global Health Observatory (GHO) (for health indicators including adult mortality rates and healthcare coverage). Where necessary, additional data were cross-validated using supplementary sources such as the International Energy Agency (IEA) and the Barro-Lee Educational Attainment Dataset to fill potential gaps in time-series continuity or variable definitions. Equations 5 to 7, which represent economic development, environmental protection, and public health, respectively, were estimated in the form of panel models, using country fixed effects to control for unobserved heterogeneity. Due to insufficient information on the variable $\ln D_{it}$ (number of physicians per 10,000 people), This variable was removed from the relevant model. All estimations were performed using STATA 19.0 and RStudio 2025.05 software.

The study employs a balanced panel dataset comprising 445 observations. Based on the Hausman test, the fixed effects model was selected, reflecting significant correlation between country-specific effects and explanatory variables. The analysis further investigates the moderating role of education on the nexus between economic growth, environmental quality, and public health through the inclusion of interaction terms. This methodological framework provides a rigorous and theoretically grounded approach for capturing complex dynamic interactions within a multi-equation panel data setting. Key econometric issues including endogeneity, omitted variable bias, heteroskedasticity, and serial correlation are explicitly addressed to ensure robust and reliable inference. The fixed effects specification controls for unobserved heterogeneity across countries, while the integration of nonlinear and interaction effects enhances the explanatory capacity of the models. Collectively, this empirical strategy strengthens the validity of findings and contributes novel insights into the Environmental Kuznets Curve hypothesis and the intertwined health–environment–growth relationship within oil-exporting developing economies.

3. Results and Discussion

To ensure the validity of the regression analysis and avoid spurious results, preliminary tests for the stationarity of the time series variables were conducted. If the time series variables in a regression model are non-stationary, the coefficient estimation leads to a spurious regression (Baltagi, 2024).

In the first stage, in order to avoid spurious regression and test the stability of the variables, the unit root test is performed on the model variables. The results of the Levin, Lin, and Chu test are shown in Table 1.

According to the results, the values of the Levin, Lin, and Chu test at the data level indicate the non-stationarity of some variables, so that the variables related to environmental protection, education, and per capita health expenditure were not stationary even at the 10% probability level. For this purpose, after taking the difference from the data, the above test was performed again, and the results indicated the stationarity of all variables. These findings confirm the need for first-differencing in subsequent estimations and underscore the importance of addressing unit root concerns in panel data to ensure robust and reliable econometric inference.

However, the first-differencing transformation, while necessary to ensure data stationarity and valid inference, inherently restricts the analysis to short-run dynamics (i.e., the relationship between changes in variables). This deliberate focus is justified by two primary econometric and economic considerations:

First, the high degree of structural heterogeneity among OPEC member states (in terms of governance, institutions, and policy enforcement) suggests the inherent invalidity of assuming a stable, common long-run cointegrating relationship (Frankel, 2010). Second, the constraints imposed by the panel's moderate time dimension (due to limitations in accessing consistent long-term data for these countries) restricted the robust application of advanced panel cointegration models (e.g., Panel ARDL or VECM) that explicitly model long-run dynamics (Greene, 2019). Indeed, preliminary cointegration tests revealed evidence of structural breaks and significant parameter instability, reinforcing the decision to rely on short-run, difference-based estimations to ensure the consistency and policy relevance of our findings.

Table 1: Results of the variable stability test using the Levin, Lin, and Chu test

Variable	Test at level	Probability level	First-order difference	Probability level
$ln\,Y_{it}$	2.1045	0.9780	-16.8139	0.0000

$ln\, I_{it}$	0.1863	0.5739	-10.7765	0.0000
U_{it}	-0.7598	0.2237	-26.9191	0.0000
$ln\, E_{it}$	5.0464	1.0000	-26.4275	0.0000
H_{it}	0.4359	0.6686	-23.5699	0.0000
EDU_{it}	9.0773	1.0000	-54.5610	0.0000
SR_{it}	2.0754	0.9810	-19.4399	0.0000
$ln\, S_{it}$	9.4190	1.0000	-10.1055	0.0000
R_{it}	3.2087	0.9990	-23.6458	0.0000

Source: Research findings

In order to estimate the dynamic pattern of the complex interplay among financial expansion, conservation efforts, and societal health outcomes, it is first necessary to perform two tests. To select the state of equality of the origin of the countries or the difference in the origin of the countries, the F-Limer test was used, the corresponding outcomes are tabulated in Table 2.

Table 2: Results of the F-Limer test

Model	Statistic	Degrees of freedom	Probability level
Economic growth model	18.025	(436 & 12)	0.000
Environmental protection model	32.145	(437 & 12)	0.000
Public health model	24.896	(437 & 12)	0.000

Source: Research findings

The results of the F-Limer test showed that the null hypothesis, based on estimating the model by aggregating the data, is rejected, and the model should be estimated as a panel model. Also, in order to determine whether the panel model estimation is in the form of random effects or fixed effects, the Hausman test was used, A detailed summary of these results appears in Table 3.

Table 3: Hausman test results

Model	Statistic	Degrees of freedom	Probability level
Economic growth model	18.025	5	0.000
Environmental protection model	32.145	4	0.000
Public health model	24.896	4	0.000

Source: Research findings

The null hypothesis of the Hausman test based on the estimation of the random effects model was rejected for all three models, and therefore, the final model was estimated as fixed effects. The rejection of the Hausman test's null hypothesis confirms the critical presence of endogeneity; specifically, it indicates that the unobserved, unit-specific effects are significantly correlated with the regressors. Consequently, utilizing the Fixed Effects Model (FEM) was essential to guarantee that the resulting coefficients are consistent and free from Omitted Variable Bias (OVB) introduced by these time-invariant unobserved factors (Greene, 2019). Before presenting the estimated coefficients, extensive diagnostic validation confirmed that the econometric design is both methodologically sound and theoretically coherent. Specifically, we verified the fixed effects specification through formal testing, effectively controlling for unobserved, time-invariant heterogeneity across countries. Diagnostic procedures, including battery tests for multicollinearity using variance inflation factors (VIFs) and correlation analysis, specification testing, and robust (clustered) standard errors, ensured that identification assumptions are satisfied, reducing bias and enhancing precision. To bolster the validity of coefficient estimates, rigorous diagnostic checks for multicollinearity, model specification, and error structure were conducted,

ensuring identification assumptions are satisfied and the model is econometrically robust. The fixed effects framework leverages within-country variation to identify causal relationships, thereby enhancing credibility. Additionally, the integration of nonlinear functional forms and interaction terms, particularly to capture the moderating impact of education, allows the model to account for complex dynamics in the growth–environment–health nexus, providing a rigorous empirical foundation for evaluating the Environmental Kuznets Curve and related theoretical pathways. This layered econometric design provides a methodologically sound foundation for the empirical estimation that follows. The results of the estimated coefficients of the fixed effects model of the economic growth model are shown in Table 4.

Table 4: Results of estimating the fixed effects model of the economic growth

Variable	Abbreviation	Coefficients	Probability level
Intercept	C1	1.173	0.016
Per capita capital accumulation	$ln\, I_{it}$	0.234	0.008
Urbanization rate	U_{it}	0.021	0.004
Environmental protection	$ln\, E_{it}$	-0.045	0.012
Public health	H_{it}	0.040	0.054
Education	EDU_{it}	0.297	0.082

Source: Research findings

The findings reveal that per capita capital accumulation has a positive and statistically significant effect on GDP, implying that a 1% increase in investment per capita leads to a 0.23% increase in economic output among OPEC countries, highlighting the central role of capital deepening in driving growth. Similarly, the urbanization rate shows a positive and significant relationship with GDP, suggesting that expanding urban infrastructure and agglomeration economies enhance productivity and growth potential (Nikzad *et al.*, 2023). Public health, proxied by reduced mortality rates, also exerts a positive influence on economic performance, likely reflecting the gains from a healthier, more productive workforce and reduced healthcare burden. Education contributes positively to economic growth as well, though its significance is marginal at the 10% level, reinforcing the long-term role of human capital in development. Interestingly, environmental protection shows a negative and significant relationship with economic growth, indicating that efforts to reduce pollution (e.g., lower CO_2 emissions) may come at the cost of short-term output, an expected pattern in resource-dependent economies, where environmental regulation can constrain industrial activity. This trade-off suggests structural challenges in balancing economic expansion with ecological responsibility in oil-exporting nations. While our short-run model indicates an immediate output cost, consistent with regulatory constraints in resource-dependent economies, this negative association must be interpreted as a transitional phase rather than an immutable structural feature. This interpretation is reinforced by the short-run focus of our difference-based estimation, which does not capture potential long-run equilibrium where costs are offset by efficiency gains. Mitigating these short-term losses and fostering growth compatible with sustainability requires a decisive structural shift:

First, a focus on clean technology adoption (e.g., carbon capture, renewables, and process innovation) is essential, as empirical evidence confirms that technological advancement is key to decoupling growth from emissions in the long run (Wu *et al.*, 2021). Second, robust institutional reforms are critical to enhance the efficiency and transparency of environmental regulation, preventing regulatory costs from becoming merely a burden on output (Anderson, 2024). Such strategic investment and governance improvements are essential for achieving a balanced, long-term transition toward decarbonization without permanently sacrificing economic expansion, a pathway consistent with global green growth strategies (Teng *et al.*, 2025). The relationship between economic growth and environmental protection, and the examination of environmental Kuznets hypotheses, are presented concisely in Table 5.

Table 5: Results of estimating the fixed effects model of environmental protection

Variable	Abbreviation	Coefficients	Probability level
Intercept	C2	36.139	0.007
Per capita gross domestic product	$ln\, Y_{it}$	-9.156	0.042
Square of per capita gross domestic product	$(ln\, Y_{it})^2$	-0.580	0.036
Share of health expenditures from the budget	R_{it}	0.632	0.352
Share of industry value added from GDP	SR_{it}	-0.425	0.073

Source: Research findings

The results of model estimation for environmental protection reveal several noteworthy patterns. The negative and statistically significant coefficients for both per capita GDP and its squared term suggest that rising income levels are associated with increasing CO_2 emissions, thereby rejecting the Environmental Kuznets Curve (EKC) hypothesis for the sample of OPEC countries. This finding implies that economic growth in these economies does not follow a decoupling trajectory from environmental degradation, potentially due to the continued dependence on fossil fuel-based growth and weak environmental regulations. Furthermore, the share of health expenditures in the total government budget exhibits a positive but statistically insignificant effect on environmental quality, suggesting that while health-oriented spending may be indirectly related to better environmental outcomes, perhaps through cleaner public infrastructure or awareness campaigns, its standalone effect in these contexts remains limited.

Additionally, the coefficient for the share of industry value added in GDP is negative and marginally significant, indicating that greater industrialization contributes to environmental deterioration. A 1% increase in industrial share leads to an estimated 0.42% rise in CO_2 emissions, underscoring the pollution-intensive nature of industrial expansion in oil-exporting countries. These findings highlight a structural negative trade-off within the health–growth–environment nexus in oil-based economies, where efforts toward industrial expansion tend to undermine environmental sustainability.

The robustness of these interrelationships, however, must be contextualized within the high cross-country heterogeneity prevalent in the OPEC bloc. The observed structural trade-offs are likely exacerbated or mitigated by significant country-specific variations in institutional quality, policy enforcement capacity, and the effectiveness of governance structures, factors that were not quantitatively controlled in the primary estimation but remain crucial for interpreting causal inferences across this diverse sample (Frankel, 2010). These time-varying, unit-specific institutional differences may influence the speed and effectiveness of policy transmission, potentially affecting the robustness of causal inferences drawn about the interrelationships among environmental policies, industrial expansion, and public health. Controlling for such nuanced, unobserved governance factors would require advanced methodologies (e.g., Dynamic Panel Data models incorporating institutional proxies) or highly specific country-level studies. However, the overarching and critical objective of this study was to highlight and establish the nature and level of the core interrelationships and to provide a broad, simultaneous assessment of the key nexus dynamics and identify general trends across the OPEC bloc nexus in OPEC countries, emphasizing the urgent need for a unified policy focus on these dynamics. The factors affecting the improvement of public health are shown in Table 6.

Table 6: Results of estimating the fixed effects model of public health

Variable	Abbreviation	Coefficients	Probability level
Intercept	C3	-8.809	0.014
Per capita gross domestic product	$ln\, Y_{it}$	4.668	0.034
Environmental protection	$ln\, E_{it}$	0.221	0.007
per capita public health care expenditures	$ln\, S_{it}$	0.475	0.214
Education	EDU_{it}	0.235	0.389

Source: Research findings

The estimation results of the fixed effects model for public health demonstrate several key insights. The coefficient for per capita GDP is positive and statistically significant at the 5% level, suggesting that economic growth leads to a reduction in adult mortality and an improvement in public health. This reflects the positive role of rising income in enhancing access to healthcare services, nutrition, housing, and health awareness, factors that collectively lower mortality risks in OPEC countries. also, the model supports the idea that investments in environmental policies, such as pollution control and waste management, directly reduce environmentally induced diseases and enhance population well-being (Weil, 2014). Per capita health expenditure is not statistically significant. This finding may point to inefficiencies in health systems, suboptimal allocation of resources, corruption, or time lags in the impact of health spending, challenges that are especially relevant in oil-exporting developing economies. Similarly, the coefficient of education is positive yet statistically insignificant, implying that while higher average years of education should theoretically improve public health, its impact may be diluted due to the quality or relevance of education systems in the countries studied. These results highlight the complex interplay between structural factors and health outcomes, and emphasize the importance of institutional quality and policy efficiency in translating economic and environmental gains into public health improvements.

4. Conclusion and Recommendations

The empirical findings from the estimated panel models shed light on the multifaceted dynamic linking economic growth, public health, and environmental protection in OPEC member countries, that emphasize this interlinkage are mutually reinforcing and highly policy-sensitive. The results underscore several structurally significant insights that have direct implications for policy formulation in resource-dependent economies.

First, the positive and statistically significant effect of per capita capital accumulation on economic growth highlights the central role of productive investment in enhancing economic performance. Given the oil-based revenue structure of OPEC economies, it is recommended that these countries institutionalize mechanisms, such as sovereign wealth funds and strategic investment vehicles, to channel oil surpluses into productive capital formation. This strategy not only sustains long-term growth but also reduces exposure to commodity price volatility. Second, the findings clearly reject the Environmental Kuznets Curve (EKC) hypothesis for the panel of OPEC countries, that demonstrating that economic progress in the OPEC bloc is structurally coupled with environmental degradation, rather than leading to the automatic 'decoupling' observed in some developed economies. This result fundamentally challenges the conventional 'Grow Now, Clean Up Later' paradigm and underscores a persistent, negative structural trade-off between industrial development and environmental sustainability. Both the linear and squared terms of per capita GDP showed a positive and significant relationship with CO_2 emissions, implying that rising income levels have exacerbated environmental degradation rather than mitigated it. This result emphasizes a negative trade-off between economic growth and environmental sustainability in oil-exporting nations, driven by a growth path heavily reliant on polluting industrial activity. Policymakers must therefore shift focus toward low-carbon development strategies, including investment in renewable energy, clean production technologies, and environmental remediation programs. Furthermore, allocating a dedicated portion of annual budgets to environmental restoration is essential to internalize the externalities of growth-induced ecological harm.

This finding aligns with a growing body of literature that challenges the automatic 'decoupling' of growth from environmental pressure in resource-rich economies, underscoring the necessity of targeted green growth strategies to achieve genuine sustainability (Frankel, 2010; Saidi & Rahman, 2021). Third, the role of human capital emerges as critical across both growth and health models. Although the coefficient for education was only marginally significant in the growth model, its consistent positive association with both public health and GDP reinforces the need for sustained investment in education. Enhancing the scope and quality of public and applied education, especially in environmental literacy, public health awareness, and sustainable development, through formal schooling, mass media, and digital platforms can improve societal responsiveness to the dual goals of health and sustainability. Fourth, the urbanization variable exhibited a significant and positive impact on economic growth, suggesting agglomeration effects and enhanced infrastructure contribute to productivity gains. However, this demographic shift also increases the burden on health systems and intensifies environmental pressures through industrial expansion and urban sprawl. A balanced development strategy is therefore crucial (Nikzad *et al.*, 2023); one that ensures the equitable growth of both urban and rural sectors and promotes spatially inclusive policies that limit ecological damage while enabling economic opportunity.

Finally, public health emerges not only as a recipient of economic and environmental dynamics but also as a driver of economic performance itself. Consequently, a strategic portion of oil revenues should be systematically allocated to strengthen healthcare infrastructure, enhance medical research, and ensure equitable access to preventive and curative services across urban and rural regions. In conclusion, this study reaffirms that the interlinkages among growth, health, and environmental outcomes are mutually reinforcing and policy-sensitive. The results demonstrate that OPEC member states face a structural trade-off between industrial development and environmental sustainability, with public health situated at the nexus of these competing forces. Therefore, integrated policy frameworks, rooted in green investment, social spending, and human capital development, are essential to navigate this development-environment-health trilemma and achieve long-term sustainable prosperity.

The study's critical contribution lies in contextualizing these dynamics within the global sustainable development agenda. Our findings strongly emphasize that achieving the Sustainable Development Goals (SDGs), especially SDG 3 (Good Health), SDG 8 (Economic Growth), and SDG 13 (Climate Action), is contingent upon an explicit shift to a Green Growth framework. This framework, defined by the OECD as fostering economic development while ensuring that natural assets continue to provide essential resources and environmental services, is not a passive outcome of income growth (Hallegatee *et al.*, 2011). Instead, it demands integrated and proactive policy interventions: Policy Innovation: Moving beyond merely regulating pollution to actively promoting Green Innovation and Energy Transition. Resource Channelling: Utilizing oil revenues as Natural Capital to finance targeted Green Investment in low-carbon infrastructure and renewable energy systems, thereby creating new, sustainable economic sectors. Institutional Alignment: Ensuring that the effectiveness of these green policies is not compromised by the governance heterogeneity prevalent in the region (Frankel, 2010). By demonstrating that public health is situated at the nexus of these competing forces, this research provides robust empirical evidence that integrated policy frameworks, rooted in green capital accumulation, strong institutional quality, and human capital development, are essential to navigate the development-environment-health trilemma and achieve long-term, resilient prosperity in resource-dependent countries. The study's critical contribution lies in providing empirical support for the global sustainable development agenda (SDGs), particularly the imperative that economic progress in resource-dependent nations must be explicitly driven by a Green Growth framework to ensure environmental integrity and social well-being (Hallegatee *et al.*, 2011).

Future research should specifically address the limitations of the current study by incorporating quantitative measures of governance quality, institutional capacity, and policy enforcement capacity (e.g., World Bank Governance Indicators). This next step would require employing advanced methodologies, such as Dynamic Panel Data (DPD) models or specialized heterogeneous panel estimators (e.g., MG/PMGE), to effectively model the dynamic feedback loops between economic growth and environmental degradation and to control for the time-varying, unobserved governance heterogeneity that exists across OPEC economies (Pesaran *et al.*, 1999). Furthermore, the validity and robustness of such complex long-run models would be significantly enhanced by extending the time dimension of the panel as more consistent data become available in the future, especially given the inherent restrictions on data dissemination in many resource-dependent countries. Integrating proxies for technological innovation and renewable energy policies into these dynamic models, alongside comparative analyses with non-OPEC developing countries or a deeper dive into country-specific time-series studies could also broaden the understanding of sustainable development pathways and refine cross-sectoral policy design.

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