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Economic growth, energy consumption and environmental degradation nexus in heterogeneous countries: does education matter?

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Abstract

Background: Environmental concerns are growing globally. The world has suffered severe environmental deterioration over the years. Undeniably, the impact of environmental degradation on the earth's geographical space is alarming, making environmental stakeholders to be worried. Existing literature has examined several factors affecting the environment, but the focus has now shifted to education and the need to maximize its potentials. Although studies have examined the direct impacts of education on the environment, those investigating its moderating role are relatively new and scarce, particularly across income groups. Understanding the channel through which education might affect the environment requires the knowledge of its moderating role. Therefore, this study employs FMOLS, DOLS, ARDL-PMG, CCEMG and heterogeneous panel causality test methodologies to investigate the direct and moderating effects of education in the growth-energy-environment linkages in heterogeneous income groups of 92 countries from 1985 to 2018.

Results: The findings of this study indicate that economic growth is a long-term solution to environmental deterioration in high and upper-middle-income countries, while the opposite holds for lower-middle-income and low-income countries. In addition, energy consumption is linked with environmental degradation across all income groups. Also, the study finds that education's direct effects aggravate environmental degradation across all income groups. Moreover, its moderating role ameliorates the adverse effects of energy consumption on environmental degradation in high and upper-middle-income groups but worsens it in the lower-middle-income and low-income groups.

Conclusion: This study examines the role of education in economic growth, energy consumption and environmental degradation nexus. The study concludes that education is important for environmental sustainability as it encourages pro-environmental behaviors and attitudes and supports energy-efficient products and investments in green technologies. However, education may also aid energy-intensive activities and dirty technology by supporting lifestyles that are not eco-friendly. It is important, therefore, to provide education that promotes better environmental quality.

Keywords: Environment degradation, Economic growth, Education, Moderating role

JEL: Q40, Q50, Q56, I210

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Introduction

The world has suffered severe environmental deterioration over the past two decades. Undeniably, the impact of the ecological distortions and environmental degradation on the earth's geographical space is alarming, causing environmental stakeholders and environmentalists to be highly concerned. From being just a bunch of environmental issues, these problems have resulted in environmental disasters, such as extreme weather events and rising sea levels. Due to that, countries are under pressure, striving to address environmental crises and simultaneously sustain economic growth [49]. Fundamentally, it is believed that the destruction of many countries' ecosystems is the consequence of human actions, including rapid industrialization, growing population, expansion in economic activities, urbanization and widespread consumption of fossil fuels [17, 20, 22, 48, 67]. Undoubtedly, one of the major contributors to climate change and environmental degradation is carbon dioxide (CO2) emissions [12, 20, 22].

The concerns of environmental stakeholders have spurred researchers to examine the factors affecting environmental degradation and offer solutions to environmental problems [1, 5, 21, 23, 24, 32, 50, 60, 68]. Many of these research attempts were conducted within the Environmental Kuznets Curve (EKC) hypothesis, pioneered by Grossman and Krueger [30]. The EKC linked environmental degradation to economic growth. It hypothesizes that the tendency of environmental degradation to rise during the early stages of economic growth is high and that after a certain threshold, economic growth and environmental degradation decline [26, 61, 64].

As it becomes increasingly clear the extent to which human activities have affected the environment, attention has begun to turn to education and the need to tap its potential. Education could directly affect the environment by creating awareness and encouraging individuals to protect their environment. For instance, educated individuals are likely to be more concerned about the environment and support environmental policy decisions. Education could also affect the environment by moderating energy consumption and encouraging people to lessen their environmental impact through more efficient energy use. Noticeably, education is a primary channel of knowledge, values, and skills acquisition, changing humans' environmental behaviors and attitudes to address climate change and environmental degradation challenges. Indeed, education provides an endless entryway to information and contributes to a better understanding of complex environmental messages. Correspondingly, it is identified that education raises environmental awareness, fosters an in-depth sense of responsibility, steers people away from environmentally harmful conduct, motivates individuals to use energy resources more efficiently and supports environmental policies [13, 16, 31, 46, 64, 66, 77]. However, education could generate adverse effects on the environment and pro-environmental behavior, such as increasing the consumption of non-renewable resources and access to polluting technologies, which leads to negative repercussions on the environment (see [6, 25, 36, 65]).

Figure 1 shows the possible transmission channels among the variables. Education shows two opposing effects. First, education promotes environmental awareness, which in turn encourages the pro-environmental behaviour of the people. The pro-environmental behaviour of the people leads to support for environmental policy and efficient use of energy. Additionally, educated people are expected to earn more income, putting them in better positions to support environmental policy. However, the second opposing effect of education encourages people to consume more non-renewable energy and gives them more access to polluting technologies, increasing environmental degradation.

The flow of Fig. 1 from the left-hand side shows that education leads to environmental awareness, pro-environmental behavior (which also leads to support for environmental policy), and efficient energy consumption. All of which lead to a reduction in environmental degradation (minus arrow). From the middle: Educated individuals earn improved income, enabling them to support environmental policy, which reduces environmental degradation (minus arrow). From the right-hand side: Education can make individuals increase their consumption of non-renewable energy and access to polluting technologies, increasing environmental degradation. The two arrows from the bottom show that when the EKC is confirmed, economic growth first increases environmental degradation, gets to a turning point and starts reducing it (meaning that economic growth is a solution to environmental degradation). In contrast, when the EKC is not valid, economic growth first reduces environmental degradation at an early stage, gets to a point, and starts increasing it (meaning that economic growth is not a solution to environmental degradation).

Studies have considered the direct impact of education and how it affects the environment. However, most of these studies do not consider the moderating role of education. The moderating role of education has essential policy outcomes as it provides invaluable insights to policymakers. The moderating role of education is necessary to examine how education could affect the environment through its interaction with energy consumption, thereby enabling informed policy formulation and implementation that can be better attuned to yield maximum impact. Only recently, the study of Katircioglu et al. [38] empirically considered the moderating role of education on energy consumption as one of the potential

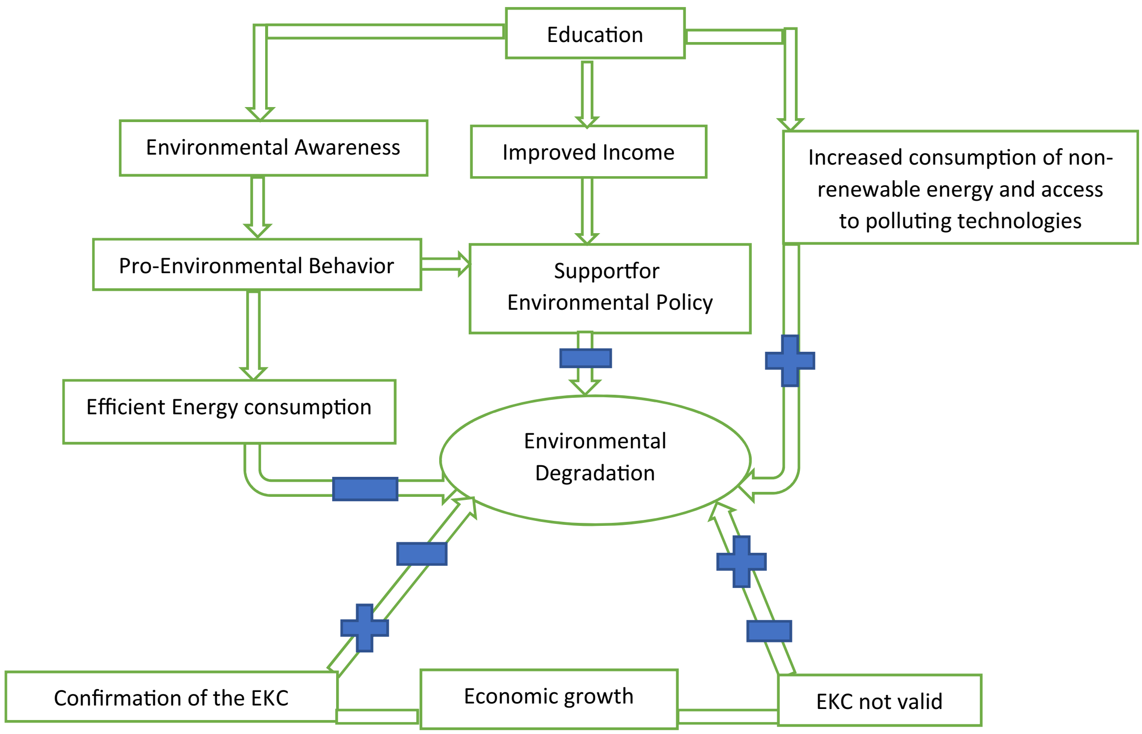

Fig. 1 Possible transmission channels among the variables

environmental degradation determinants. However, the study only focused on Cyprus. Therefore, the present paper examines the direct and moderating effects of education in growth-energy-environment relationships for four income groups. Classifying the countries into income groups is necessary since the countries that make up the global economy are diverse, and one major indicator to classify this diversity is income. Also, people's attitudes toward the environment may vary between different income groups [18, 29], hence the need to verify whether empirical findings differ among the groups [21].

This present study differs from earlier ones and adds to the existing knowledge because it would be the first to examine the moderating role of education in heterogeneous income groups as far as is known. This study categorizes the study countries into different income groups based on the World Bank's latest classifications. The study explains the differences in environmental quality among the income groups and gives specific recommendations for effective policy formulation. Additionally, this study calculates the marginal effects for all the income groups and examines causal relationships by employing a test that accounts for cross-sectional dependence and heterogeneity, which Katircioglu et al. [38] did not consider. Thus, it provides evidence of education's direct and moderating effects on environmental degradation based on income groups. The important findings in this study give a new viewpoint on the relationships between economic growth, energy consumption and environmental degradation. More relevantly, it offers insights and updated policy support for effective policy formulation to improve environmental quality.

The remainder of this paper is organized in the following manner: "Literature review" section assesses related literature, "Methodology and data" section summarizes the methodologies, and "Empirical results & discussion" section analyses the data and deliberates the key findings. The last section concludes and makes policy recommendations.

Literature review

The alarming pattern of environmental problems is giving concerns to environmental stakeholders globally. Researchers and policymakers have endeavored to understand and identify the primary causes of these problems and forecast their future direction. Accordingly, such efforts have prompted a rise in studies that concentrate on discovering environmental degradation determinants. Most of the studies focused on the environmental impacts of growth and energy consumption. However, few other studies considered education as one of the potential environmental determinants.

In detail, many studies have examined the impacts education has on the environment in the past and found that education promotes pro-environmental conduct and behavior in various circumstances. For instance, it is noted that educated individuals are more inclined to reduce, reuse, and recycle [27, 42, 62, 76]. Other studies have found that people with education are more likely to make better consumption choices, such as buying eco-labeled and energy-efficient items, as well as exhibiting energy-saving behaviors [10, 43, 69]. At the same time, existing literature has demonstrated that individuals with solid educational backgrounds have a stronger possibility of adopting energy-efficient behaviors [59].

Furthermore, there is empirical evidence that pro-environmental attitudes are highly associated with one's educational experience. For instance, it is uncovered that better-educated people are steadily keen to play a part in supporting green electricity and sacrificing financial well-being to enrich the environmental quality and report environmental concerns [15, 72]. Equally important, many findings described a positive relationship between education and one's willingness to support emissions reduction policy, renewable energy and environmental protection through higher payment of taxes [9, 40, 78].

However, some studies indicated that education levels generate adverse effects on the environment and pro-environmental behavior, such as increasing the consumption of non-renewable resources and access to polluting technologies, which leads to adverse repercussions on the environment [25, 36, 65]. At the same time, other studies indicated that a higher percentage of people in high-income countries prefer general environmental protection to economic growth and tend to prioritize environmental goals than those in low-income countries [18, 29]. More education can improve environmental awareness and regulations concerning natural resources usage and energy consumption, thereby improving environmental quality. Inglesi-Lotz and Morales [35] explains how education could affect energy consumption. Education increases the awareness level in any economy. This increased awareness could enable energy consumers to make informed and better decisions concerning energy consumption, which, in turn, may lead to a reduction in energy consumption.

More studies have examined the roles of education on environmental degradation in recent times. Chankrajang and Muttarak [13] revealed that acquiring knowledge relevant to environment-friendly behavior results in pro-environmental actions, which in return, facilitates reducing CO2 and protecting nature. Furthermore, education is essential to understand climate change globally and its associated adverse outcomes. Similarly, Balaguer and Cantavella [6] employed higher education data within the EKC framework for Australia and found education to improve environmental quality. Chankrajang and Muttarak's findings on the positive influences of education on environmental quality and pro-environmental behavior are also widely restated in other studies. For example, educated individuals are more mindful and conscious of the external impacts of their behaviors and, thus, more concerned with social welfare in Europe [47].

Similarly, education was found to improve the environment in Australia [6], Turkey [26], Organization for Economic Co-operation and Development (OECD) [73, 74], and the Asia–Pacific Economic Cooperation countries [75]. On the other hand, [73, 74] found that education increases environmental degradation to a certain level, improving environmental quality. In the same vein, Mahalik et al. [44] revealed that primary education degrades the environment in Brazil, India, China, and South Africa, while secondary education improves it.

In considering the indirect role of education, Katircioglu et al. [38] examined the direct and moderating effects of higher education on the environment through energy consumption for Cyprus. The results showed that education's direct effect and its moderating role on energy consumption negatively affect the environment. Similarly, Subramaniam et al. [63] investigated the environmental impacts of education and poverty in 22 developing nations. The study observed that the negative consequences of poverty on the environment could be mitigated if education attains an exceptionally high threshold. The study also found that improvement in education minimizes environmental destruction by the poor.

Several studies also utilized education as a proxy for human capital but reported mixed results. For example, human capital was found to mitigate environmental degradation [4, 39, 45, 52] without decreasing economic growth [8]. However, this position was debunked by studies such as Zhang et al. [77] and Ahmed et al. [3], which revealed that human capital degrades the environment. At the same time, Danish et al. [14] reported a non-existent effect of human capital in improving environmental quality. Conversely, Tang et al. [64] analyzed both direct and indirect roles of human capital in 114 nations and uncovered that human capital substantially influences renewable energy consumption.

Analyzing the literature on education shows that most studies established its direct relationship with the environment. However, the conclusions of these studies on the effect of education on pro-environmental attitudes and behaviors are mixed. For example, most literature indicates that education mitigates environmental degradation and enhances pro-environmental attitudes and behaviors. Others found that education is detrimental to environmental quality. According to them, educated people are more supportive of environmental policy measures. Few found no link between education and the environment. Katircioglu et al. [38] appears to be the only notable study that assessed the moderating role of education through its interaction with energy consumption, specifically for Cyprus.

Tang et al. [64] investigated the effects of the interaction of human capital (measured as average years of schooling) with renewable energy consumption for 114 countries but without considering their income group classifications. Such inclusion of countries with varying income levels in the same panel may result in inaccurate estimation and could be inadequate for policymaking since the countries' income levels may have important environmental implications. Also, the study only examined renewable energy. Examining only renewable energy for a study of this nature may underestimate the impacts of energy consumption on the environment because most economies rely on fossil fuels.

In addition, the link between education and environmental degradation may be weak when measured by years of schooling. Human capital proxied by average years of schooling provides little insight. It does not, unlike gross enrolment, reflect the capacity of each level of the education system. The disparity between gross enrollment and average years of schooling is pronounced in many countries. For example, according to data from the World Bank, most countries in our analysis have similar and constant years of education. However, the discrepancies in gross enrolment of these countries are substantial and vary from year to year. As a result, gross school enrollment is a better measurement, and it is used in this study.

This present study addresses these issues by examining the effects of education's direct and moderating roles with total energy consumption on environmental degradation in different income groups.

Methodology and data

Model specification

This paper employs the EKC hypothesis to examine the impacts of economic growth and energy consumption on environmental degradation while controlling for the education variable. Given the aim of this study and following previous studies [20, 22, 38], the following model is specified for the direct impact of education:

$$\begin{aligned} CO2_{it} = &\beta_0 + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 \\ &+ \beta_3 ENG_{it} + \beta_4 EDU_{it} + \mu_{it} \end{aligned} \tag{1}$$

where CO2 is the ln of carbon emissions (in metric tons), as a proxy for environmental degradation, ENG is the ln of energy consumption (in a million tonnes of oil equivalent) per capita, GDP is the ln of real Gross Domestic Product per capita (2010 constant prices) as a proxy for economic growth, GDP^2 is GDP squared, EDU is the ln of education measured as gross primary school enrollment and μ_{it} the error term. All variables are in natural logs (ln). We use primary education enrollment to measure education. This choice is because primary education is the first step in making an individual's character. It ensures the broad-based learning of an individual, including developing social, cultural, emotional, cognitive, and physical skills [70]. As one of our interests is to ascertain the moderating role of education on environmental degradation, we extend Eq. (1) by including the interaction variable of education and energy consumption [38, 51] as follows:

$$\begin{aligned} CO2_{it} = &\beta_0 + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 ENG_{it} \\ &+ \beta_4 EDU_{it} + \beta_5 (ENG * EDU)_{it} + \mu_{it} \end{aligned} \tag{2}$$

where ENG*EDU is the interactive term of the logs between energy consumption and education.

Theoretically, β_1 is expected to be positive, while β_2 is negative to confirm the EKC hypothesis (inverted U-shaped curve). On the contrary, if β_1 is negative while β_2 is positive, then the EKC hypothesis is not validated (U-shaped curve). A priori, we expect economic growth and energy consumption to increase environmental degradation, whereas education and its moderating variable are expected to mitigate it. From Eq. (2), we can calculate the marginal effects of education on environmental degradation by partial derivation:

$$\frac{\partial CO2_{it}}{\partial ENG_{it}} = \beta_3 + \beta_5 EDU_{it} \tag{3}$$

Data

This study employs annual unbalanced data for 92 heterogeneous countries from 1985 to 2018. The availability of data determines the period and countries included in the study. Data on carbon emissions and energy consumption (converted into per capita form) are obtained from Energy Information Administration (2020) database, while the remaining series are from the World Development Indicators (2021). We classify the countries into four income groups based on the World Bank classifications. These are high-income countries (HIC hereafter), upper-middle-income countries (UMIC hereafter), lower-middle-income countries (LMIC hereafter), and low-income countries (LIC hereafter). We examine these income groups to understand the determinants of environmental degradation from the global perspective and compare these groups to understand better how to tackle environmental degradation. The included countries are listed in Table 11 (see Appendix).

Estimation strategy

This study begins with a descriptive analysis, followed by correlation analysis, panel unit root test, cointegration and cross-sectional dependence (CD) test[1] [49]. The unit root is examined using both 1st- and 2nd-generation tests. The tests are IPS test [34], Pesaran test [55, 56], ADF-Fisher test [28] and LLC test [41]. To test the CD, we employ the Breusch-Pagan LM test [11], Bias-corrected scaled LM test [7], Pesaran scaled LM test and Pesaran CD test [55]. We employ the Fully Modified Ordinary Least Square (FMOLS) [53, 54] and the Dynamic Ordinary Least Square (DOLS) [37] to assess the long-run association among the variables. The FMOLS and DOLS are very efficient in estimating cointegrating panels. Next, we use the Pedroni and Kao cointegration tests to ascertain the cointegration among the variables.

Also, we employ the Pooled Mean Group (PMG) [57] to complement FMOLS and DOLS estimations and check the estimation's robustness. PMG is preferred because it gives short-run and long-run estimates and provides additional information concerning the relationship of the estimated indicators. Interestingly, the PMG estimation uses the cointegration form of the ordinary ARDL model, as shown by Pesaran et al. [57]. Furthermore, we employ the Common Correlated Mean Group (CCEMG) estimator. Next, we compute the marginal effects of energy consumption on environmental degradation at different levels of education. Finally, we examine the causal links among variables using the Dumitrescu and Hurlin [19] panel causality test. The test accounts for both CD and heterogeneity.

[1] CD is present in panel data as a result of intra- and inter-country links. The estimates must be devoid of cross-sectional dependence to get consistent and unbiased results [58]. Therefore, it is necessary to test the CD in the panel data.

Empirical results & discussion

Empirical results

Table 1 details the descriptive statistics and correlation coefficient matrix of the variables. The standard deviations of most of the variables show huge variations, indicating wide dispersion from their means, except for CO2 and energy consumption variables which are not too dispersed from their means in the low-income group. The pairwise correlation coefficients shown in the lower panel of the Table reveal that most variables are positive, except the education variable, which is negatively correlated with economic growth and energy in the HIC, CO2 and energy in the UMIC. In contrast, economic growth is negatively correlated with CO2 in the LIC.

The panel unit root findings are presented in Table 2. The results suggest that the panel has unit roots and the variables are I (1) in all the income groups. While the Pesaran and LLC tests indicate that some variables are stationary at the level, other tests reveal that they have unit roots. As a result, we conclude that they are non-stationary at the level, which permits us to utilize the FMOLS and DOLS because the methods were designed to estimate co-integrating relationships with a mix of I (1).

Next, we utilize the Pedroni cointegration test in Table 3. The test proposes seven test statistics. A good number of these test statistics confirm the cointegration among the variables in each income group. For robustness check, we use the Kao panel cointegration test. The test also confirms cointegration in all the income groups. Therefore, we conclude that cointegration exists among the variables of the study. This result implies that the variables move together in the long-run, and their long-run relationships can be estimated using FMOLS and DOLS to ascertain their long-run relationships. Table 4 reports the CD test results. The results reject the null hypothesis of no cross-sectional independence.

Table 5 presents the FMOLS results. We estimate two models. The first model assesses the direct impacts of economic growth, energy consumption and education, whereas the second model includes the interaction term of energy and education.

Discussion

The findings in Table 5 show that the estimated coefficients for economic growth are positive in the FMOLS estimation. Economic growth's detrimental impact on emissions is that many countries have experienced tremendous development in recent decades, which has increased the demand for energy. Notably, the excessive reliance on fossil fuels in the primary sector and the transfer to the secondary industry add fuel to the fire.

Furthermore, the growth of infrastructure development and the increase in the consumption of goods and services contribute to environmental degradation. However, the squared terms of economic growth coefficients are negative and statistically significant for HIC and UMIC. These results confirm an inverted U-shape link between economic growth and environmental degradation, validating the EKC hypothesis. The results indicate that the environments in the HIC and UMIC are degraded at the initial stages of economic growth. Nevertheless, as the economy expands, environmental quality begins to improve. This finding demonstrates the importance of economic growth in reducing CO2 emissions and improving environmental quality in HIC and UMIC. This finding is in line with earlier studies (e.g., [1, 64, 73, 74, 77]).

In comparison, the economic growth coefficients for LMIC and LIC are negative, whereas the coefficients of their squared terms are positive and statistically significant. These results suggest that the EKC hypothesis does not hold for these income groups. This finding supports the existence of a U-shaped association between economic growth and environmental degradation in LMIC and LIC. For this reason and contrary to the EKC hypothesis, economic growth is not a panacea for LMIC and LIC environmental concerns. This outcome aligns with previous studies (e.g., [2, 52]). The differences in the effects of economic growth on the environment between HIC/UMIC and LMIC/LIC could be due to the differences in their income levels. For instance, the mean income is $32,756.230 for the HIC, $5229.194 for UMIC, $1774.959 for LMIC and $493.820 for the LIC between 1985 and 2018.

Also, it is found that the coefficients of energy consumption are positive in all the income groups. These results indicate that energy consumption is another factor contributing to global environmental deterioration. The world has been experiencing a rise in energy demand. A sizeable portion of this demand is through the combustion of fossil fuels [33]. Consequently, energy consumption is contributing highly to global environmental degradation. This finding is consistent with previous research on the effects of total energy consumption on environmental degradation [1, 26, 38, 44] but differs from some, which found that renewable energy consumption decreases environmental degradation [64, 75].

Surprisingly, the coefficients of the education variable are positive and statistically significant in all the income groups except in UMIC, which implies that the direct impact of education contributes to environmental degradation in HIC, LMIC and LIC. This outcome can be attributed to the fact that many educated individuals may be unaware of the environmental effects of their actions, and even if they are, they may be unconcerned about the environment as long as they can achieve their personal goals. In consequence, they recklessly generate negative externalities that undermine environmental quality. In such situations, it is logical to assume that education enables access to more pollution-intensive technologies and a comfortable lifestyle, increasing the production and consumption of goods and services. Thus, education in the absence of training for energy-saving and targeted environmental awareness programs derives environmental degradation [3]. These findings support the notion that education cannot reduce environmental degradation without an environmental-friendly syllabus. This finding aligns with previous studies [3, 38, 44], indicating that primary education negatively influences the environment in Brazil, Russia, India, China and South Africa (BRICS) countries. However, the finding does not agree with other studies, which discovered that education reduces environmental degradation [6, 26, 73–75].

Having established the direct impacts of education, we examine its moderating effects. As expected, the interaction term coefficients are negative and statistically significant in HIC and UMIC. This finding implies that education can transform the detrimental effect of energy consumption into a mitigating impact on the environment. The interaction term between energy consumption and education has a negative coefficient, implying that education improves environmental quality. Individuals with education are more likely to steer away from environmentally destructive behavior toward more efficient energy resources [64]. Eventually, efficient energy resources improve environmental quality and protect the environment in HIC and UMIC.

Conversely, the finding indicates that the interaction term coefficients are positive and statistically significant for LMIC and LIC. This finding implies that education unfavorably moderates the impacts of energy consumption on the environments in these income groups. Education is likely to increase non-renewable resources and enable access to energy-intensive technology. This conclusion can be ascribed to the fact that many nations, particularly the LIC, lack educational programs focused on environmental sustainability. Thus, environmental damage might result from education without energy-saving content and specialized environmental awareness programs [3]. This finding aligns with that of Katircioglu et al. [38].

Robustness check

We utilize the PMG-ARDL technique to check the robustness of our estimation results. The long-run results presented in Tables 5 and 6, are similar to those of PMG-ARDL in Table 7. The coefficients are relatively similar in size, signs, and significance. The results confirm that our estimates are robust. The short-run results of the PMG-ARDL reveal significant positive relationships between energy consumption and environmental degradation in all the income groups, indicating that energy consumption degrades the environment in the four income groups. The remaining variables are not statistically significant, except education which is negatively related to environmental degradation for LMIC. The PMG-ARDL results show different convergence speeds toward the equilibrium path for both the direct and indirect models (Table 7). The convergence speeds are 19.1% and 22.7% (HIC); 19.2% and 43.5% (UMIC); 19.9% and 20.0% (LMIC); 24.5% and 25.4% (LIC), for the direct and indirect models respectively. We also employ the CCEMG to account for the CD. The results of the CCEMG in Table 8 are fairly similar to those of other estimations (FMOLS, DOLS, PMG-ARDL).

Marginal effects

Table 9 shows the marginal effects for all the income groups, evaluated at the minimum, mean, and maximum education values. The calculation is based on the FMOLS results.The finding indicates that the marginal effects are statistically significant for all income groups. The marginal effects of education are negative in HIC and UMIC, irrespective of education levels. The marginal effects become larger as education increases. These findings imply that the detrimental impact of energy consumption on environmental degradation reduces as more people are being educated. The result further suggests that a quality education curriculum with environmental awareness content would increase environmental knowledge and encourage eco-friendly behavior, processes, systems and technologies.

In contrast, it is revealed that the marginal effects are positive and increasing with education levels in the LMIC and LIC. The results imply that increased school enrollment exacerbates the adverse effects of energy consumption in these income groups. The finding could be due to the lack of environmental awareness content in the school curriculum of these countries. It could also be due to their learning process. For instance, the low- and middle-income countries have made immense headway in getting children into school, but learning is not assured. About 53% of children in these countries cannot read and understand a short story by the time they are completing primary school [71].

Causality test

The findings of the causality test are reported in Table 10. The test is necessary to ascertain the causal direction among the variables for policymaking. The results show a two-way causality between economic growth and environmental degradation in the HIC, UMIC and LMIC, confirming the feedback hypothesis, whereas the results show a unidirectional causal link in the LIC. The causality between energy consumption and environmental degradation is bidirectional for the HIC, LMIC, and LIC, while there is no causal link for the UMIC [44]. The feedback hypothesis is found between education and environmental degradation for all income categories, except for the LIC, which reveals a unidirectional relationship between environmental degradation and education. A similar finding is reported in Zafar et al. [75]. In HIC and LMIC, a bidirectional causal link exists between energy consumption and economic growth, consistent with [73, 74] while in UMIC (economic growth to energy) and LIC (energy to economic growth), a unidirectional causal relationship exists.

Additionally, the findings support a feedback hypothesis between education and economic growth in the UMIC and LMIC. In contrast, the outcomes show a one-way causality from economic growth to energy consumption in HIC and LIC. Similarly, the causal link between education and energy consumption is bidirectional in the UMIC and LMIC but unidirectional in LIC from education to energy consumption. The neutrality hypothesis is confirmed for HIC, implying that education does not affect energy consumption. The bidirectional causality between environmental degradation and the income groups' variables shows that these variables affect the environment, supporting our earlier long-run estimations.

Conclusion and policy implications

In the last few decades, researchers have made tremendous efforts to uncover the major causes of environmental degradation. Environmental degradation has been linked to a wide range of variables. However, research into the potential moderating effects of education on environmental deterioration has remained largely unexplored. This knowledge gap underscores the significance of this study. We used data from 92 countries between 1985 and 2018 to investigate education's direct and moderating effects in growth-energy-environment linkages. The countries are categorized into four income groups based on World Bank classifications. We employ the FMOLS approach in conjunction with the DOLS and PMG-ARDL methodologies. We also compute education's marginal effects. Finally, we use heterogeneous panel causality to investigate the variables' causal linkages. The paper's empirical findings yield several interesting inferences with substantial policy implications.

For the HIC and UMIC, our finding validates the EKC hypothesis. However, the finding could not confirm the EKC hypothesis for the LMIC and LIC, indicating that economic growth is not, on its own, a magic wand capable of solving environmental problems in the LMIC and LIC. In addition, energy consumption contributes to environmental deterioration in all income groups. Similarly, education directly affects the environment in all income groups except UMIC. However, the moderating effect of education is shown to mitigate the negative environmental impact of energy consumption in HIC and UMIC but exacerbates it in the LMIC and LIC.

Policy implications of our findings show that economic growth is one of the silver bullets for reversing environmental degradation in HIC and UMIC. Countries in these income groups should prioritize economic growth measures and address environmental issues in their development agendas. Nonetheless, the HIC and UMIC should employ more innovative, energy-efficient, and environmentally friendly technology, particularly in the industrial sector, to boost economic growth and improve overall environmental quality.

The non-validity of the EKC hypothesis in the LMIC and LIC, on the other hand, implies that economic growth is not a solution to environmental deterioration in these income groups. As a result, effective policies are essential to bringing about a significant and timely reduction in environmental degradation. However, governments in LMIC and LIC should not stifle growth by enforcing stringent environmental rules that jeopardize possible future growth. Governments should instead devise methods for shifting away from non-renewable energy consumption and toward renewable energy usage.

The adverse environmental effects of education across income groups demonstrate that education does not always translate into more environmentally responsible behavior or improved environmental quality. As a result, environmental education must be included in their school curriculum. However, in HIC and UMIC, education has been demonstrated to play a moderating role in mitigating the detrimental effects of energy use on the environment. As a result, countries in these income categories should continue to embrace environmental education to improve environmental quality, as education may motivate individuals to utilize energy more efficiently. On the other hand, in LMIC and LIC, where education's moderating roles aggravate environmental deterioration, the education curriculum should be transformed to include environmental knowledge, skills, and the necessary mindset to enable energy-efficient behaviours that reduce environmental degradation.

The existence of bidirectional links between the variables shows that they are mutually dependent. As a result, environmental education in the school curriculum and attracting clean and energy-efficient technology while encouraging economic growth should be implemented to lessen their feedback effects. Furthermore, the confirmation of unidirectional causality from economic growth, energy consumption, and education to environmental deterioration suggest that these countries advance at the expense of the environment. Consequently, policymakers should develop policies to reduce their detrimental environmental impacts. Similarly, the unidirectional causality between education and energy consumption implies that education supports increasing energy consumption. Hence, individuals should be educated on using energy efficiently.

To summarise, governments and other environmental stakeholders across the income groups should realize that there exists no one-size-fits-all strategy for solving environmental problems. Instead, it is a combination of policies formulated to stimulate economic growth and enhance environmental quality while focusing on education. Education is critical for environmental sustainability as it cultivates pro-environmental behaviors and attitudes and encourages energy-efficient products and investments in green technologies. However, education may also promote energy-intensive activities and dirty technology by supporting lifestyles that are not particularly eco-friendly. Therefore, it is essential to provide education that aids better environmental quality. We propose that governments and policymakers in these economies continue to invest in environmental education, encourage clean energy usage, promote pro-environmental behavior, and reduce the adverse effects of energy consumption on the environment. Future research should consider other variables, such as educational policies, quality of education, and their moderating effects.

Appendix

See Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11.

Table 1 Descriptive statistics and correlation analysis results

Variable	CO2	GDP	ENG	EDU
High-income				
Mean	292.950	32,756.230	4.658	102.506
Max	6003.095	92,119.52	16.387	128.644
Min	0.3	2762.764	0.3538	68.608
Std. Dev	916.449	18,113.720	2.750	6.306
Correlation coefficients				
CO2	1			
GDP	0.464	1		
ENG	0.339	0.765	1	
EDU	0.004	− 0.113	− 0.121	1
Upper middle income				
Mean	355.666	5229.194	1.241	105.967
Max	10,837.43	15,190.1	4.045	130.478
Min	0.060	537.578	0.192	72.094
Std. Dev	1349.520	2481.472	0.785	8.988
Correlation coefficients				
CO2	1			
GDP	0.135	1		
ENG	0.503	0.614	1	
EDU	− 0.085	0.036	− 0.127	1
Lower middle income				
Mean	57.894	1774.959	57.922	99.014
Max	2227.675	4828.626	50,487.68	149.957
Min	0.019	1.495	0.015	5.002
Std. Dev	225.218	1015.760	1703.862	18.944
Correlation coefficients				
CO2	1			
GDP	0.061	1		
ENG	0.367	0.380	1	
EDU	0.021	0.416	0.055	1
Low-income				
Mean	1.564	493.820	0.054	85.767
Maximum	11.496	913.092	0.260	156.404
Minimum	0.1	164.337	0.013	21.708
Std. Dev	1.659	183.782	0.043	35.913
Correlation coefficients				
CO2	1			
GDP	− 0.023	1		
ENG	0.349	0.497	1	
EDU	0.223	0.226	0.392	1

Table 2 Panel stationarity tests results

Variables	LLC	IPS	ADF-Fisher	Pesaran
High-income				
CO2	0.095	3.712	29.178	2.401
GDP	− 2.992***	− 0.397	67.961	− 1.422*
ENG	− 2.053**	2.561	37.858	2.925
EDU	− 3.596***	-3.036	124.757***	− 2.586**
ΔCO2	− 7.147***	-14.840***	320.912***	− 16.567***
ΔGDP	− 10.073***	-10.702***	227.706***	− 9.524***
ΔENG	− 7.556***	− 15.136***	329.377***	− 14.233***
ΔEDU	− 8.546***	− 10.324***	217.784***	− 7.235***
Upper-middle-income				
CO2	− 1.339*	0.939	35.953	− 1.434*
GDP	−1.195	3.731	27.362	− 2.957**
ENG	− 1.711**	0.343	35.467	− 1.221
EDU	− 0.274	0.633	33.804	− 1.302*
ΔCO2	− 6.603***	− 10.674***	189.351***	− 10.257***
ΔGDP	− 11.954***	− 12.847***	240.669***	− 7.424***
ΔENG	− 6.272***	− 10.177***	180.363***	− 8.623***
ΔEDU	− 4.990***	− 6.672***	123.632***	− 6.493***
Lower-middle-income				
CO2	− 1.249	− 0.622	61.783	− 1.280*
GDP	3.180	3.678	42.979	− 0.312
ENG	2.504	0.832	55.263	− 0.719
EDU	2.731	2.410	60.633	− 1.771**
ΔCO2	− 9.741***	− 15.711***	324.675***	− 14.274***
ΔGDP	− 4.706***	− 8.000***	224.521***	− 7.208***
ΔENG	− 10.814***	− 14.546***	333.087***	− 11.929***
ΔEDU	− 5.210***	− 8.436***	218.124***	− 6.016***
Low-income				
CO2	0.584	0.418	15.837	0.584
GDP	0.163	0.862	18.322	1.314
ENG	1.567	1.170	19.774	1.567
EDU	− 0.903	1.129	27.935	− 0.132
ΔCO2	− 7.677***	− 10.986***	146.623***	− 7.677***
ΔGDP	− 5.232***	− 8.328***	110.059***	− 8.962***
ΔENG	− 13.615***	− 15.690***	223.887***	− 13.615***
ΔEDU	− 1.996**	− 3.137***	48.925***	− 5.579***

***, **, and * indicate statistically significant at 1%, 5%, and 10%, respectively

Table 3 Results of Cointegration Tests

Pedroni Residual Cointegration Test

Variable	High-income		Upper-middle-income		Lower-middle-income		Low-income	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Panel v-Statistic	2.889***	1.757**	0.572	− 0.474	3.462***	2.893***	1.055	0.966
Panel rho-Statistic	− 2.227**	0.583	− 0.122	1.491	− 1.579*	0.679	− 1.239	0.083
Panel PP-Statistic	− 12.128***	− 12.821***	− 3.626***	− 3.109***	− 7.872***	− 6.013***	− 6.644***	− 5.178***
Panel ADF-Statistic	− 4.460***	− 4.763***	− 0.144	1.461	− 3.363***	-0.674	− 6.691***	− 1.966**
Group rho-Statistic	1.801	3.691	1.585	3.082	1.853	3.354	0.500	1.889
Group PP-Statistic	− 7.955***	− 8.339***	− 3.948***	− 5.005***	− 5.952***	− 5.863***	− 5.624***	− 4.476***
Group ADF-Statistic	− 4.601***	− 4.204***	− 2.634***	− 3.191***	− 2.312**	− 0.964	− 5.241***	− 2.319**
Kao Cointegration Test (ADF)	− 3.111***	− 3.241***	− 3.078***	− 3.205***	2.164**	1.572*	− 1.954**	− 3.303**

*** , **, * represents a statistical rejection level of the null of no cointegration at 1%, 5% and 10% significance levels, respectively

Table 4 Results of cross-sectional dependence tests results

Test	High-Income	Upper-Middle-Income	Lower-Middle-Income	Low-Income
Breusch-Pagan LM	5312.836***	2331.681***	6742.483***	1106.464***
Pesaran scaled LM	158.967***	103.527***	231.474***	90.561***
Pesaran CD	19.882***	18.327***	71.136***	30.291***

*** indicates significance at 1% level, and a rejection of the null hypothesis of no cross-sectional dependence

Table 5 FMOLS Results

Variable	High-Income		Upper-Middle-Income		Lower-Middle-Income		Low-Income	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
GDP	1.744***	1.934***	1.375***	1.432***	− 1.330***	−1.273***	− 7.961***	− 8.760***
	(0.005)	(0.005)	(0.021)	(0.020)	(0.004)	(0.004)	(0.013)	(0.014)
GDP^2	− 0.055***	− 0.073***	− 0.053***	− 0.058***	0.123***	0.113***	0.706***	0.739***
	(0.008)	(0.008)	(0.016)	(0.015)	(0.005)	(0.005)	(0.018)	(0.018)
ENG	0.988***	4.228***	1.086***	1.645***	0.474***	− 0.441***	0.877***	− 1.189***
	(0.009)	(0.009)	(0.031)	(0.030)	(0.009)	(0.010)	(0.019)	(0.019)
EDU	0.806***	1.578***	− 0.013	− 0.002	0.216***	0.566***	0.541***	2.167***
	(0.009)	(0.009)	(0.025)	(0.024)	(0.008)	(0.008)	(0.007)	(0.007)
ENG*EDU		− 0.694***		− 0.197***		0.179***		0.485***
		(0.014)		(0.027)		(0.011)		(0.019)
R-Squared	0.993	0.995	0.998	0.998	0.972	0.972	0.868	0.888

*** , **, and * indicate statistically significant at 1%, 5%, and 10%, respectively

Table 6 DOLS Results

Variable	High-income		Upper-middle-income		Lower-middle-income		Low-income	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
GDP	0.653***	0.856***	1.261***	1.570***	− 1.158***	− 1.120***	− 9.502***	− 9.190***
	(0.251)	(0.278)	(0.377)	(0.541)	(0.048)	(0.048)	(1.498)	(1.922)
GDP^2	− 0.025**	− 0.037***	− 0.071***	− 0.091***	0.131***	0.122***	0.776***	0.725***
	(0.012)	(0.014)	(0.022)	(0.031)	(0.005)	(0.005)	(0.123)	(0.156)
ENG	1.008**	1.857***	1.160***	1.050***	0.666***	− 0.471*	0.987***	− 1.148***
	(0.023)	(0.513)	(0.041)	(0.346)	(0.027)	(0.245)	(0.078)	(0.380)
EDU	0.175**	0.402**	0.134*	− 0.039	0.159***	0.530***	0.535***	2.518***
	(0.071)	(0.183)	(0.070)	(0.064)	(0.046)	(0.089)	(0.046)	(0.267)
ENG*EDU		− 0.190*		0.023		0.259***		0.532***
		(0.109)		(0.074)		(0.055)		(0.080)
R-Squared	0.997	0.996	0.998	0.996	0.978	0.978	0.916	0.951

***, **, and * indicate statistically significant at 1%, 5%, and 10%, respectively

Table 7 PMG-ARDL Results

Variable	High-income		Upper-middle-income		Lower-middle-income		Low-income	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Long-run estimate								
GDP	− 0.272	0.654**	1.184***	1.964***	− 1.198***	− 1.415***	− 7.810***	− 6.679***
	(0.261)	(0.264)	(0.183)	(0.222)	(0.358)	(0.524)	(2.358)	(2.037)
GDP^2	0.037***	− 0.018	− 0.080***	− 0.101***	0.094***	0.107***	0.688***	0.542***
	(0.013)	(0.013)	(0.012)	(0.013)	(0.023)	(0.033)	(0.189)	(0.168)
ENG	0.951***	− 0.056	1.205***	2.638***	1.178***	− 0.109	0.965***	− 1.922***
	(0.042)	(0.523)	(0.035)	(0.436)	(0.048)	(0.389)	(0.134)	(0.686)
EDU	− 0.267***	− 0.333**	0.134	0.528***	0.209**	0.896***	0.339***	3.269***
	(0.089)	(0.169)	(0.100)	(0.076)	(0.089)	(0.169)	(0.089)	(0.571)
ENG*EDU		− 0.206*		− 0.346***		0.285***		0.756***
		(0.110)		(0.095)		(0.084)		(0.160)
Short-run estimate								
ECT	− 0.191***	− 0.227***	− 0.192***	− 0.435***	− 0.199***	− 0.200***	− 0.245***	− 0.254***
	(0.044)	(0.054)	(0.046)	(0.088)	(0.040)	(0.042)	(0.054)	(0.042)
ΔGDP	6.065	0.410	0.182	3.118	− 4.198	− 1.202	− 14.925	10.686
	(4.407)	(3.689)	(6.872)	(11.236)	(6.990)	(5.116)	(17.927)	(16.897)
ΔGDP^2	− 0.294	− 0.018	− 0.015	− 0.150	0.260	0.071	1.177	− 0.793
	(0.209)	(0.178)	(0.427)	(0.661)	(0.480)	(0.356)	(1.414)	(1.340)
ΔENG	0.685***	0.990	0.669***	5.654	0.587***	1.799	0.415***	0.595
	(0.099)	(4.277)	(0.094)	(7.024)	(0.067)	(1.894)	(0.150)	(3.382)
ΔEDU	− 0.115	− 0.592	− 0.237	0.244	− 0.278**	− 0.559	− 0.450	− 0.666
	(0.165)	(1.616)	(0.145)	(0.659)	(0.146)	(0.633)	(0.334)	(2.332)
ΔENG*EDU		− 0.076		− 1.152		− 0.259		− 0.048
		(0.923)		(1.490)		(0.404)		(0.772)
Constant	0.434***	− 0.188*	− 0.242	− 3.337***	1.229***	0.808***	5.827***	2.767***
	(0.122)	(0.103)	(0.249)	(0.713)	(0.266)	(0.197)	(1.286)	(0.482)

***, **, and * indicate statistically significant at 1%, 5%, and 10%, respectively

Table 8 CCEMG results

Variable	High income		Upper middle income		Lower middle income		Low income	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
CCMG results								
GDP	6.886*	8.213**	0.987**	− 0.420	− 20.41***	− 13.27***	− 24.44***	0.748
	(3.655)	(4.010)	(0.484)	(4.677)	(2.319)	(1.822)	(3.083)	(3.041)
GDP^2	− 0.345*	− 0.408**	− 0.042	0.044	1.379	0.901***	1.919	0.055
	(0.184)	(0.202)	(0.298)	(0.289)	(1.566)	(0.123)	(2.392)	(2.449)
ENG	0.810***	− 4.227	1.037***	7.403***	0.839***	2.275	0.628***	2.462***
	(0.102)	(6.329)	(0.056)	(0.634)	(0.084)	(2.891)	(0.134)	(0.290)
EDU	0.168***	− 1.341***	− 0.483**	0.386	− 0.183**	− 1.199	− 0.570**	− 1.796
	(0.023)	(0.258)	(0.228)	(0.402)	(0.077)	(0.957)	(0.192)	(1.905)
ENG*EDU		− 1.077***		− 1.378***		0.298***		− 0.356
		(0.361)		(0.372)		(0.061)		(0.652)
Trend	0.013**	0.013**	0.007*	0.007**	0.022***	0.017**	0.044***	0.043***
	(0.006)	(0.005)	(0.004)	(0.004)	(0.005)	(0.007)	(0.011)	(0.012)

***, **, and * indicate statistically significant at 1%, 5%, and 10%, respectively

Table 9 Marginal effects of primary education

	Min	Mean	Max
High-income	− 43.386	− 66.911	− 85.051
Upper-middle-income	− 12.557	− 19.230	− 24.059
Lower-middle income	0.454	17.283	26.401
Low-income	9.339	40.408	74.667

Table 10 Heterogeneous panel causality test results

Null hypothesis	High-income	Upper-middle-income	Lower-middle income	Low-income
	Zbar-Stat	Zbar-Stat	Zbar-Stat	Zbar-Stat
GDP ≠ CO2	3.229***	1.967**	5.909***	5.220***
CO2 ≠ GDP	2.821***	2.932***	1.674*	0.207
ENG ≠ CO2	1.975**	0.494	4.881***	6.810***
CO2 ≠ ENG	2.183**	1.201	5.074***	4.776***
EDU ≠ CO2	2.346**	4.486***	1.886*	0.535
CO2 ≠ EDU	2.413**	2.792***	5.456***	3.787***
ENG ≠ GDP	2.984***	−0.215	2.707***	0.511
GDP ≠ ENG	6.125***	3.530***	8.223***	10.307***
EDU ≠ GDP	0.637	3.524***	3.940***	1.315
GDP ≠ EDU	1.796*	14.483***	5.358***	3.366***
EDU ≠ ENG	1.539	2.861***	4.215***	2.170**
ENG ≠ EDU	1.579	6.433***	1.422	3.470***

*, ** and *** are statistical significance at 10%, 5% and 1% levels, respectively

Table 11 List of countries

High-income				
Australia	Denmark	Italy	Panama	Uruguay
Austria	Finland	Malta	Portugal	South Korea
Belgium	France	Mauritius	Spain	Seychelles
Brunei	Greece	Netherlands	Sweden	
Canada	Iceland	Oman	Switzerland	
Chile	Ireland	New Zealand	UK	
Cyprus	Israel	Norway	USA	
Upper-middle-income				
Albania	Bulgaria	Cuba	Indonesia	Mexico
Argentina	China	Ecuador	Iran	Peru
Belize	Colombia	Grenada	Jordan	South Africa
Botswana	Costa Rica	Guatemala	Malaysia	Thailand
				Turkey
Lower-middle-income				
Algeria	Congo-Brazzaville	Ghana	Mongolia	Senegal
Benin	Cote d'Ivoire	India	Morocco	Sri Lanka
Bhutan	Egypt	Kenya	Myanmar	Tunisia
Bolivia	El Salvador	Kiribati	Nepal	Vietnam
Cabo Verde	Honduras	Lesotho	Nigeria	
Cameroon	Eswatini	Mauritania	Philippines	
Low-income				
Burkina Faso	Madagascar	Mali	The Gambia	
Burundi	Malawi	Mozambique	Togo	
Ethiopia	Niger	Rwanda	Uganda	

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