Energy diversification and economic growth: Following the neglected role of productivity growth in an analysis of 131 countries

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Abstract

Energy diversification is closely linked to energy efficiency, ecological and environmental issues and therefore highly important for sustainable outcomes. Besides, energy diversification can directly affect economic growth, since energy is a fundamental production input. Furthermore, it can also indirectly affect economic growth through changes in productivity increase. Based on this theoretical foundation, this study investigates the direct and productivity interactive effects of energy diversification on economic growth for 131 countries and their subgroups classified according to the levels of socioeconomic development, energy diversification, fossil energy abundance and income. For this purpose, the study calculates a diversification indicator according to energy sources consumed by using the normalized Herfindahl-Hirschman index and estimates growth equations for both GDP growth and per capita GDP growth. The findings show that the direct effect of energy diversification is negative. However, by including the interaction term in the models, it was revealed that energy diversification also has a significant positive effect on growth through increased productivity. These findings indicate that different directional mechanisms operate in the nexus of energy diversification and economic growth. Furthermore, the findings for country groups show that OECD, high energy diversified, high- and upper-middle-income countries have the capability to eliminate the negative effects of energy diversification and experience only its positive interactive effect. Besides, the results for groups according to income level also provide insight into the technological difficulties of energy diversification and imply that further diversification is possible in some countries per se due to market incentives, and in some others, it requires government support.

Keywords: energy diversification; normalized Herfindahl-Hirschman index; economic growth; panel data; productivity growth

1. Introduction

Although energy diversification has a technologically efficient basis, it can now be argued that the main motivation for this diversification is ecological or environmental sustainability, which constitutes an important aspect of sustainable economic growth. Reducing the use of traditional or dirty energy sources is supported by both the institutional regulations of international society and the environmental, energy and economic policies of countries shaped as a result of normative pressures of various social forces. For this reason, the increase in energy demand because of expanding economic activity urges the development and use of new or clear energy sources. Briefly, this stance on different sources of energy alters the energy mix, representing a shift away from fossil energy sources and toward renewable, clean, or green energy sources. Naturally this change in energy basket also affects the level of economic activity itself. Based on this theoretical and logical basis, this study explores the impact of energy diversification on economic growth.

Potential gains of energy diversification stem from supply security, promotion of competition and innovation, and the transition to sustainability which refers to better adaptation of energy systems to conditions in various contexts [1-6]. Therefore, energy diversification or energy transition that shapes energy basket is not only related to the quantity of energy forms used, but also to their quality, which expresses their energetic and environmental characteristics [7], and is important in determining energy efficiency, energy intensity, energy security and carbon intensity of countries and their climate change policies [8-10]. However, a fundamental difficulty for economists is that environmental damage caused by the overconsumption of traditional or fossil energy sources, or the exhaustion of non-renewable energy sources is not included in the GDP calculations, unlike, for example, the wear of fixed assets. On the other hand, fossil energy abundance, which is a likely cause of concentration in fossil energy sources, has been labelled as natural resource blessing and natural resource curse [11], pointing to completely different economic performances or development paths. In addition, the Dutch disease [12, 13], which points to the problems of developing the manufacturing industries of fossil energy-rich countries, has connections with energy diversification.

Despite the potential enhancing effects of energy diversification on economic growth, which was tried to clarify above by its possible gains, it can also suppress economic activity. Because, although new energy sources have environmental advantages and are supported by government subsidies in many countries, traditional energy systems on which existing production structures are based have high fixed costs, energy-related capital goods have a long economically efficient life, natural monopoly conditions or economies of scale are prevalent in energy markets, existing firms have advantages in distribution channels, there are high switching costs for buyers and existing technologies, fossil energy suppliers have market power and threats [14-22]. In this market structure, the impact of energy diversification on economic growth at expense of intensively used traditional energy sources and in favor of renewable, clean, or green energy sources may be negative due to reallocation effects.

On the other hand, the fundamental codes and actual experiences of economic development demonstrate that energy diversification is possible on the basis of efficiency. Concerns about climate change and global warming, the risks of high dependence on certain energy sources, the will to develop energy types based on domestic resources, the use of energy exports by supplier countries in line with their political objectives may have been influential in countries' inclination to renewable, clean, or green energy sources. However, energy diversification in this direction requires to be energy-efficient due to economic constraints [23]. Moreover, diversification that reduces the weight of fossil or conventional energy sources in use is probably possible in a socioeconomic environment that supports a culture of efficiency in general, not just with an increase in energy efficiency. Therefore, the effect of energy diversification on economic growth may be related to productivity increases. More precisely, productivity growth can differentiate the effect of energy diversification on economic growth or energy diversification can be expected to affect economic growth also through the interaction of productivity growth. So, in addition to addressing the direct effect of energy diversification on economic growth, the main contribution and novelty of this study is that it deals with the effect of energy diversification on economic growth through the interaction of productivity increase for the first time in the energy diversification-growth literature.

Thus, this study investigates the effect of energy diversification on economic growth in a sample of 131 countries with data available, and for the country groups that differ in socioeconomic development level, energy diversification level, fossil energy abundance, and income level. For this purpose, this study uses energy consumption data for 8 energy types according to their sources and calculates energy concentration level as an indicator of energy diversification using the normalized Herfindahl-Hirschman index. This index, in the literature, is also used by Reference [4, 24-25]. Besides, Reference [8, 26] also used this index, but in its original unnormalized form. In this regard, another distinguishing feature of the study is that it measures energy diversification in a standardized technique by considering more energy sources, applying a calculation method that is newly used in the current literature. Furthermore, the study uses data from many more countries than have been considered in previous studies and tries to elaborate the possible role of development, energy diversification, fossil energy abundance and income levels of countries.

Hence, different from the current literature that deals with the energy diversification or renewable, clean, or green energy use and growth nexus, this study examines the impact of energy diversification by modelling the direct growth-hindering effect from reallocation mechanisms and the moderating or growth-promoting effect through the interaction of productivity increase. In this respect, this study opens up a discussion that energy diversification has forces that are expected to affect economic growth both positively and negatively. In fact, current literature has managed to demonstrate support for both the growth-promoting and growth-suppressing effects of both energy diversification and increased use of renewable, clean, or green energy. This also provides a basis for the main argument in this study. In this regard, although there is a substantial volume of growth-supporting findings in the literature, Reference Marques and Fuinhas [27], Ocal and Aslan [28], Bhattacharya et al. [29], Chen et al. [30], Khan et al. [31], Gozgor and Paramati [24], Ahmed et al. [25] and Wang at al. [32] presented findings showing that energy diversification or increased use of renewable, clean, or green energy negatively affect economic growth.

In line with the main purpose indicated, this study estimates GDP and per capita GDP models, in which the energy diversification and interaction term of energy diversification and productivity growth, as well as variables related to labor force, capital and productivity, are included as explanatory variables. In addition, estimates for country groups in different categories of socioeconomic development, energy diversification, oil and natural gas abundance and income level are expected to provide insight into the extent to which countries in different groups have the institutional structure that has the competence to eliminate the negative effects of energy diversification. Moreover, findings for different country groups can also point to how the positive effect of energy diversification through the interaction of productivity growth differs in the context of the country groups in question. Finally, they are also expected to provide a robustness check for all-country estimates.

As for the structure of the study, the rest of the paper is organized as follows. Section 2 reviews previous studies. Section 3 introduces the model estimated and dataset. Section 4 describes the estimation procedure. Findings are presented in section 5 and section 6 discusses them and draws conclusions. Finally, section 7 provides practical implication and section 8 expresses limitation of the study.

2. Literature review

In literature, as far as we can detect, there are only five studies that use the normalized Herfindahl-Hirschman index to calculate energy diversification and investigate the effect of energy diversification calculated in this method on economic growth. Among them, Gozgor and Paramati [24] calculated this index by considering 7 types of energy consumed, namely coal, hydroelectricity, natural gas, nuclear energy, oil, and renewable energy, and investigated its effect on economic growth for panel data groups covering EU, G20 and OECD countries. But their reported statistics for the calculated energy diversification variable are impossibly high. Using the same index, Ahmed et al. [25] examined the effect of energy diversification on economic growth for 4 Nordic countries: Denmark, Finland, Sweden, and Norway. Nonlinear panel data method was used in both studies and their results support each other. Accordingly, energy diversification negatively affects economic growth in short run, and positively in long run. Liu et al. [4] also followed Gozgor and Paramati [24] in measuring the level of energy diversification and investigating its effect on sustainable development index in Asia Pacific Economic Cooperation member countries. Their panel cointegration and causality tests show that energy diversification positively affects sustainable development in long run and there is a unidirectional causality from energy diversification to sustainable development. Rubio-Varas and Muñoz-Delgado [8] and Akrofi [26] also calculated the Herfindal-Hirschman index for energy diversification, but in its unnormalized basic form. The first one of these studies examined how energy concentration level has changed for 8 European countries over a long historical period and showed that latecomers and also small energy consumers (Italy, Portugal, Spain, and Sweden) had historically lower concentration levels in their energy mix relative to earlycomers and also large energy consumers (the United Kingdom, France, Germany, and the Netherlands) and experienced faster energy transitions in the long run. Akrofi [26], on the other hand, examined energy diversification and transition trends in 12 African economies and found low negative correlation coefficients between growth and the index they calculated for most countries, but reported that they were insignificant.

Besides, there is a large literature on the impact of renewable, clean, and green energy on economic growth. Naturally, the increased use of all these energy types is related to or involve some aspects of energy diversification. Bohlmann et al. [33] and Khan et al. [31], for example, investigated the effect of transition to low-carbon or alternative energy types. In the simulations of a regional computable general equilibrium, Bohlmann et al. [33] concluded that the energy transformation in the presence of appropriate political measures may stimulate South Africa's economic growth. Findings of Khan et al. [31], on the other hand, based on augmented mean group and common correlation estimation mean group methods for 38 International Energy Agency (IEA) member countries indicate that there is no significant relationship between the energy transition indicator and economic growth in short run, and a negative nexus in long run.

Pang at al. [34], Hamit-Haggar [35] and Wang and Lee [36] investigated the growth effects of clean energy. Based on data envelopment analysis of 87 countries, Pang at al. [34] reported results supporting that this effect is positive. In panel data cointegration and causality analyzes for 11 Sub-Saharan African countries, Hamit-Haggar [35] presented findings indicating a cointegration relationship and a unidirectional causality relationship from clean energy consumption to economic growth. Finite mixture model findings of Wang and Lee [36] also indicate that clean energy supports Chinese growth.

Literature examining the energy-growth nexus often focuses on the impact of renewable energy sources. For example, using panel data from 24 European countries, Marques and Fuinhas [27] estimated a model that also includes energy-related variables such as energy consumption and energy dependence and found that the use of renewable energy negatively affects economic growth. However, Omri et al. [37], Alper and Oguz [38] and Ntanos et al. [39] came to different results for 17 developed and developing countries, a group of EU members and 25 European countries, respectively. Namely, Omri et al. [37] found unidirectional causality from economic growth to renewable energy and bidirectional causality between nuclear energy and economic growth in dynamic simultaneous-equation panel data analysis. For individual countries, however, their conclusions regarding the direction of causality are not the same. Asiedu at al. [40], on the other hand, found both cointegration and bidirectional causality between renewable energy consumption and economic growth in 26 European countries. Nevertheless, Alper and Oguz [38] reported that renewable energy consumption supports economic growth for all countries within the scope of their study, based on the results of the asymmetric causality test. The findings of Ntanos et al. [39] are also similar, including the nuance that the growth effect of renewable energy consumption is stronger in high-income countries. Unlike these, Li and Leung [41] and Yilanci et al. [42] found no causality from renewable energy consumption to economic growth for 7 European countries and 17 emerging countries, respectively.

Bhattacharya et al. [29], Rahman and Velayutham [43], Shahbaz et al. [44], and Ivanovski et al. [45] used both renewable and non-renewable energy consumption, and main results of first two on renewables differ from those of others. That is, findings of Rahman and Velayutham [43] for five South Asian countries and Bhattacharya et al. [29] for 38 top renewable-energy-consuming countries indicate that renewable energy consumption affects growth more strongly than non-renewable energy consumption. However, findings of Shahbaz et al. [44 for 38 renewable-energy-consuming countries are different and show that the growth effects of non-renewable energy use are stronger than renewable energy. Furthermore, for India, Ukraine, the US, and Israel Bhattacharya et al. [29] found that the effect of renewable energy consumption on economic growth is negative. Ocal and Aslan [28] also reported negative effect of renewables in their study for Türkiye. But for this country, Bhattacharya et al. [29] reached a different conclusion. Unlike others, Ivanovski et al. [45] examined the effect of renewable and non-renewable energy consumption on economic growth by using a non-parametric method, which assumes that this effect changes over time. For OECD countries, their results indicate that the effect of non-renewable energy consumption on growth increases over time, while the effect of renewable energy consumption on growth is mostly not supported by their findings. For non-OECD countries, on the other hand, they found that the effect of both types of energy consumption on economic growth is positive and non-linear.

Reference [46-48] were concerned with the specific effects of different types of renewables. The first of these estimated panel fixed effects and error correction models covering South Asian Association for Regional Cooperation countries and reported that all three energy sources, geothermal, hydro, and wind, positively affect economic growth. The second study estimated a panel error correction model covering 8 Asian countries (China, Bangladesh, Sri Lanka, Indonesia, Pakistan, Nepal, Malaysia, and India) and found that wind power, geothermal, and biomass affect economic growth, meanwhile, hydropower and solar power do not. Reference [48], on the other hand, applied augmented mean group and common correlated effects mean group approaches for 10 Asian countries (Bangladesh, China, India, Indonesia, Japan, Malaysia, Maldives, Nepal, Pakistan, and Vietnam) and concluded that increases in energy consumption from different renewable energy sources have a positive effect on economic growth.

Besides Li et al. [45], Anser et.al. [30]and Wang at al. [32] also considered nonlinearity in renewable energy and economic growth nexus. For 103 countries, Anser et.al. [30] modelled nonlinearity with a threshold value of renewable energy use and reported negative and positive effects for developed countries below and above the threshold, respectively. For OECD countries they found only linear positive effects, but no effect for developing countries. Nevertheless, according to the findings of Wang at al. [32] from nonlinear model, the effect of renewable energy consumption differs according to the political, financial, economic, and composite risk of the country. Accordingly, the effect of renewables is strengthened for political and composite risk value above a certain threshold. However, the positive effect is supported for certain medium values of economic and financial risk.

In this point, it can be said that energy diversification indicators were only considered by Rubio-Varas and Muñoz-Delgado [8], Akrofi [26], Gozgor and Paramati [24], Ahmed et al. [25] and Liu et al. [4]. Others focused on the impact of energy transition, clean energy, green energy, and renewable energy, which can also be linked to energy diversification in some respects. Besides Gozgor and Paramati [24] and Ahmed et al. [25], Khan et al. [31], Hamit-Haggar [35] and Asiedu at al. [40] considered short- and long-term analyses. Nonlinear modelling of the energy economic growth nexus by Ivanovski at al. [45], Chen et al. [30] and Wang at al. [32] is also based on the impression that this nexus is not invariant. In addition, while literature results mostly indicate that the energy diversification or transition and use of clean, green or renewable energy sources boosts economic growth, Marques and Fuinhas [27], Ocal and Aslan [28], Bhattacharya et al. [29], Chen et al. [30], Khan et al. [31], Gozgor and Paramati [24], Ahmed et al. [25] and Wang at al. [32], on the other hand, obtained findings pointing to growth-hindering effects. These differing results in current literature, both supporting and hindering effects on economic growth, also provide a basis and motivation for the main argument of this study. Therefore, unlike the previous studies, this study employs a model in which energy diversification may have direct and indirect effects on economic growth due to its reallocation effects and interaction with productivity growth. The reallocation effects of energy diversification and its effect through the interaction of productivity growth (converting effect) are likely to be growth-hindering and growth-boosting, respectively.

3. Data and model specification

The model considered in this study is an augmented version of the Solow growth model, including the energy diversification and interaction term of energy diversification-productivity growth. Solow's neoclassical model, expressed in percentage changes, explains economic growth by the growth rates of labor force, physical capital, and total factor productivity. For this circumstance, the model used can be expressed by the following equation:

$$growth_{it} = \beta_0 + \beta_1 labor_{it} + \beta_2 capital_{it} + \beta_3 poductivity_{it} + \beta_4 concentration_{it} + \beta_5 (concentration * productivity)_{it} + \varepsilon_{it} \quad (1)$$

Here, dependent variable $growth$ is the economic growth rate. $labor$, $capital$ and $productivity$ are the percentage changes in the labor force, capital, and productivity, respectively. For economic growth, this study uses GDP and per capita GDP growth rates. $labor$ is annual percentage change in the labor force. $capital$ was measured by gross fixed capital formation annual growth rate. Data on economic growth, labor force and physical capital were taken from World Bank World Development Indicators database. $productivity$ which is productivity growth, was calculated as annual percentage changes in the productive capacities index published by UNCTAD. The index itself consists of the geometric average of eight productive capacities index categories: natural capital, human capital, energy, transport, ICT, institutions, structural change and private sector. $concentration$ and $concentration * productivity$ were included in the model to determine the effect of energy diversification on economic growth, which is the main purpose of this study. As we indicated earlier, energy diversification can directly affect economic growth negatively due to reallocation, and indirectly positively through the interaction of productivity growth. In this regards, $concentration$ variable and $concentration * productivity$ interaction term were included in the model to test the main argument of the study. Furthermore, the inclusion of interaction variable allows us to examine how productivity growth influences the effect of energy diversification on economic growth. To calculate $concentration$, this study uses the normalized Herfindahl Hirschman index and data from the International Energy Agency on energy consumption by source, given in 8 types: coal, crude oil, oil products, natural gas, wind, solar, etc., biofuels and waste, electricity, and heat. The Herfindahl Hirschman index is mostly used for the information it gives on the competition level in markets and is based on the sum of the squares of the market shares of the firms. Normalized form of this index calculated for 8 energy sources can be expressed as follows:

$$concentration = \frac{\sqrt{\sum_{i=1}^{8}\left(\frac{e_i}{E}\right)^2} - \frac{1}{\sqrt{8}}}{1 - \frac{1}{\sqrt{8}}} \quad (2)$$

Here, e_i ve E represent the energy consumption from source i and the total energy consumption, respectively. The $concentration$ may take values from 0 to 1. As can be understood from the equation, if the energy consumption comes from the sources equally, that is, in the case of full diversification, the index takes the value of 0. In comparison, if all of the energy consumed comes from a single source, that is, in the case of full concentration, the index takes the value of 1.

The last independent variable in Equation 1 is the interaction variable calculated by multiplying $concentration$ and $productivity$. The estimated coefficient for this variable is expected to provide insight into the impact of energy concentration/diversification on economic growth depending on productivity growth.

For ease of tracing, we also presented description and sources of our data in Table 1.

Table 1. Data description and sources

variables	description	sources
$growth$	GDP growth (annual %)	World Bank World Development Indicators
$growthpc$	GDP per capita growth (annual %)	
$labor$	total labor force (annual % change)	
$capital$	gross fixed capital formation (annual % growth)	
$poductivity$	productive capacities index (annual % change)	UNCTADstat Data centre
$concentration$	normalized Herfindahl Hirschman index for total final energy consumption by source	energy consumption by source from the IEA
$poductivity * concentration$	interaction term	product of $concentration$ and $productivity$

Within the scope of the study, there are 131 countries[1] with accessible data covering 2001-2019 years. The analyses performed for the panel covering all countries and the OECD (38 countries)[2] and non-OECD (93 countries); average concentration is lower (64 countries) [3] and higher (67 countries) than the median value; resource-rich (48 countries) [4] and non-resource-rich (83 countries); high- (50 countries)[5], upper-middle- (37 countries)[6], lower-middle- (35 countries)[7] and low- (9 countries)[8] income level country groups. Findings for country groups are expected to shed light on how the impact of energy diversification on economic growth differs according to countries' socioeconomic development stages, energy diversification levels, abundance of natural resources and income levels, and also to provide a robustness check for the findings of the model covering all countries.

4. Econometric methodology

Panel data were used in the study and therefore the cross-sectional dependence in data was first examined by using Pesaran [49] CD test, which is commonly used in literature for this purpose. The CD test statistic can be formulated as follows:

$$CD_p = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T_{ij}}\hat{\rho}_{ij} \quad (3)$$

Here, $\hat{\rho}$'s are the binary correlation coefficients. N and T are the number of cross-sections and observations. Considering the findings of Pesaran [49] CD test, this study applies Pesaran [50] CIPS test for unit root analysis. The model for this test can be expressed as follows:

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + \sum_{j=1}^{p} \delta_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{p} d_{ij} \Delta \bar{y}_{t-j} + e_{it} \quad (4)$$

In this test, the unit root check for each panel unit is based on t statistics of the coefficient b. The overall test statistic for the panel (CIPS) is calculated as the average of t statistics [51].

The study then uses Hausman [52] test to determine which panel data method, the fixed or random effect, is suitable for our model. The Hausman test statistic based on examining the correlation between unit effects and independent variables is as follows:

$$H = (\hat{\beta}_f - \hat{\beta}_r)' [Var(\hat{\beta}_f) - Var(\hat{\beta}_r)]^{-1} (\hat{\beta}_f - \hat{\beta}_r) \quad (5)$$

Here, β's are coefficients for fixed effects and random effects. If the test rejects null hypothesis, then the fixed-effects model is applied.

In accordance with the findings of Hausman test, the fixed effects estimation method was used in this study. Fixed effects method allows the constant term in the model to vary across panel units and capturing the combined overall effect of omitted or unobserved unit-specific and global variables. This main feature of this approach also makes it easier to focus on the effect of the variables in question. Moreover, in estimations this study considers the robust standard errors of Driscoll and Kraay [53]. Compared with other panel data estimators, Driscoll–Kraay standard errors are well calibrated when autocorrelation, heteroskedasticity and cross-sectional dependence are present. Therefore, Driscoll–Kraay's standard error approach provides more reliable and robust results [54].

5. Empirical findings

Before running the economic growth equations, the study applied the Peseran [50] unit root test, which models cross-sectional dependence, to examine whether the variables are stationary or not. Findings of the Pesaran [49] CD test presented in Table 2 and they support the cross-sectional dependence in all variables for all country groups except the low-income group. This conclusion, which is also thought to be a result of globalization or the spillover of economic, institutional, and technological effects, indicates that the relevant variables of different countries are affected by each other or by external variables commonly. For low-income group countries, on the other hand, there seems to be an isolated situation. Although the stationarity properties of the variables of this group were checked with traditional unit root tests, Peseran [50] test was applied due to its superiority.

Table 2. Findings of cross-sectional dependence test

	$growth$	$growthpc$	$labor$	$capital$	$poductivity$	$concentration$	$concentration * productivity$
whole sample	88.40***	81.05***	8.76***	55.58***	57.90***	50.92***	60.79***
OECD	63.63***	62.77***	6.16***	43.41***	35.96***	14.42***	37.10***
non-OECD	46.41***	39.17***	5.84***	28.90***	32.02***	35.92***	33.74***
below-median	75.66***	72.49***	6.85***	50.86***	60.31***	14.12***	60.88***
above-median	24.37***	19.64***	2.08**	13.38***	12.76***	42.01***	14.38***
non-oil	61.09***	58.63***	4.13***	43.80***	43.21***	23.64***	44.24***
oil-rich	31.34***	25.67***	5.91***	20.27***	19.18***	26.70***	21.45***
high-income	63.39***	61.86***	9.27***	42.71***	30.81***	21.89***	32.42**
upper-middle-income	38.27***	35.30***	1.77*	21.59***	22.48***	2.46**	22.40***
lower-middle-income	7.66***	6.70***	2.77***	7.02***	13.34***	22.61***	14.19***
low-income	1.17	1.20	1.28	0.54	1.26	9.33***	1.18

Note: ***, ** and * indicate that the relevant statistics are significant at 1%, 5% and %10 levels, respectively.

Table 3 reports the Peseran [50] CD statistics. The findings in the table indicate that, except for the $labor$ in the low-income group, all variables in different panels are stationary. For the low-income group, findings indicating this result were also obtained in conventional panel unit root tests. Therefore, the growth equations for this country group were estimated excluding $labor$ from the model.

Table 4, on the other hand, presents the findings of Hausman test. As can be seen from the table, the Hausman χ^2 statistics calculated for the models of both economic growth variables show that the fixed effects estimators are appropriate. Therefore, for all country groups Equation 1 was estimated under the fixed effects model. In addition, the Driscoll and Kraay [53] procedure was used in these estimates. As noted earlier, Driscoll and Kraay [53] estimators provide heteroskedasticity- and autocorrelation-consistent standard errors that are robust to cross-sectional dependence.

Table 3. Findings of unit root test

group	model	$growth$	$growthpc$	$labor$	$capital$	$poductivity$	$concentration$	$concentration * productivity$
whole sample	none	-2.648***	-2.748***	-2.867***	-3.286***	-3.790***	-1.637**	-3.650***
	constant	-2,847***	-2,857***	-3.117***	-3.418***	-3.952***	-2.245**	-3.713***
	trend	-3,341***	-3,260***	-3,341***	-3.689***	-3.794***	-2.426	-3.884***
OECD	none	-2.549***	-2.645***	-3.332***	-2.838***	-4.030***	-1.669**	-4.162***
	constant	-2.971***	-2.880***	-3.461***	-2.847***	-4.134***	-2.324**	-4.372***
	trend	-3.083***	-3.190***	-3.773***	-3.216***	-4.408***	-2.634*	-4.608***
non-OECD	none	-2.823***	-2.829***	-2.466***	-3.468***	-3.696***	-1.587*	-3.688***
	constant	-2.762***	-2.786***	-3.113***	-3.413***	-3.786***	-2.349**	-3.817***
	trend	-3.093***	-3.025***	-3.454***	-3.779***	-3.859***	-2.416	-3.658***
below-median	none	-2.661***	-2.713***	-3.584***	-3.005***	-3.547***	-1.736**	-3.711***
	constant	-2.796***	-2.823***	-3.574***	-3.414***	-3.816***	-2.128**	-3.920***
	trend	-3.158***	-3.010***	-4.031***	-3.684***	-3.727***	-2.696*	-3.894***
above-median	none	-2.844***	-2.826***	-2.267***	-3.480***	-3.875***	-1.579*	-3.832***
	constant	-3.129***	-3.029***	-2.606***	-3.716***	-3.838***	-2.234**	-3.890***
	trend	-3.379***	-3.280***	-2.817***	-3.657***	-3.968***	-2.576	-4.017***
non-oil	none	-2.442***	-2.601***	-3.056***	-3.177***	-3.897***	-1.525*	-3.811***
	constant	-2.762***	-2.786***	-3.113***	-3.413***	-3.786***	-2.349**	-3.817***
	trend	-3,093***	-3.025***	-3.454***	-3.779***	-3.859***	-2.416	-3.658***
oil-rich	none	-2.789***	-2.841***	-2.433***	-3.515***	-3.710***	-1.824***	-3.606***
	constant	-3.287***	-3.225***	-2.749***	-3.533***	-3.944***	-2.117*	-3.754***
	trend	-3.452***	-3.357***	-3.096***	-3.520***	-4.031***	-2.221	-3.954***
high-income	none	-2.652***	-2.627***	-3.202***	-3.130***	-4.043***	-1.550*	-4.027***
	constant	-2.662***	-2.890***	-3.492***	-3.195***	-4.181***	-2.257**	-4.394***
	trend	-3.450***	-1.199***	-3.862***	-3.445***	-4.650***	-2.737**	-4.335***
upper-middle-income	none	-3.347***	-3.101***	-2.836***	-3.472***	-3.506***	-1.815***	-3.514***
	constant	-3.775***	-3.764***	-2.825***	-3.479***	-3.638***	-2.115*	-3.625**
	trend	-3.690***	-3.924***	-3.254***	-3.494***	-3.638***	-2.798**	-3.562***
lower-middle-income	none	-2.682***	-2.802***	-2.582***	-3.410***	-3.583***	-1.371	-3.556***
	constant	-3.069***	-3.376***	-2.557***	-3.553***	-3.598***	-2.425***	-3.534***
	trend	-3.530***	-3.473***	-2.821**	-4.181***	-3.664***	-2.776**	-3.624***
low-income	none	-2.636***	-2.904***	-0.297	-3.479***	-3.284***	-1.804**	-3.319***
	constant	-3.251***	-3.353***	-1.650	-3.654***	-3.060***	-2.189*	-3.894***
	trend	-3.655***	-3.405***	-2.249	-2.886*	-3.500***	-1.816	-4.223***

Note: ***, ** and * indicate that the relevant statistics are significant at 1%, 5% and %10 levels, respectively.

Table 4. Hausman χ^2 test findings

	dependent variable: $growth$	dependent variable: $growthpc$
whole sample	84.34***	76.27***
OECD	20.44***	25.77***
non-OECD	51.63***	52.26***
below-median	95.88***	79.32***
above-median	42.36**	40.61***
non-oil	100.27***	76.72***
oil-rich	25.62***	23.84***
high-income	12.12**	18.73***
upper-middle-income	11.19**	10.32*

lower-middle-income	19.90***	23.43***
low-income	55.74***	60.07***

Note: ***, ** and * indicate that the relevant statistics are significant at 1%, 5% and %10 levels, respectively.

We presented our findings based on fixed effects method of Equation 1 in two different ways: the model without and with the $concentration$ and $productivity$ interaction variable. In addition to the explanatory variables given in Equation 1, we also included dummy variables to the model for 2009 year and for the positive and negative extreme growth rates of some countries. Table 5 and Table 6 present the model findings without the interaction term for dependent variables of $growth$ and $growthpc$, respectively. Here, a brief explanation is given for these initial findings, followed by a more detailed discussion of the key findings presented in Tables 7 and 8. The coefficients estimated for the $concentration$ in Table 5 and Table 6 are positive for all country groups. Among these, the coefficients for the all-countries sample, non-OECD, above-median, non-oil, lower-middle-income, and low-income groups are statistically significant. For OECD, below-median, oil-rich, high-income, and upper-middle-income groups, on the other hand, this negative effect of energy diversification was not supported. These findings reveal that the negative effect of energy diversification on economic growth differs in line with the expectations according to the socioeconomic development, energy diversification and income levels of the countries. In addition, the findings indicating the same conclusion for fossil energy rich countries is thought to be due to many socioeconomically developed or high-income or upper-middle-income economies which would suppress the negative effect of diversification in this group. The findings for the other explanatory variables were found to be consistent with the model findings including the interaction term in Table 7 and Table 8. Therefore, explanations for $labor$, $capital$ and $productivity$ were given based on the interaction term added model.

Table 5. Initial findings: the model without interaction term (dependent variable $growth$)

	whole sample	OECD	non-OECD	below-median	above-median	non-oil	oil-rich	high-income	upper-middle income	lower-middle-income	low-income
$labor$	0.1829***	0.2141***	0.1702***	0.0637	0.2224***	0.1044**	0.2562***	0.2631***	0.0172	0.0926	
	(0.0383)	(0.0659)	(0.0515)	(0.0491)	(0.0533)	(0.0463)	(0.0516)	(0.0474)	(0.0668)	(0.0655)	
$capital$	0.0885***	0.1597***	0.0792***	0.1685***	0.0641***	0.1156***	0.0650***	0.1025***	0.1092***	0.0803***	0.0308
	(0.0116)	(0.0385)	(0.0109)	(0.0115)	(0.0119)	(0.0147)	(0.0136)	(0.0172)	(0.0137)	(0.0200)	(0.0187)
$poductivity$	0.1222***	0.0241***	0.1129***	0.14.16***	0.0926**	0.1179***	0.0946	0.1066*	0.0908	0.1362	0.1102**
	(0.0299)	(0.0686)	(0.0333)	(0.0485)	(0.0390)	(0.0292)	(0.0843)	(0.0532)	(0.0799)	(0.0442)	(0.0421)
$concentration$	6.0856***	2.8042	7.0353***	4.2232	7.4800***	5.6490***	7.9731	2.2347	0.8844	6.6988***	18.8730**
	(2.2047)	(2.7502)	(2.6456)	(3.3404)	(2.4554)	(1.7048)	(7.0216)	(3.5477)	(5.3805)	(2.0792)	(5.7137)
d_{2009}	-3.1920***	-3.9399***	-2.4246***	-3.0271***	-2.1938***	-3.2920***	-2.5524***	-4.6054***	-3.9644***	-0.4500	0.1163
	(0.3342)	(0.6751)	(0.3790)	(0.2265)	(0.3368)	(0.2617)	(0.4308)	(0.4028)	(0.5258)	(0.3007)	(0.4811)
$d_{aze\_2005-2007}$	24.7366***		24.7300***	24.8434***			24.8299***		24.1834***		
	(1.8982)		(1.9504)	(1.5901)			(2.2315)		(1.9183)		
d_{gnq_2001}	57.4306***		57.9723***		58.8738***		58.7365***		56.7732***		
	(2.4280)		(2.2474)		(2.5184)		(2.1999)		(1.9415)		
d_{irq_2003}	-41.0029***		-40.6523***		-40.1173***		-40.1775***		-41.5609***		
	(1.9341)		(1.9010)		(1.8554)		(1.9401)		(2.1445)		
d_{irq_2004}	54.7760***		54.2591***		53.3410***		53.3767***		55.6679***		
	(1.4257)		(1.2980)		(1.0458)		(0.9627)		(1.4616)		
d_{irl_2015}	17.5717***	14.6137***			18.6536***	16.4237***		16.7246***			
	(0.5845)	(1.7854)			(0.6885)	(0.5890)		(0.7539)			
d_{lby_2011}	-44.6337***		-45.3225***		-45.8874***		-45.5308***		-45.0992***		
	(3.4337)		(3.4268)		(3.5148)		(3.7619)		(3.5657)		
d_{lby_2012}	80.2257***		80.7625***		82.3128***		82.5470***		77.2410***		
	(2.8953)		(2.8872)		(2.8387)		(3.0854)		(3.0863)		
d_{qat_2006}	9.3982***		10.2270***		10.1909***		9.4976***	6.9772***			
	(1.9465)		(1.6029)		(1.4559)		(1.3817)	(2.0845)			
$d_{syr\_2012-2013}$	-23.9492***		-24.3570***		-24.7329***		-24.5275***				-26.8091***
	(1.5808)		(1.7435)		(1.7807)		(2.2410)				(1.5261)
d_{yem_2015}	-25.9413***		-26.8551***		-28.6589***		-28.6088***				-30.7952***
	(2.8219)		(2.9955)		(3.0897)		(3.6118)				(2.5168)
d_{zwe_2009}	58.4824***		579496***		58.2031***	57.7846***				55.8586***	
	(2.8806)		(2.8643)		(2.8756)	(2.8076)				(3.0095)	
$cons$	0.3481	0.9430	0.0532	1.3455	-1.1068	0.7616	-0.9644***	1.3047	3.0955	0.5433	-9.1376***
	(0.1.0097)	(1.0353)	(1.4051)	(0.9869)	(1.5198)	(0.6984)	(3.4959)	(1.2888)	(2.4411)	(0.8956)	(4.0056)
F	1229213.27	1020.08	1419024.14	822.85	816925.55	1168.45	107175.39	3460.85	34858.86	620.04	207.71
R-squared	0.5751	0.6337	0.5793	0.5764	0.6008	0.4787	0.6347	0.4318	0.7084	0.4294	0.5346

Note: ***, ** and * indicate that the relevant statistics are significant at 1%, 5% and %10 levels, respectively.

Table 6. Initial findings: the model without interaction term (dependent variable $growthpc$)

	whole sample	OECD	non-OECD	below-median	above-median	non-oil	oil-rich	high-income	upper-middle income	lower-middle-income	low-income
$labor$	-0.1509***	0.1318**	-0.1917***	-0.0215	-0.2117***	-0.0454	-0.2428***	-0.2316**	-0.0823	-0.0790	
	(0.0545)	(0.0616)	(0.0650)	(0.0461)	(0.0688)	(0.0646)	(0.0776)	(0.0879)	(0.0668)	(0.1038)	
$capital$	0.0866***	0.1591***	0.0774***	0.1674***	0.0621***	0.1161***	0.0627***	0.1053***	0.1061***	0.0790***	0.0263
	(0.0119)	(0.0384)	(0.0106)	(0.0121)	(0.0109)	(0.0151)	(0.0123)	(0.0179)	(0.0136)	(0.0197)	(0.0145)
$poductivity$	0.1197***	0.2360***	0.1070***	0.1591***	0.0852**	0.1182***	0.0762	0.1213**	0.0960	0.1310	0.0829
	(0.0276)	(0.0712)	(0.0296)	(0.0537)	(0.0367)	(0.0309)	(0.0751)	(0.0532)	(0.0797)	(0.0415)	(0.0452)
$concentration$	5.9051***	0.5297	7.0447***	2.4568	7.9235***	5.4124***	8.6890	2.3244	3.0024	6.3014***	17.6900**
	(2.0112)	(2.8395)	(2.4238)	(3.3041)	(2.2574)	(1.9393)	(6.8994)	(3.9755)	(5.3823)	(1.9640)	(5.6450)
d_{2009}	-3.3328***	-3.9202***	-2.5642***	-3.0668***	-2.3455***	-3.2937***	-2.7147***	-4.8425***	-3.9892***	-0.4429	0.0711
	(0.3335)	(0.6683)	(0.3614)	(0.2341)	(0.3074)	(0.2640)	(0.4126)	(0.4379)	(0.5185)	(0.2879)	(0.4493)
$d_{aze\_2005-2007}$	23.6492***		23.5839***	24.2689***			23.3936***		23.6854***		
	(1.8930)		(1.9499)	(1.5849)			(2.1954)		(1.9104)		
d_{gnq_2001}	54.1154***		54.6652***		55.5778***		55.5047***		53.2001***		
	(2.3481)		(2.3050)		(2.4171)		(2.1402)		(1.7815)		
d_{irq_2003}	-40.1211***		-39.7619***		-39.2208***		-39.2400***		-40.6851***		
	(1.8015)		(1.7604)		(1.7218)		(1.8046)		(2.0138)		
d_{irq_2004}	53.0604***		52.5149***		51.5654***		51.4952***		53.9396***		
	(1.4243)		(1.3020)		(1.0839)		(1.0145)		(1.4281)		
d_{irl_2015}	17.8195***	14.8249***			18.9024***	16.6308***		16.7747***			
	(0.6592)	(1.7575)			(0.7883)	(0.6014)		(0.7006)			
d_{lby_2011}	-43.3197***		-44.2790***		-45.5098***		-45.8227***		-41.6676***		
	(3.3004)		(3.2973)		(3.4102)		(3.6685)		(3.3785)		
d_{lby_2012}	89.2970***		89.5562***		90.4046***		90.0255***		88.6232***		
	(2.7103)		(2.7177)		(2.7175)		(3.6685)		(2.9113)		
$d_{syr\_2012-2013}$	-22.0626***		-22.6453***		-23.4230***		-23.6592***				-23.4008***
	(1.1196)		(1.2837)		(1.2797)		(1.7648)				(0.9734)
d_{yem_2015}	-24.4976***		-25.3723***		-27.0340***		-26.9700***				-30.5315***
	(2.6460)		(2.7705)		(2.8579)		(3.3342)				(2.2059)
d_{zwe_2009}	58.2108***		57.6542***		57.8550***	57.4477***				55.5617***	
	(2.7595)		(2.7274)		(2.7371)	(2.6752)				(2.8829)	
$cons$	-0.3376	1.1389	-0.8506	1.3135	-2.3152*	0.0640	-2.0804	0.9577	1.4168	-0.7168	-11.0679**
	(0.9118)	(1.0656)	(1.2950)	(0.9760)	(1.3853)	(0.8092)	(3.4234)	(1.4209)	(2.4573)	(0.8439)	(4.0990)
F	724623.27	792.66	302289.60	758.37	397459.54	774.66	167717.78	805.63	38510.94	661.04	158.27
R-squared	0.5781	0.63.02	0.5867	0.5652	0.6120	0.4723	0.6469	0.3876	0.7190	0.4304	0.5677

Note: ***, ** and * indicate that the relevant statistics are significant at 1%, 5% and %10 levels, respectively.

Findings of the estimated models for GDP and GDP per capita growth rates are reported in Tables 7 and Table 8, respectively. The two tables are broadly highly consistent with each other. As can be seen in Table 7, coefficients for the $labor$ are positive and statistically significant except for below-median, upper-middle- and lower-middle-income panels. $capital$, on the other hand, is found to have positive effect on GDP growth in all models except the low-income group. As for $productivity$ coefficients, they are found to be statistically significant in all models except lower-middle- and low-income countries. The coefficients of these three variables show that $productivity$ affects economic growth more than $labor$ and $capital$. Besides, 2009 and country dummy variables are also statistically significant.

As for the $concentration$, the main variable of interest to the study, coefficient of this variable is positive and statistically significant in the panel covering all countries. This finding confirms the direct negative reallocation effect of energy diversification on economic growth. As in Table 6, this effect is also supported by the findings for non-OECD, above-median, non-oil, lower-middle- and low-income groups in Table 7. The outputs for GDP per capita estimates, given in Table 8, also point to the same result. On the other hand, the coefficient of the $concentration * productivity$ interaction variable for the panel covering all countries is negative and statistically significant in both tables. This finding indicates that energy diversification positively affects economic growth in the presence of productivity increase.

The estimated $concentration$ coefficients and interaction terms for country groups provide more in-depth insights or understanding. As can be seen from Table 7 and Table 8, the negative reallocation effect of energy diversification is not supported for OECD, belove-median, oil-rich, high- and upper-middle-income country groups. For these country groups, only the interaction term, which expresses the indirect positive effect of energy diversification, is found to be statistically significant. Whereas the interaction term is not statistically significant for lower-middle- and low-income country groups in both tables, and additionally for above-median country group in Table 7. For these country groups, findings support only the negative reallocation effect of energy diversification.

Table 7. Main findings: the model including interaction term (dependent variable $growth$)

	whole sample	OECD	non-OECD	below-median	above-median	non-oil	oil-rich	high-income	upper-middle income	lower-middle-income	low-income
$labor$	0.1806***	0.2219***	0.1676***	-0.0148	0.2197***	0.1068**	0.2490***	0.2561***	0.0228	0.0915	
	(0.0375)	(0.0622)	(0.0504)	(0.0461)	(0.0522)	(0.0454)	(0.0502)	(0.0484)	(0.0663)	(0.0670)	
$capital$	0.0862***	0.1626***	0.0769***	0.1663***	0.0635***	0.1131***	0.0627***	0.1040***	0.1087***	0.0784***	0.0302
	(0.0116)	(0.0389)	(0.0110)	(.0118)	(0.0119)	(0.0143)	(0.0136)	(0.0168)	(0.0121)	(0.0216)	(0.0189)
$poductivity$	0.4798***	0.5730***	0.4705***	0.6119***	0.2903*	0.3948***	0.5316**	0.5370**	0.8842***	0.3466	0.3917*
	(0.1215)	(0.2044)	(0.1299)	(0.1467)	(0.1501)	(0.1304)	(0.2583)	(0.2453)	(0.1369)	(0.2635)	(0.0296)
$concentration$	6.9455***	4.1450	8.0124***	3.9533	7.9820***	6.3503***	8.6126	3.1649	3.1139	7.3149***	20.1049**
	(2.1884)	(3.0170)	(2.6916)	(3.4515)	(2.5615)	(1.7318)	(7.2328)	(3.5204)	(5.2525)	(2.3901)	(6.1190)
$concentration$	-0.6339***	-1.5991**	-0.6099***	-1.5989***	-0.3144	-0.5318**	-0.6791**	-1.0490*	-1.6730***	-0.3839	0.0738
$* productivity$	(0.2027)	(0.6933)	(0.2010)	(0.4799)	(0.2060)	(0.2286)	(0.3092)	(0.5612)	(0.4094)	(0.4851)	(0.5289)
d_{2009}	-3.1074***	-3.9286***	-2.3660***	-3.0543***	-2.2161***	-3.2369***	-2.5114***	-4.4520***	-3.6260***	-0.4569	
	(0.3005)	(0.6841)	(0.3555)	(0.2361)	(0.3402)	(0.2469)	(0.4205)	(0.3940)	(0.4397)	(0.2985)	
$d_{aze\_2005-2007}$	25.0305***		25.0439***	24.0596***			25.2376***		24.6926***		
	(1.8097)		(1.8684)	(1.6087)			(2.2260)		(1.8232)		
d_{gnq_2001}	57.8296***		58.3139***		58.9735***		59.0226***		57.9307***		
	(2.4203)		(2.4146)		(2.5370)		(2.2902)		(1.7555)		
d_{irq_2003}	-40.7090***		-40.4026***		-40.0464***		-40.0117***		-40.5526***		
	(1.9452)		(1.8943)		(1.8413)		(1.8740)		(2.2274)		
d_{irq_2004}	53.9018***		53.4952***		53.0658***		52.8109***		52.6532***		
	(1.2421)		(1.1801)		(1.0582)		(1.0539)		(1.5445)		
d_{irl_2015}	17.8493***	14.2789***			18.7995***	16.6433***		16.7063***			
	(0.6165)	(1.8587)			(0.7343)	(0.5911)		(0.7523)			
d_{lby_2011}	-44.6832***		-45.3115***		-45.7874***		-45.3322***		-45.5730***		
	(3.4321)		(3.4133)		(3.4949)		(3.7346)		(3.6829)		
d_{lby_2012}	80.3862***		80.9260***		82.3441***		82.6866***		77.3366***		
	(2.9154)		(2.9071)		(2.8446)		(3.0917)		(3.1196)		
d_{qat_2006}	9.7280***		10.5816***		10.3818***		10.0199***	6.9128***			
	(1.8829)		(1.5686)		(1.4202)		(1.4105)	(2.0308)			
$d_{syr\_2012-2013}$	-24.1284***		-24.4407***		-24.6677***		-24.3492***				-26.4298***
	(1.6140)		(1.7419)		(1.7592)		(2.2267)				(1.2937)
d_{yem_2015}	-27.4166***		-28.1762***		-29.1687***		-29.7459***				-31.0714***
	(3.2609)		(3.2565)		(3.1580)		(3.5241)				(2.5628)
d_{zwe_2009}	58.5423***		58.0088***		58.2467***	57.9061***				55.9748***	
	(2.8981)		(2.8718)		(2.8767)	(2.8733)				(3.1472)	
$cons$	-0.0735	0.52976	-0.4682	0.8782	-1.3923	0.4473	-1.3584***	0.9435	2.0053	0.2321	10.0008**
	(0.9750)	(1.1170)	(1.4149)	(1.0084)	(1.5687)	(0.7118)	(3.6083)	(1.2644)	(2.3230)	(1.0764)	(4.2721)
F	1.67e+07	1065.73	2776214.96	655.28	722372.99	1603.61	186336.22	3628.76	127579.39	1176.90	448.50
R-squared	0.5786	0.6379	0.5822	0.5692	0.6012	0.4828	0.6368	0.4393	0.7164	0.4308	0.5364

Note: ***, ** and * indicate that the relevant statistics are significant at 1%, 5% and %10 levels, respectively.

Table 8. Main findings: the model including interaction term (dependent variable $growthpc$)

	whole sample	OECD	non-OECD	below-median	above-median	non-oil	oil-rich	high-income	upper-middle income	lower-middle-income	low-income
$labor$	-0.1477***	0.1405**	-0.1936***	-0.0148	-0.2142***	-0.0429	-0.2486***	-0.2370**	-0.0766	-0.0802	
	(0.0543)	(0.0572)	(0.0648)	(0.0461)	(0.0685)	(0.0633)	(0.0777)	(0.0880)	(0.0664)	(0.1056)	
$capital$	0.0844***	0.1624***	0.0749***	0.1663***	0.0614***	0.1135***	0.0602***	0.1070***	0.1056***	0.0770***	0.0260
	(0.0117)	(0.0388)	(0.0105)	(0.0118)	(0.0108)	(0.0146)	(0.0121)	(0.0174)	(0.0118)	(0.0213)	(0.0147)
$poductivity$	0.5120***	0.6567***	0.4923***	0.6119***	0.3158**	0.4143***	0.5766**	0.6200**	0.9089***	0.3466	0.2162
	(0.1236)	(0.2096)	(0.1245)	(0.1467)	(0.1436)	(0.1318)	(0.2364)	(0.2694)	(0.1272)	(0.2619)	(0.2276)
$concentration$	6.8518***	2.0587	8.0987***	3.9533	8.5088***	6.1623***	9.4171	3.4022	5.2868	6.9327***	18.2733**
	(1.995)	(3.1143)	(2.4496)	(3.4515)	(2.3413)	(1.9478)	(7.0712)	(3.9916)	(5.2414)	(2.2448)	(6.0037)
$concentration$	-0.6969***	-1.5476**	-0.6575***	-1.5989***	-0.3668*	-0.5687**	-0.7783***	-1.2152**	-1.7142***	-0.3933	-0.1822
$* productivity$	(0.2035)	(0.6852)	(0.1949)	(0.4799)	(0.1960)	(0.2282)	(0.2848)	(0.6000)	(0.3747)	(0.4838)	(0.2812)
d_{2009}	-3.2376***	-3.9164***	-2.5010***	-3.0543***	-2.3715***	-3.2348***	-2.6684***	-4.6652***	-3.6424***	-0.4499	-0.0189
	(0.2978)	(0.6789)	(0.3365)	(0.2361)	(0.3091)	(0.2495)	(0.4030)	(0.4265)	(0.4323)	(0.2847)	(0.4869)
$d_{aze\_2005-2007}$	23.9841***		23.9242***	24.0596***			23.8653***		24.2072***		
	(1.8098)		(1.8678)	(1.6087)			(2.1702)		(1.8179)		
d_{gnq_2001}	54.5359***		55.0306***		55.6923***		55.8261***		54.3860***		
	(2.2825)		(2.2993)		(2.4392)		(2.2308)		(1.5868)		
d_{irq_2003}	-39.8052***		-39.4938***		-39.1388***		-39.0525***		-39.6519***		
	(1.8037)		(1.7444)		(1.6989)		(1.7262)		(2.0777)		
d_{irq_2004}	52.1100***		51.6931***		51.2456***		50.8504***		50.8507***		
	(1.2740)		(1.2149)		(1.1130)		(1.1094)		(1.5388)		
d_{irl_2015}	18.1130***	14.4430***			19.0714***	16.8656***		16.7550***			
	(0.6975)	(1.8143)			(0.8253)	(0.6190)		(0.7093)			
d_{lby_2011}	-43.3071***		-44.2567***		-45.3856***		-45.5682***		-42.1531***		
	(3.2756)		(3.2780)		(3.3869)		(3.6314)		(3.4887)		
d_{lby_2012}	89.5086***		89.7380***		90.4454***		90.2009***		88.7211***		
	(2.7339)		(2.7418)		(2.7238)		(3.0033)		(2.9512)		
$d_{syr\_2012-2013}$	-22.2244***		-22.7300***		-23.3430***		-23.4409***				-23.2212***
	(1.1577)		(1.2908)		(1.2632)		(1.7558)				(0.7866)
d_{yem_2015}	-26.1066***		-26.7945***		-27.6277***		-28.2695***				-30.6623***
	(3.0897)		(3.0392)		(2.9029)		(3.2375)				(2.2707)
d_{zwe_2009}	58.2721***		57.7176***		57.9057***	57.5777***				55.6808***	
	(2.7779)		(2.7359)		(2.7342)	(2.7435)				(3.0207)	
$cons$	-0.8116	0.6677	-1.4148	0.8782	-2.6496*	-0.2720	-2.5349	0.5397	0.2998	-1.0356	-11.4766**
	(0.8672)	(1.1480)	(1.2848)	(1.0084)	(1.4163)	(0.8143)	(3.5106)	(1.4195)	(2.3360)	(1.0356)	(4.3408)
F	735757.92	905.66	249188.16	655.28	501314.10	1254.15	112796.64	1462.73	115382.52	1224.12	555.42
R-squared	0.5825	0.6356	0.5897	0.5692	0.6126	0.4769	0.6497	0.3976	0.7272	0.4319	0.5682

Note: ***, ** and * indicate that the relevant statistics are significant at 1%, 5% and %10 levels, respectively.

6. Discussion and conclusions

This study investigates the effect of energy diversification on economic growth for a panel of 131 countries, and their subgroups that differ according to the socioeconomic development level, energy diversification level, oil and natural gas abundance, and income level. Different from the existing literature, this study argues that energy diversification or increased use of clean, renewable, green energy may influence economic growth in different ways. These can be characterized as growth-suppressing effects due to reallocation and growth-promoting or moderating effects through the interaction of increased productivity. Although the issue has not been addressed in this context so far, the results in current literature in the form of negative and positive effects on growth also provide support for this theoretical or logical basis. Furthermore, this study measures energy diversification by the normalized form of Herfindahl-Hirschman index. In the literature so far, in its standardized form the index has been used only by Gozgor and Paramati [24], Ahmed et al. [25] and Liu et al. [4]. Their results indicate that the impact of energy diversification on economic growth may be different in short and long run. This study, on the other hand, takes the discussion a step further by including many more countries and considering that the energy diversification economic growth nexus may vary depending on countries' socioeconomic characteristics, energy diversification levels, oil and natural gas abundances and income levels. In addition, our model includes energy diversification variable and more importantly, energy diversification-productivity growth interaction term.

In the case of estimates covering all 131 countries, our findings from both the GDP growth and GDP per capita growth equations support the growth-suppressing effect of energy diversification and the growth-enhancing effect through the interaction of productivity growth. Estimates of the model, which do not include the interaction term, also supported that energy diversification negatively affects growth. These findings point out that productivity linked consequences should be considered in studies dealing with the impact of energy diversification or increased use of renewable, clean, or green energy sources, on economic growth.

Findings on country groups defined according to different characteristics of countries provide a more in-depth insight into the subject. The hindering effect of energy diversification on economic growth was not supported for OECD, more energy diversified (energy concentration below-median), fossil energy-rich, high- and upper-middle-income countries. This result is thought to be due to the countries' institutional structure that can overcome the negative reallocation effects of energy diversification. The impression regarding institutional structure seems to be plausible for countries that are advanced in terms of socioeconomic development, energy diversification and income levels, and for the oil-rich countries, a significant part of which is also advanced in these features.

In current literature, the negative impact of increased use of renewable energy has been reported by Marques and Fuinhas [27] and Chen et al. [30] and this impact has been linked to rising energy prices reflected by high investment costs or high costs caused by public policies, which slow down the economic activity. However, the negative effect can be more prevalent for countries with weak institutional structures that economic and energy policies are unable to overcome such challenges. Besides, our findings indicating that energy diversification weakens economic growth in non-OECD, above-median, lower-middle- and low-income countries also support this argument. In addition, the magnitude of this effect for low-income countries was found to be higher and this also provides an additional anchor for this claim.

Moreover, our estimates for country groups supported the economic growth-enhancing effect of energy diversification through the interaction of productivity gains except for the lower-middle- and lower-income country groups. In addition, in the comparison of OECD and non-OECD as well as below- and above-median countries, for the first country groups the effect of diversification on growth through the interaction of productivity increase was found to be much stronger. These findings indicate that the institutional, cultural, technological, and legal infrastructure supported by socioeconomic development is important for energy diversification to contribute to economic growth. In addition, the positive effect of the energy diversification-productivity growth interaction variable was supported for high- and upper-middle-income countries, but not for lower-middle- and low-income countries, and this also implies the indicated interpretation. Furthermore, the findings obtained for high- and upper-middle-income countries both are consistent with the predictions of neoclassical growth theory and point to the technological constraints of energy diversification. Namely, the contribution of energy diversification to economic growth through the interaction of productivity increase in high-income countries is found to be weaker than that of upper-middle-income countries, which is consistent with the prediction of the neoclassical growth model that high-income countries are expected to experience slower growth. On the other hand, high-income countries have higher energy diversification than upper-middle-income countries, and the averages of the concentration index calculated for these two country groups are 0.3682 and 0.4061, respectively. Increasing energy diversification at its higher levels may entail higher costs and this may be a reasonable justification for the indicated difference in findings.

Finally, the findings regarding labor force, physical capital and productivity variables were also consistent with generally expectations. Especially, productivity growth was found to significantly affect economic growth in all models.

7. Practical implications

The findings of this study on the energy diversification and economic growth nexus indicate that energy diversification has both growth-suppressing and growth-promoting effects, and that these may differ according to the characteristics of countries. The growth-suppressing effect may arise because of the probable negative market incentives for energy diversification. Therefore, significant government support is thought to be needed for these countries to achieve their diversification targets within the framework of their energy policies. In countries where the negative reallocation effect was not supported and the growth-promoting effect of energy diversification through the interaction of productivity growth was supported, market incentives are thought to work in favor of diversification, thus pointing out that government support is not a necessity.

In addition, the findings for country groups indicate that avoiding the negative effects of energy diversification and the active functioning of its positive effects may be linked to institutional structures of countries. Namely, energy diversification in different institutional structures can provide rooms for inefficient redistribution activities or for activities that promote capital formation and productivity growth. Therefore, it can be argued that institutional development that links productivity growth to solid dynamics is also essential for the growth-supporting effects of energy diversification.

Moreover, the negative impact on economic growth of the transition from fossil or traditional energy sources to clean or renewable energy sources does not take the environmental impacts of the former into account. Namely, national accounting systems do not consider the environmental deterioration caused by fossil fuels while including physical capital depreciation in calculations. Therefore, the negative direct effect of energy diversification on measured growth figures does not necessarily indicate that this effect contradicts long-term sustainability.

8. Limitations and further research

Finally, in the calculation of energy diversification, giving equal weight to each type of energy, namely fossil-based energy types that cause environmental problems, and clean or green energy sources may be the possible limitations of the study. Therefore, to develop an energy diversification indicator, which considers the weights given to energy types on an ecological, environmental or sustainability basis, is thought to provide significant advances in future studies.

Declaration of conflicting interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

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Endnotes

[1] **All countries:** Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Benin, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cameroon, Canada, Chile, China, Colombia, Congo Dem. Rep., Congo Rep., Costa Rica, Côte d'Ivoire, Croatia, Cuba, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Estonia, Ethiopia, Finland, France, Gabon, Georgia, Germany, Ghana, Greece, Greek Cyprus, Guatemala, Haiti, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea Rep., Kuwait, Kyrgyzstan, Latvia, Lebanon, Libya, Lithuania, Luxembourg, Malaysia, Malta, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, North Macedonia, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russia, Saudi Arabia, Senegal, Serbia, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syria, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Türkiye, Turkmenistan, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Uzbekistan, Yemen Rep., Zambia, and Zimbabwe

[2] **OECD countries:** Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye, United Kingdom and United States

[3] **Countries with below-median energy concentration rate:** Argentina, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Cuba, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Hungary, Iceland, India, Indonesia, Italy, Kazakhstan, Korea Rep., Kyrgyzstan, Latvia, Lithuania, Moldova, Mongolia, Netherlands, New Zealand, North Macedonia, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Romania, Russia, Senegal, Serbia, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Thailand, Tunisia, Türkiye, Ukraine, United Kingdom, United States and Uruguay

[4] **Fossil energy-rich countries** : Algeria, Angola, Argentina, Australia, Azerbaijan, Bahrain, Brazil, Brunei Darussalam, Canada, China, Colombia, Congo Dem. Rep., Congo Rep., Denmark, Ecuador, Egypt, Equatorial

Guinea, Gabon, India, Indonesia, Iran, Iraq, Italy, Kazakhstan, Kuwait, Libya, Malaysia, Mexico, Niger, Nigeria, Norway, Oman, Peru, Qatar, Romania, Russia, Saudi Arabia, Sudan, Syria, Thailand, Trinidad and Tobago, Tunisia, Turkmenistan, United Arab Emirates, United Kingdom, United States, Uzbekistan, and Yemen Rep.

[5] **High-income countries:** Australia, Austria, Bahrain, Belgium, Brunei Darussalam, Canada, Chile, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Greek Cyprus, Hong Kong, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Kuwait, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Oman, Panama, Poland, Portugal, Qatar, Romania, Saudi Arabia, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States and Uruguay

[6] **Upper-middle-income countries:** Albania, Argentina, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, China, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Equatorial Guinea, Gabon, Georgia, Guatemala, Indonesia, Iraq, Jamaica, Kazakhstan, Libya, Malaysia, Mauritius, Mexico, Moldova, North Macedonia, Paraguay, Peru, Russian Federation, Serbia, South Africa, Thailand, Turkiye and Turkmenistan

[7] **Lower-middle-income countries:** Algeria, Angola, Bangladesh, Benin, Bolivia, Cameroon, Congo Rep., Cote d'Ivoire, Egypt, El Salvador, Ghana, Haiti, Honduras, India, Iran Islamic Rep., Jordan, Kenya, Kyrgyz Republic, Lebanon, Mongolia, Morocco, Myanmar, Nepal, Nicaragua, Nigeria, Pakistan, Philippines, Senegal, Sri Lanka, Tajikistan, Tanzania, Tunisia, Ukraine, Uzbekistan, Zimbabwe

[8] **Low-income countries:** Congo Dem. Rep., Ethiopia, Mozambique, Niger, Sudan, Syria, Togo, Yemen Rep., and Zambia