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Analyzing the Impact of Sectoral Energy Use on Environmental Degradation: A Cross-Country MMQR Approach

Hafsa Jabeen[1]*, Ayesha Naz[2]*, and Abdul Rashid[3*]

Abstract

This paper used Moments Quantile Regression (MMQR) in investigating the sector-specific impact of energy consumption on environmental degradation along quantiles running over the year 1990-2023. The decomposition of energy usage into five major segments namely industrial, transport, residential, commercial, and agricultural is expanded on the IPAT framework, where an overall environmental degradation index is also developed through the use of Principal Component Analysis (PCA). The panel data of the developed, developing, and aggregate country groups have indicated that industrial, residential, and commercial sectors of energy use invariably increase environmental degradation in all the quantiles with intense effects witnessed among developing economies. The energy consumption of transport undermines the quality of the environment in developing countries and enhances it in developed ones, which indicates the impact of cleaner technologies. The energy use in agriculture is heterogeneous, which enhances degradation in the developing economies and mitigates the same in the developed countries. Consistent exacerbating effects are available on GDP and population growth, but technological progress is observed to counteract environmental degradation, especially on the top and lower quantiles. The research therefore adds to the literature with a sector specific, quantile analysis of the energy-environment nexus, and the need to have a technology specific and specific policy interventions.

Keywords: *Sector-wise Energy Consumption, Environmental Degradation, MMQR*

JEL Classification: *C21, Q43, Q53*

1. Introduction

The nexus of sectoral energy consumption and environmental degradation has been receiving a growing scholarly and policy attention due to its centrality in defining the outlook of global environmental sustainability. The pattern of energy usage in different sectors of the economy is industrial, transportation, residential and commercial that are quite different and each of them has a different impact on the environmental pressures which include greenhouse-house emissions (GHG), resource depletion, and pollution. As the world energy demand is expected to increase especially in the emerging economies, a detailed insight into the sector-specific mechanisms through which the use of energy leads to environmental degradation is essential in designing effective and focused mitigation policies.

[1] *International Islamic University, Islamabad, Pakistan
[1] PHD Scholar, Department of Economics, Email (Corresponding Author): hafsa.phd221@iiu.edu.pk
[2] Assistant Professor, Department of Economics, Email: ayesha.naz@iiu.edu.pk
[3] Professor, Director General, Department of Economics, Email: abdulrashid@iiu.edu.pk

One of the most energy-intensive and environmentally-inducing sectors, among others, is the industrial sector. Manufacturing, construction and extractive industries are included in this sector and are highly dependent on fossil-based energy sources (oil, coal, natural gas and electricity) that contribute a significant proportion of the total world CO 2 emissions (Li and Lin, 2016). Cement, steel, and other chemical industries are particularly carbon-intensive and thus contribute significantly to global climate change as well as air pollution locally (Zhang et al., 2020). The constant use of non-renewable energy sources in the industrial processes not only increases the pace of the resources exhaustion but also increases the number of particles and harmful emissions, negatively impacting the human health and ecological systems (Wang et al., 2019). In reply, policy and technological changes, which would facilitate cleaner production technologies, industrial energy efficiency, and the use of renewable energy sources like biomass and solar energy, are needed to reduce the environmental impact of the sector (Lu et al., 2021).

On the basis of the environmental problems in the industrial sector, the transportation sector also contributes to the global environmental degradation. Transportation also contributes to the global warming of the atmosphere emitting almost 23 percent of all energy-related CO 2 emissions, which are mainly powered by petroleum products, including gasoline and diesel, which leads to the air pollution in the city (IEA, 2021). The growth of ownership of vehicles, air travel, and the international trade-based freight transportation has increased the environment burden of the sector (Zhang et al., 2020). It is worth noting that road transport, in particular, takes up about 70⁻ percent of all transportation energy consumption and contributes to the formation of smog and atmospheric instability by releasing significant degrees of nitrogen oxides (NOx) Carbon monoxide (CO), and volatile organic compounds (VOCs) (Li and Lin, 2016). The significance of the environmental impact of international shipping and aviation also highlights the urgency of sustainable mobility towards using energy-efficient technologies, including electric vehicles (EVs), hybrid engines, and investments in low-carbon infrastructure of the public transport (IEA, 2021).

Coupled with the industrial and transportation sectors, the commercial and residential sectors are also important sources of the environmental degradation through their energy consumption patterns. These industries are mainly involved in energy use in space heating, cooling, lighting and use of appliances. The use of fossil energy including oil and coal and the use of traditional biomass to cook and heat food and water lead to a high level of both indoor and outdoor air pollution in most developing countries (Wang et al., 2019). This does not only aggravate deforestation and CO 2 emissions but it is also very dangerous to health. On the other hand, with rising urbanization and standards of living in the developed economies, the demand on energy has risen, especially in high-rise residential structures and commercial structures. Increased building insulation and the introduction of appliances with lower energy use and distributed renewable energy systems - rooftop solar photovoltaic systems can positively transform the environmental impact of these sectors (Lu et al., 2021). Moreover, the regulatory interventions that is encouraging the green building codes, energy audit and smart demand administration are important in expediting the energy transition in residential and commercial infrastructures.

Since an ecological footprint of such sectors is cumulative, it is clear that a universal strategy of environmental policy cannot be applied. Instead, interventions targeted at the sectors are needed to help in mitigating the degradation of the environment. As an example, industrial processes and transportation systems can be made more energy-efficient, residential and commercial buildings can be encourages to use less energy, and GHG emissions can be cut by a significant margin without economic performance (Wang et al., 2019). Moreover, these specific actions should be supported by a solid policy system on the national and international levels with the focus on investing in low-carbon technologies, building partner relationships between the state and business, and cross-sector cooperation to achieve the effective execution of the sustainability objectives (Lu et al., 2021).

In that regard, the inclusion of renewable energy technologies into the work of all industries can be seen as the effective way of decreasing the level of fossil fuel consumption and limiting the carbon footprint. The implementation of renewable energy resources, such as hydropower, wind, and solar, in combination with other technological advances, such as smart grids, high-tech battery storage, and energy-efficient appliances, has the potential to reinvent the existing energy systems into more sustainable and resilient ones (Zhang et al., 2020). These transitions are necessary not only to the realization of national environmental goals but also the global climate targets that are being accomplished in the international levels like the Paris Agreement.

Finally, the facts emphasize that sectoral energy use is a major factor that contributes to environmental degradation which includes the transportation, industrial and commercial-residential sectors. The intensive use of fossil fuels in these sectors contributes to climate change, depletion of natural resources, and poor quality of air and water. To overcome these obstacles, a multidimensional approach including energy efficiency measures specific to the sector, the popularization of renewable energy technologies, and consistent policy interventions are required. This type of a comprehensive approach is necessary to minimize the ecological footprint of energy consumption and promote the global agenda on environmental sustainability.

Nevertheless, there is still a lot to be desired in the relationship between energy consumption and environmental degradation even though the body of research has grown. Much of the work done is narrowed down to individual countries thus reducing cross country insights. Simple linear relationships are also assumed in many studies and little consideration is made on the threshold effects that can be different across economies. Single measurements like CO 2 emissions commonly reflect the quality of the environment, yet its multidimensional quality is ignored. Endogeneity, heterogeneity, and panel bias are often left unaddressed in an approach that is traditional. Lastly, the contribution of sectoral differences, i.e. industry, transport, agriculture, residential, and commercial uses of energy has been not well studied giving an incomplete picture of the impact of energy consumption on environmental change.

These constraints give some critical research questions. To begin with, what effect does the consumption of energy by various sectors have on the degradation of the environment? Second, are any of these effects dependent on the levels of environmental pressure? Thirdly, does a composite Environmental Degradation Index (EDI) give a stronger measure of environmental quality as compared to single indicators? Fourthly, are sectoral effects varied among developed, developing and full-panel groups? Lastly, what are the possible policy implications to come up with an energy use balance, economic growth and sustainability?

In a bid to answer these questions, the study attempts to achieve five objectives. It is first, it enlarges the IPAT framework by incorporating the sector-specific energy consumption in the study of environmental degradation. Second, it constructs a composite EDI through Principal Component Analysis (PCA) in order to measure several dimensions of environmental quality. Third, it uses the Method of Moments Quantile Regression (MMQR) to determine unequal effects on the distribution of environmental degradation. Fourth, it contrasts the outcomes between developed, developing and full-country panel groups to point out the cross-country heterogeneity. Lastly, it produces policy-relevant information to support industry-specific measures of mitigating environmental degradation and continuing to grow economically.

The rest of the study is organized in the following manner: Section 2 will review the relevant literature in detail. Section 3 explains the methodology and estimating strategies. Section 4 discusses the results of the empirical analysis in detail. Section 5 finally ends the study and gives the policy recommendations on the basis of the study.

2. Literature Review

The relationship between sector-specific energy consumption and environmental destruction has become of more interest to scholars due to the implications of the energy consumption in environmental policy and sustainable development. The energy is consumed by various sectors such as agriculture, transport, industry, residential and commercial activities with varying magnitudes and levels of intensity in that these sectors contribute to the quality of the environment either positively or negatively. Although there are sectors that increase the rate of environmental degradation due to the high emission of greenhouse gases (GHG), there are other sectors that can be mitigated as per the energy sources, efficiency levels, and technological advances. There has been growing body of empirical studies that have attempted to untangle these industry specific dynamics with the effects both positive and negative on the environment being found.

Since the start with the agricultural sector, there have been contradictory results. The study of Hafeez et al. (2020) examined how the energy demand and agriculture contributed to the deterioration of the environment among the countries of the One Belt One Road Initiative (OBOR) during 1980-2017. Upon co-integrating, FMOLS, and DOLS, the research found out the long-run relationship between the energy demand, agricultural activity and environmental degradation. It is important to note that forest cover had been found to diminish environmental degradation and agricultural expansion and increasing energy demand were identified with environmental harm. Likewise, Dar and Asif (2019) analyzed the impact of agricultural contribution on carbon emission in the form of renewable energy use and urbanization by analyzing five countries of South Asian Association of Regional Cooperation

(SAARC). Their results revealed that there was a unidirectional causality between agricultural contributions and use of renewable energy implying that renewable energy in agriculture can enhance the mitigation of environmental degradation. Pata (2021) further pursued this direction of inquiry in BRIC countries and discovered a bidirectional relationship between agricultural activities and environmental degradation, which was more complicated.

The additional investigation on the phenomenon in developing economies by Salari et al. (2021) and Wang et al., (2025) highlighted that the increased output in agriculture causes more degradation of the environment. Supplementing this, Sarkodie et al. (2019) investigated 14 countries in Africa and discovered that although value-added in agriculture contributed to decreasing pollution, the result is that energy consumption in agriculture increased carbon production, thus highlighting the duality of agriculture growth and energy usage. Zhang et al. (2019) introduced a sector-specific analysis in China that showed that there existed both short- and long-term negative correlation between agricultural energy consumption and carbon emission. Using ARDL, Granger causality, and impulse response functions, the study showed that on the one hand, the economic growth is based on the energy use of agriculture, but, conversely, even in some cases, it can also lead to the reduction of carbon emissions, which is not the case in other studies.

Continuing on energy-agriculture-emissions triangle, Dogan (2019), Yurtkuran (2021) and Waheed et al. (2017) observed that agricultural production has a positive long-run relationship with carbon emissions in China, Turkey, and Pakistan. Their findings indicate the similarity with Hossain and Chen (2021), who discovered that the sphere of agricultural energy, population development, and agricultural economic activity are critical determinants of environmental degradation. In the same study, Jebli and Youssef (2016) provided the same conclusions to Tunisia and revealed that the increase in agricultural practices leads to emission, particularly in the lack of sustainable energy options.

Going to the transport sector, it is a significant source of environmental degradation as well as documented. Based on the information on five ASEAN economies, Chandran and Tang (2013) adopted the methodology of Granger causality and cointegration to reveal the bidirectional causality of transport energy consumption and carbon emissions in Malaysia and Thailand. Adam et al. (2020) confirmed this result by applying generalized method of moments (GMM) to investigate Sub-Saharan Africa in 1980-2011 and found out that carbon emission increases dramatically when energy use in transportation increases. These findings are consistent with global studies such as those conducted by Yin et al. (2015) which have proven that the use of transportation energy in China is strongly positively correlated with CO2 emissions. In the same manner, Danish et al. (2018) used ARDL and vector error correction models on Pakistan and affirmed that energy utilization in the transport sector contributes to environment degradation. The above studies all underline the necessity to switch to clean means of transport and alternative fuels.

The issue of industrialization and its environmental impacts have also been a subject of high level of scholarship. In a cross-country study of 73 countries, based on income level, Li and Lin (2015) and Montagna et al., (2025) discovered that although industrialization has the potential to reduce energy intensity in high income countries, it increases CO2 emission levels- especially lower-middle and high-income countries. This paradox brings out how the industrial structure and technological sophistication mediates the energy consumption results. Sohag et al. (2017) also demonstrated that industrial and service sectors contribute to the global emissions of CO2 to a considerable extent. The results indicate that although energy use in industries is a necessary required factor in the economic development, it continues to be a major contributor to environmental degradation unless it is supplemented by energy efficient practices or clean technologies.

It is also in residential sector where the population has a significant impact on environmental quality. It contributes about 27 and 17 percent of world energy and emission of carbon respectively (Nejat et al., 2015). In the third world, there is a dependency on biomass, coal, and oil not only damages the quality of the air but also causes deforestation and heating and cooking contribute to it as well CO2 emissions. As Zhang et al. (2017) and Feng et al. (2011) explain, per capita residential energy consumption increases carbon emission and energy intensity. The need of sustainable urban Miao (2017) also aided the design, having access to the data of the cities in China and defined what data could be used to support the design population density, wealth, and city density as significant determinants that influence energy consumption and carbon emissions in the household.

The housing industry has also significant impact on the quality of the environment. It takes about 27% and 17% of the global energy and carbon emissions respectively (Nejat et al., 2015). In developing nations, the use of biomass, coal, and oil to heat and cook does not only reduce the quality of the air but also leads to deforestation and carbon dioxide emissions. Zhang et al. (2017) and Feng et al. (2011) report that per capita residential energy utilization increases the carbon emission and energy intensity. Miao (2017) also supported the need of sustainable urban design, relying on the data about the city level in China and determined population density, affluence, and urban compactness among the significant factors that influenced household energy consumption and carbon emissions.

The business industry, which has not been researched much, has shown an increasing environmental presence. Zaman et al. (2013) examined the relationship between commercial energy consumption and Pakistani macroeconomic indicators, and observed that there were long-run relationships and also found that the causality was unidirectional. More significantly, the effect between commercial electricity use and carbon emissions turned out to be two-sided. On the same note, in their research on the China business industry, Wang and Lin (2017) have found that carbon emission can be minimized by enhancing energy intensity and restructuring energy sources. These results demonstrate the relevance of energy efficiency and modernization of the commercial sector as the priority of policy measures.

The manufacturing sub-sector which is a major part of the industry has been put under the test with regard to its impact on the environment. Tanveer et al. (2021) used the nonlinear and linear ARDL models on the 1985-2018 timeframe of Pakistan and came to the conclusion that enhanced energy consumption in the manufacturing sector results in the decline of environmental quality. Similarly, Mi et al. (2014) presented the data collected in Beijing that industrial structural changes can counteract the CO2 emission and energy consumption, which is a possible way to reconcile the industrial development and the environmental sustainability.

To conclude, the literature reviewed proves that the connection between environment degradation and sector-wise energy usage is complex and environmentally dependent. Agricultural and residential industries are not that good, but on the other hand, the transport and industrial sectors demonstrate a strong positive correlation with the negative effects on the environment. The business sector which is relatively poorly studied is proving to be a major cause to environmental degradation. All these results speak in favor of the significance of sector-specific approaches, renewable energy integration, and technological advances to reduce environmental degradation and lead to sustainable development.

The available literature provides some interesting information about the energy consumption sectoral and the impacts of the same on the environment, but there remain a number of gaps. To start with, various studies concentrate on particular nations or regional blocs meaning that they cannot be generalized to the rest of the world. Secondly, whereas most studies focus on the causality between energy consumption and environmental degradation is linear or bidirectional, little studies examine the non-linear or threshold effects, which might differ across sectors and incomes. Also, it is not integrated with energy consumption patterns at both sector and overall environmental measure like composite indices on environmental degradation. There are also methodological weaknesses with many studies using the traditional methods of estimation and fail to take into consideration the possible endogeneity or dynamic panel bias. The above gaps suggest the necessity to have more holistic, comparative, and methodologically sound studies that can explain the multifaceted and diverse effects of sector-specific energy consumption on environmental degradation under various economic settings.

The following study contributes to the existing literature in a number of important ways. To begin with, it adds to the classical IPAT (Impact = Population x Affluence x Technology) model, the five main economic activity sectors, including industrial, transport, agriculture, residential, and commercial levels, to provide a more detailed and sector-specific view of the environmental degradation. Second, the study creates a composite Environmental Degradation Index (EDI) based on the Principal Component Analysis (PCA), unlike other works that tend to use single proxies of environmental impact because this enables the assessment of the environmental quality in a multidimensional and more robust way. Lastly, the approaches taken to quantify the varying effects sectoral energy consumption has during the distribution of environmental damage are the Method of Moments Quantile Regression (MMQR) approach. The method allows the individual to identify the differential effects at the lower, median, upper quantiles among other quantiles, giving greater insights than the use of the mean based estimators. Lastly, the research stands out by performing a disaggregated comparison of country classifications, i.e. developed, developing and the entire panel, therefore, allowing one to understand distinctly how sectoral energy consumption affects environmental degradation at different stages of economic development.

3. Model and Methodology

3.1 Theoretical Framework

This paper establishes its theoretical basis on the IPAT approach (Impact = Population x Affluence x Technology) through which the destruction of the environment is seen as the result of demographic, economic, and technological forces. To be more specific, the study includes a sectoral perspective of energy consumption because it is recognized that industries, transport, agriculture, residential, and commercial activities exert environmental pressure differently.

To give an example, industrial production is based on energy-intensive processes that are usually fossil-intensive, producing emissions, consuming resources, and waste. A large contributor to the greenhouse gases and urban air pollution is the transport sector which is majorly fueled by petroleum. Another pressure on the environment is agriculture, which requires energy resources in irrigation and mechanization and leads to the ecological stress both directly and indirectly. Residential and commercial buildings are also contributing feature with an ever-increasing pressure of the demand on heating, cooling, lighting as well as appliances further straining the energy systems, especially in situations where the dependence on non-renewable sources is maintained.

Notably, the connection between sectoral energy consumption and environmental performance might not have a straight line. In the less-developed economies, the increasing energy usage in these sectors tends to deteriorate the environmental conditions which is an initial form of the Environmental Kuznets Curve (EKC). However, in the more advanced stages of development, technological advancements, the use of cleaner forms of energy, and a structural transformation in the forms of activities that use less energy can moderate or even reverse some of these adverse impacts. This shows how non-linear and heterogeneous effects can have been experienced across sectors and income groups. The observation that environmental degradation is essentially multidimensional also sees the study transcend the one-dimensional measurements like CO2 emissions. Rather, it uses a composite Environmental Degradation Index (EDI) to represent a more comprehensive range of environmental pressures and outcomes, which also enables a more complete assessment of the sustainability issues.

With this in a nutshell this framework implies that there have been dissimilar distribution of energy consumption to the environment by the sector by the stage of development and the general growth course. The study offering a more detailed theoretical foundation of the processes of energy use in environmental change by taking the IPAT model further and adding the explicit consideration of sector-specific dynamics of energy usage, the study offers a more detailed account of the direct and indirect effects of energy use on environmental change.

In addition, the consumption of energy in various industries has a tremendous effect on the degradation of the environment basing on its scale and processes of production. Commercial energy consumption depends on fossil fuels; it adds to increase in emissions of greenhouse gases. It comprises office and retail space electricity (Cheng & Hu, 2010). The residential energy use includes the use of energy to cool and heat residences. Besides this, inefficient uses of cooling and heating cause an increase in carbon emission that eventually deteriorates the environment (Bergek and Jacobsson, 2003).

According to Pimentel et al. (2005), energy usage for fertilizers and mechanization in agriculture also results in greenhouse gas emissions and resource depletion. To counteract these consequences, sustainable methods are required. Because fossil fuels are widely used in industrial energy consumption, there is a significant need for greener technologies and increased energy efficiency (Kramer & Lilieholm, 2012). Finally, the energy consumption of transportation, which includes cars and airplanes, is a major cause of air pollution and global warming. Reducing environmental effects requires switching to efficient transportation and alternative fuels (Sorrell, 2009). The fact that every sector's energy use contributes to environmental degradation through emissions, pollution, and resource strain highlights the need for improved efficiency and cleaner technology.

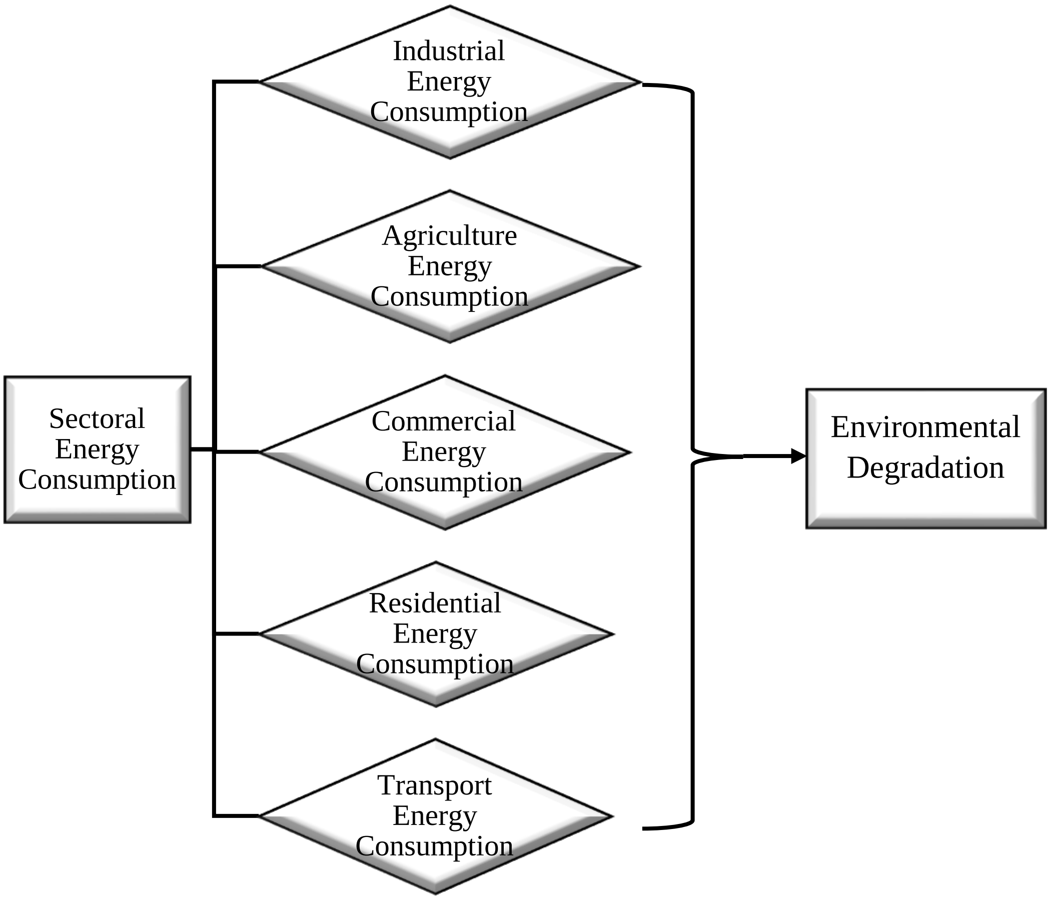

Figure 1: Impact of Sectoral Energy Consumption on Environmental Degradation

3.2 Model

The general expression of the IPAT equation is given below,

$$I_{it} = P_{it}^{\alpha 1}\, A_{it}^{\alpha 2}\, T_{it}^{\alpha 3}\, \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

In the above equation, environmental impact represented by I while affluence, population and technology are denoted by A, P and T respectively. $\alpha_1, \alpha_2,$ and α_3 are the parameters and the error term is ε_{it} . More specifically, environmental impact (I) is referred as environmental degradation. Hence, we can replace the 'I' by any of the proxy of environmental degradation (EDG). However, 'A' is replaced by the GDP that is used as a proxy variable for economic development. POP denotes the population that is measured by total population and TECH represents the technology which measures in term of total patent applicants. This is mentioned in equation (2) below.

$$EDG_{it} = POP_{it}^{\alpha 1}\, GDP_{it}^{\alpha 2}\, TECH_{it}^{\alpha 3}\, \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

In equation (2), EDG indicates environmental degradation and by incorporating the sectoral energy consumption (SEC) into this equation, we get (3)

$$EDG_{it} = POP_{it}^{\alpha 1}\, GDP_{it}^{\alpha 2}\, TECH_{it}^{\alpha 3}\, SEC_{it}^{\alpha 4}\, \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

The variable of sectoral energy consumption (SEC) comprises energy use across various sectors, including agriculture (AEC), industry (IEC), residential (REC), commercial (CEC), and transport (TEC), as specified in Equation 4.

$$EDG_{it} = POP_{it}^{\alpha 1}\, GDP_{it}^{\alpha 2}\, TECH_{it}^{\alpha 3}\, AEC_{it}^{\alpha 4}\, IEC_{it}^{\alpha 5}\, REC_{it}^{\alpha 6}\, CEC_{it}^{\alpha 7} TEC_{it}^{\alpha 8} \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

Equation 5 presents the logarithmic specification of Equation 4, allowing for a more interpretable linear relationship among the variables.

$$\begin{aligned} lnEDG_{it} = {} & \alpha_0 + \alpha_1 ln(POP_{it}) + \alpha_2 ln(GDP_{it}) + \alpha_3 ln(TECH_{it}) + \alpha_4 ln(AEC_{it}) \\ & + \alpha_5 ln(IEC_{it}) + \alpha_6 ln(REC_{it}) + \alpha_7 ln(CEC_{it}) + \alpha_8 ln(TEC_{it}) \\ & + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots (5) \end{aligned}$$

Equation 5—which is shown in figure 1 under theoretical framework section—helps to accomplish the study's objective about sectors energy use and its effects on environmental degradation. Moreover, the coefficients of this equation highlight the magnitude of these sectors in contributing environmental degradation.

The amount of data includes a panel of developing nations and developed nations between the year of 1990 and 2023. The international energy agency (IEA) has obtained sectoral energy consumption data, i.e., the consumption of electricity in tera-joules in the industrial, transport, residential, and other sector. The World Development Indicators (WDI) database has been used to obtain data on the environmental degradation, GDP, technology, and population. In order to create a complete Environmental Degradation Index (EDG), four indicators are used, methane (CH4) emissions, carbon dioxide (CO2) emissions, other greenhouse gas (GHG) emissions and nitrous oxide (N2O) emissions with the help of the Principal Component Analysis. With the help of this multidimensional approach, one can make more subtle analysis of the relationship between energy consumption at sectoral level and environmental degradation at various levels of economic development.

Table 1: Description of Study Variables

Variables	**Definition/Description**
Commercial Energy Consumption	The amount of energy used by commercial sector
Residential Energy Consumption	It is the total usage of energy by the residential household
Agriculture Energy Consumption	Agriculture energy consumption is the total energy used by farmers for producing the agriculture output
Industrial Energy Consumption	It is the energy consumed by the industrialists to produce industrial products.
Transport Energy Consumption	It is the per unit consumption of energy in the transport sector
Technology	The total patents applicants include the both residents and non-resident that is used to measure the technology.
Total Population	The basis for determining the total population is the de facto definition of population, which encompasses all residents regardless of citizenship or legal status. The figures shown are estimates for the middle of the year.
GDP	In a given period of time, typically a quarter or a year, the total economic worth of all completed goods and services produced inside a nation's borders is measured by the gross domestic product, or GDP.

3.3 Estimation Strategy: Method of Moments Quantile Regression

In this paper, the authors have employed the method of moment’s quantile regression (MMQR) of Machado and Silva (2019) to investigate the different impacts of explanatory variables on the conditional distribution of the dependent variable. MMQR estimates structural relationships at different points (quantiles) of the outcome distribution, and this captures distributional heterogeneity and allows more meaningful and reliable conclusions to be made compared to the traditional mean regression methods, which only estimate the conditional mean.

The MMQR technique is based on classical quantile regression model developed by Koenker and Bassett (1978) which approximates the conditioned form of the quantile and therefore give a more detailed account of the underlying data. Nevertheless, the conventional quantile regression can be problematic when quantile regression is applied to panel data, particularly in a situation where individual fixed effects and endogeneity are involved. To overcome them, Machado and Silva (2019) suggested a procedure that enables estimating quantile-specific effects but identifying it by the method of moments, which is consistent and efficient in the case of individual heterogeneity. The MMQR estimates are obtained by inverting the conditional distribution function evaluated to have quantile-specific moment conditions that allow the investigator to detect and interpret the covariate effects on the whole distribution of the dependent variable, not just at the mean. This is specifically so with environmental and energy economics where the implication of factors like the energy consumption in the sector could be significantly different at different levels of environmental degradation.

Moreover, the MMQR methodology is highly suitable in the panel data context since it can take into consideration unobserved individual heterogeneity, nonlinearities, and is resistant to heteroskedasticity and outliers (Machado and Silva, 2019). The MMQR is used in this study to determine the effect of sectoral consumption of energy on environmental degradation in various quantiles (e.g., Q10, Q25, Q50, Q75, Q90) to channel the different levels of environmental degradation of low, median and high consumption of energy. Through this strategy, the analysis will offer a subtle insight into the nature of energy dynamics that impact the outcomes of the environment under different conditions.

The IPAT model (Impact = Population x Affluence x Technology) has long been a classic of environmental research because it is simple. Its best power is in its comprehensive nature that is easy to interpret and communicate the impacts of population, economic growth, and technology on environmental outcomes. In addition, its clear identity can enable researchers to expand the model to have other factors like sectoral energy usage though it has a solid theoretical foundation. The use of IPAT in this research is due to its theoretical simplicity, communicability, and policy applicability with its econometric shortcomings dealt with using advanced techniques like MMQR and GMM. This will provide intellectual and empirical strength.

4. Results and Discussion

4.1 Descriptive Statistics of Study Variables

Table 2 presents descriptive statistics of the sector-specific energy consumption with respect to its impact on environmental degradation, with an emphasis on significant differences between sectors. In farms, homes, transportation and industry, the mean is always greater than the median, meaning that the distributions are skewed in that there are a few high-consuming outliers. Such outliers are usually large-scale operations or units in areas where energy need is higher due to factors such as the use of high levels of technology, level of income, climate or the level of the economy.

The same holds true to environmental degradation whereby the mean is significantly greater than the median, suggesting that a few regions or industries with either heavy industrialization or loose regulation of the environment are the biggest contributors to environmental degradation. In farming, there is a broad mean-median difference with a large proportion of farms having an average energy demand near zero, and the proportion of large-scale farms with high levels of irrigation or mechanization having big energy demands. The residential market is also showing the same skew, and it can probably be attributed to higher-income households with more appliances or houses and more extreme climates that need more energy to heat or cool down. In transport sector, the overall energy consumption is dominated by few high-energy users like huge logistics or shipping companies. The most differentiated one is industrial energy consumption, with a small number of very large energy consumers increasing the mean dramatically. High standard deviation, positive skewness, high Kurtosis, and Jarque-Bera statistic confirm this as being the result of non-normal distribution induced by the presence of extreme values.

The level of energy efficiency also differs greatly. Although the average score implies that it is moderately efficient, the slightly low median, as well as the large standard deviation and positive skew, implies that only a few entities are well-performing, and the rest are underperforming. This implies that there is a possibility of wider enhancement by embracing the activities of effective organizations. The average reliance on energy is moderate, with fairly equal distribution, but the variability still exists in the form of infrastructure, energy source, and efficiency disparity in different regions.

The distributions of GDP and technology are also skewed to the right, meaning only a few entities have a disproportionately high level of the economy or technological development. The effect of outliers is supported by high standard deviations and kurtosis which are supported by Jarque-Bra results. Similar skewness can be observed in the data of population and some places with a high concentration of people contribute immensely to the mean and variability.

Generally, the statistics indicate that the extreme numbers contribute to most of the fluctuations in energy usage, efficiency, reliance and other similar indicators. These inequalities indicate that there is a need to have specific policy interventions particularly to high consuming entities. Individualized approaches to outliers can be used to maximize the use of energy, minimize the degradation of the environment, and encourage sustainable development in all sectors.

4.2 Pairwise Correlation

The outcome of the analysis of pairwise correlation between energy consumption by the sector and environmental degradation is presented in Table 3, and it demonstrates some important relationships. Environmental degradation is moderately positively correlated with industrial energy consumption, meaning that the higher the industrial activity, the more the pollution and waste. The positive correlation with transportation energy use is even more acute and indicates the significant environmental implication of transport systems that are fuel-powered like vehicles and logistics processes.

There is also a moderate positive correlation between residential energy consumption and environmental degradation, implying that the growing consumption of energy in the households, primarily through heating, cooling and appliances, puts pressure on the environment. On the same note, there is a positive correlation between commercial energy consumption and environmental damage as offices and retail areas demand lots of energy to illuminate, cool and furnish the premises. The same situation can be applied in agricultural sector where energy-intensive agricultural activities such as irrigation, machinery utilization are linked to the higher rate of environmental degradation. Conversely, energy efficiency has a moderate relationship with environmental degradation in the sense that the better the energy efficiency, the less the environmental degradation. That is why using some energy-saving technologies and practices is beneficial. There is a weak positive relationship between energy dependence and environmental results, which implies that the impact of energy source reliance on environmental outcomes is not very strong in this scenario. Similarly, the correlation between GDP and the environment is only marginally positive and this suggests that the view of economic output alone is not a significant determinant of the quality of the environment in the dataset.

Technology has a negative relationship that is strong to environmental degradation so that increased technological development would mitigate the effects on the environment, probably due to cleaner production procedures and more effective utilization of energy. The size of the population and environmental degradation however exhibit a positive strong relationship as the high demand on resources by larger populations increases the demand on energy and waste production. Overall, population, transportation, as well as industrial energy consumption are revealed as the biggest causes of environmental degradation. On the other hand, key areas of reducing environmental degradation include the technological advancement and efficiency in energy use. These outcomes imply that special intervention in sectors that have high impact with investments made in clean technologies are critical in encouraging sustainable environmental practices.

Table 2*: *Descriptive Statistics

	EDG	AEC	CEC	REC	TEC	IEC	GDP	TECH	POP
Mean	0.0768	5063.48	18124.01	29615.87	6138.766	71110.45	19372.37	24279.72	73503664
Median	0.0177	17.0000	140.0000	177.5000	11.0000	293.0000	9743.046	1828.000	15123104
Maximum	1.0000	1717220.	6255299.	13395407	1697967.	47898589	112417.9	1786653.	1.43E+09
Minimum	9.67E-05	0.5000	1.0000	2.0000	0.5000	3.0000	98.9312	-4.0000	254826.0
Std. Dev.	0.1668	47423.80	169316.6	348324.5	55074.99	1232556.	20857.70	117309.2	2.09E+08
Skewness	3.6276	26.8058	28.2785	31.6816	18.1597	32.7461	1.5196	9.1706	5.1779
Kurtosis	16.3906	865.6972	936.7941	1102.190	462.6941	1152.945	5.2673	106.6378	30.0420
Jarque-Bera	23001.61	74089468	86787711	1.20E+08	21086575	1.32E+08	1425.861	1098489.	83152.94
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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Table 3: Pairwise Correlation for Impact of Sectoral Energy Consumption on Environmental Degradation

Variables	**EDG**	**IEC**	**TEC**	**REC**	**CEC**	**AEC**	**GDP**	**TECH**
IEC	0.2254***							
TEC	0.3817***	0.4525***						
REC	0.2416***	0.2958***	0.0714***					
CEC	0.2865***	0.3425***	0.4926***	0.3744***				
AEC	0.2721***	0.1531***	0.5227***	0.3669***	0.4710***			
GDP	0.0189***	-0.028	-0.060***	-0.0469**	-0.0573***	-0.0637***		
TECH	-0.5068***	0.1030***	0.1544***	0.1084***	0.1282***	0.1272***	0.2691***	
POP	0.6315***	0.1094***	0.1638***	0.1285***	0.1445***	0.1563***	-0.289***	0.5768***

4.3 Results of Panel Unit Root Tests

4.3.1 Pesaran CD, CIPS, and CADF Tests for Panel Diagnostics

Table 4 presents the findings of the Pesaran cross-dependency test, indicating that there is a cross-dependency between the variables. This indicates that the unit root test for second generation panels should be used. To do this, we used the cross sectional augmented Dickey Fuller test (CADF) and Shin (CIPS) tests. These tests' results are shown in Tables 4 and 5. This indicates that every variable, with the exception of the technology variable, which is stationary at level, is stationary at first difference.

Table 4: Results of Cross Dependence and CIPS Panel Unit Root for Sectoral Energy Consumption Model

Variables	CD Test	CIPS	
		Level	First Difference
EDG_{it}	70.57***	-1.339	-4.226***
IEC_{it}	38.87***	-1.535	-3.933***
TEC_{it}	50.26***	-1.219	-2.690***
REC_{it}	178.75***	-0.415	-3.717***
CEC_{it}	174.78***	-0.887	-3.440***
AEC_{it}	35.68***	-1.716	-3.454***
GDP_{it}	215.81***	-1.063	-3.420***
$TECH_{it}$	7.75***	-2.242***	-
POP_{it}	92.43***	-0.468	-2.291***

****, **, & * shows the significance at 1%, 5%, & 10% level respectively. Result of CIPS is obtained with constant. The critical values for CIPS are -2.03 (10%), -2.10 (5%), and -2.20 (1%).*

Table 5: Results of CADF Panel Unit Root for Sectoral Energy Consumption Model

Variables	Level			First difference		
	t-bar Stats	Z-statistic		t-bar Stats	Z-statistic	
EDG_{it}	-1.712	0.515	(0.697)	-3.285	-13.481	(0.000)
IEC_{it}	-1.683	0.771	(0.780)	-3.212	-12.837	(0.000)
TEC_{it}	-0.920	7.566	(1.000)	-2.098	-2.917	(0.002)

REC_{it}	-0.727	9.281	(1.000)	-2.808	-9.235	(0.000)
CEC_{it}	-1.147	5.545	(1.000)	-2.593	-7.322	(0.000)
AEC_{it}	-1.591	1.595	(0.945)	-2.940	-10.414	(0.000)
GDP_{it}	-1.701	0.618	(0.732)	-2.846	-9.581	(0.000)
$TECH_{it}$	-2.345	-5.116	(0.000)	-	-	
POP_{it}	-2.022	-2.241	(0.013)	-2.465	-6.183	(0.000)

Results are obtained with constant. The critical values are -2.030, -2.100, and -2.200 at 10%, 5%, and 1% level of significance respectively. Probability values are given in bracket ().

4.3.2 Results of Slope Heterogeneity

The study checked the slope heterogeneity (SH) before doing the formal analysis. Table 6 present the results of this preliminary analysis which shows that there is a statistically significant relationship between SH and adjusted SH at the 1% level of significance. Therefore, the study concludes that slope is not homogeneous, implying that selected panel parameters show the heterogeneity for the sectoral consumption of energy and environmental degradation.

Table 6: Results of Slope Heterogeneity Test for Sectoral Energy Consumption Model

Test	Statistics	P-value	Decision
$\tilde{\Delta}$	22.677***	0.000	Slope coefficients are heterogeneous
$\tilde{\Delta}_{adjusted}$	28.191***	0.000	

*Asterisks *** shows the significance at 1% level.*

4.3.3 Results of Method of Moments of Quantile Regression (MMQR)

This study uses the MMQR technique to determine the amount of sectoral utilization of energy associated with environmental degradation. Table 7 displays the findings for the complete panel, developing panel, and developed panel. The findings show that across all quantiles, the industrial energy consumption coefficient is positive and statistically significant. It suggests that the industrial sector's rising energy use causes environmental deterioration across the board. These results are consistent with previous research by Sohag et al. (2017) and Tanveer et al. (2021). Energy, which is largely obtained from fossil fuels like coal, oil, and natural gas, is frequently needed for the creation of goods and services in industrial operations. The combustion of these fuels releases pollutants into the atmosphere, which causes acid rain, air pollution, and climate change. Among these are sulfur dioxide (SO2), nitrogen oxides (NOx), and carbon dioxide (CO2). Another reason is that businesses are more likely to rely on non-renewable energy sources due to the economic pressure to increase output while minimizing expenses. More energy use in industrial sector means more fossil fuel extraction and transportation, which means more habitat loss, oil spills, and polluted water, all of which worsen environmental degradation.

The analysis of the coefficient of transport energy consumption in all quantiles is statistically significant and positively linked with environmental degradation for full and developing panel. This result is consistent with the study of Yin et al. (2015), Danish et al. (2018), Raza et al. (2019), and Mohsin et al. (2019). It implies that environmental degradation raises due to transport energy consumption. The vehicles that are run on fossils fuels especially diesel and gasoline, released particulate matter into the air for example carbon dioxide and nitrogen oxides. For many reasons, including their low-price, high-energy density, and the extensive network of refineries, pipelines, and gas stations that already exists to facilitate their usage, fossil fuels are economically preferred. Higher fuel consumption is result of the increasing demand for transportation which occurs through expanding economies and increased urbanization. Habitat loss and fragmentation are other problems that arise from building highways and roads.

However, in developed panel, transport energy consumption coefficient is statistically significant and adverse associated with environmental degradation in all quantiles. The outcome of the study supports the prior studies results conducted by Choi et al. (2018), Adam et al. (2020), and Kwilinski et al., (2024). There are a number of economic and technological reasons that leads to a negative association between them. Cleaner technology like electric vehicles (EVs), hybrid automobiles, and fuel-efficient engines have become widely used as a result of the automotive industry's innovation in response to stricter emissions requirements and regulations. These innovations lessen the need for fossil fuels and cut down pollution and greenhouse gas emissions. Sustainable transportation options are economically prioritized in urban planning and public transportation infrastructure. Buses, subways, and trains are more efficient and emit fewer emissions per passenger than private cars. That's why developed countries usually have well-established public transit networks. The shift to renewable energy sources (biofuels, solar, wind, and hydroelectric power) and public transportation are also supported by government regulations and subsidies.

Furthermore, the environmental advantages of adopting electrical vehicles increase as the share of renewables. Further reductions in emissions are achieved by using the renewable energy to power the infrastructure needed to charge electric public transit. Moreover, by using renewable energy sources throughout the production process and supply chain, the carbon footprint connected with the development of electric vehicles is significantly lower than that of conventional internal combustion engine vehicles. This cleaner energy source benefits not only the electric vehicles (EVs) but also the EV ecosystem as a whole. The integration of renewable energy into the transportation sector can reduce dependency on imported fossil fuels, improve energy security, and create jobs in the renewable energy sector.

In addition, green technology has been more pervasive in the industry as a result of rising consumer awareness and desire for eco-friendly transportation alternatives. Consumers are being encouraged to move away from conventional, fossil fuel-powered vehicles by offering incentives including tax rebates, savings on running expenses, and tax reductions for electric and hybrid vehicles. Furthermore, the reduction of the environmental impact of transportation energy utilization can be achieved by investments in the research and development of advanced transportation technology and alternative fuels.

In every quantile, the whole panel's residence energy consumption coefficient is positive and statistically significant. All quantiles, with the exception of Q10, are positive and statistically significant in both developed and developing nations. The study's findings are consistent with those of Miao (2017) and Nejat et al. (2015). This positive connection between these two variables has some economic implications. Residents primarily rely on fossil fuels such as gas from natural sources, coal, and heating oil for their energy needs. Large volumes of greenhouse gases and other air pollutants are released when these fuels are burnt in home for heating, cooling, and electricity. In areas that are unable to use the renewable alternatives or with outdated energy infrastructure, these fossil fuels may be the most cost-effective and convenient option for domestic energy usage.

The second reason is that the need for residential energy to run houses, appliances, and electronics is increasing in parallel with rising incomes and urban populations. Energy production relies on natural resources like water for hydroelectric power and land for biomass energy, both of which are strained to their limits by this rising demand, which in turn increases emissions. Energy waste and environmental damage are also caused by residential areas' outdated infrastructure and poor building designs. Households are financially motivated to reduce energy expenditures, but these incentives tend to put short-term savings ahead of long-term environmental consequences, which means that residential energy use is positively associated with environmental degradation.

The commercial energy consumption coefficient is statistically significant and positive throughout the all quantiles. The finding of the study is similar to the study of Cui et al. (2016), Hussain et al. (2019) and Saudi et al. (2019) that supports positive connection between the commercial energy use and environmental deterioration. There are a number of economic considerations that are essential to commercial activity that cause a positive correlation between. Commercial buildings, such as those in the office, retail, and hotel industries, frequently use HVAC, lighting, and electrical appliances that consume a lot of energy. Coal, natural gas, and petroleum products are the backbones of these operations, and their combustion results in the emission of greenhouse gases.

Moreover, when companies make financial decisions, their objective is to maximize profits while cutting costs. One way to achieve objective is to utilized energy sources that are both affordable and compatible with what is already in place. Renewable energy sources may find it difficult to compete with fossil fuels due to their high initial costs and undeveloped supply chains, which contribute to the fossil fuels' preference. Companies are putting more pressure on ecosystems and natural resources to keep up with rising consumer demand and economic growth. Pollution from commercial sector, waste management and transportation, as well as habitat loss and land degradation, are common outcomes of this expansion.

The coefficient of the use of agricultural energy is statistically significant in all the whole panel quantiles except in Q90. Moreover, the study findings reveal that the agricultural energy consumption has a large positive coefficient at the Q 10, Q 25, Q 75, and Q 90 quantiles in case of the countries that tend to be developing. The coefficient of agricultural energy use is however not significant at a median quantile (Q50). Findings of the study are also aligned with the findings of the previous studies by Waheed et al. (2017), Dogan (2019), Hafeez et al. (2020), Yurtkuran (2021) and Hossain and Chen (2021). In developing countries, the application of old machines, ineffective irrigation system and overexploitation of chemical inputs such as fertilisers and pesticides are straining the environment. Moreover, such inputs lead to emissions since they are normally obtained using fossil fuels. The economic force behind the use of these inputs is the increase of agricultural productivity to meet the growing food demand due to the growing populations and changing diets.

In addition, economic globalization and competitiveness in the market also stimulate farmers to maximize yields and profit, which often results in unsustainable land management practices. Examples of such practices include soil erosion by intensive farming methods, agricultural run-offs to water bodies and deforestation to make agricultural land. Also, it leads to the increased consumption and aggravation of environmental effects due to the absence of alternative sources of energy and use of obsolete technology.

Developed countries, on the other hand, energy consumption on agriculture is negative and statistically significant at lower, median, and upper quantile. These findings are similar to those of the research by Dar and Asif, (2019) and Zhang et al. (2019). The economic justification is that the application of the contemporary cultivating methods is useful in the minimization of environmental degradation. Modern agricultural equipment, including automated irrigation systems and accuracy farming technologies led to the use of energy in production processes being lower. In an effort to upgrade the quality of the environment, the farmers are resorting to renewable forms of energy such as solar power and wind energy to satisfy their energy needs. This makes them less reliant on fossil energy and emissions are minimized.

Moreover, the developed nations often possess good environmental regulations and economic incentives to use environmentally friendly farming techniques. Farmers are urged to use practices such as the rotation of crops, reduced tillage, and integrated pest management which have a low adverse effect on the environment. Secondly, the government offers the subsidies in form of financial aid to develop environmentally friendly methods of agricultural practices. Such investments are useful in maintaining water quality, improving soil health, and safeguarding biodiversity besides reducing energy consumption. Such a bad relationship is caused by technological innovation, regulatory frameworks, customer preferences, and financial incentives.

The research findings indicate that all the quantiles and panels (both full, developing, and developed countries) exhibit statistically significant and strongly correlated coefficients on GDP and population and environmental deterioration. This connection implies that environmental degradation tends to go up with the increase in the output of the economy and the number of citizens. The increasing impact of the higher quantiles can be explained by the increased resources utilization and wastage of affluent and more populated cultures, which can be compared with the IPAT model, which states that population (P), wealth (A, which can be measured by GDP), and technology (T) influence the environmental impact (I).

Regarding technology, the significant negative coefficients at lower quantiles (Q10 and Q25) and upper quantiles (Q75 and Q90) suggest that technological advancements contribute to reducing environmental degradation in full panel. However, the lack of significance at the median quantile (Q50) indicates that the benefits of technology may diminish as consumption levels reach extreme highs, possibly due to saturation effects or unsustainable consumption patterns. In developing countries, the negative coefficient is consistently significant at the 1% and 5% levels, indicating that technological improvements play a crucial role in mitigating environmental impacts at median and upper quantiles. In developed countries, the negative coefficient is significant at all quantiles, highlighting that technological advancements contribute significantly to environmental protection, although the impact may vary depending on the level of consumption.

Table 7: Results of MMQR regarding Sectoral Energy Consumption Model

	Variables	**Location**	**Scale**	**Q10**	**Q25**	**Q50**	**Q75**	**Q90**
	$lnIEC_{it}$	0.124***	0.010	0.107***	0.113***	0.122***	0.132***	0.143***
		(0.027)	(0.017)	(0.028)	(0.025)	(0.026)	(0.035)	(0.049)
	$lnTEC_{it}$	0.128***	0.011*	0.111***	0.116***	0.126***	0.136***	0.148***
		(0.010)	(0.006)	(0.010)	(0.009)	(0.010)	(0.013)	(0.019)
	$lnREC_{it}$	0.193***	0.108***	0.034	0.084***	0.176***	0.279***	0.391***
		(0.033)	(0.025)	(0.030)	(0.026)	(0.031)	(0.049)	(0.074)
	$lnCEC_{it}$	0.235***	0.058*	0.149***	0.176***	0.226***	0.281***	0.342***
		(0.028)	(0.022)	(0.027)	(0.023)	(0.026)	(0.042)	(0.064)
	$lnAEC_{it}$	0.0004	0.042***	0.061***	0.042***	0.006	0.034**	0.077***
		(0.012)	(0.007)	(0.013)	(0.012)	(0.012)	(0.015)	(0.020)
Developing	$lnGDP_{it}$	0.045*	0.001	0.047**	0.046*	0.045**	0.144***	0.243***
		(0.025)	(0.015)	(0.022)	(0.020)	(0.023)	(0.034)	(0.047)
	$lnTECH_{it}$	-0.028***	-0.024***	-0.007	-0.004	-0.024***	-0.048***	-0.074***
		(0.008)	(0.005)	(0.010)	(0.009)	(0.008)	(0.010)	(0.013)
	$lnPOP_{it}$	1.069***	0.033***	1.019***	1.035***	1.064***	1.096***	1.131***
		(0.019)	(0.010)	(0.021)	(0.019)	(0.018)	(0.022)	(0.029)
	$Constant$	-9.214***	0.116	-9.386***	-9.332***	-9.233***	-9.122***	-9.003***
		(0.191)	(0.113)	(0.172)	(0.161)	(0.182)	(0.251)	(0.350)
	$lnIEC_{it}$	0.019	0.106***	0.106***	0.111***	0.140***	0.250***	0.281***
		(0.047)	(0.037)	(0.040)	(0.032)	(0.042)	(0.068)	(0.112)
	$lnTEC_{it}$	-0.200***	-0.026	-0.160***	-0.178***	-0.196***	-0.218***	-0.250***

		(0.032)	(0.019)	(0.030)	(0.028)	(0.031)	(0.041)	(0.059)
	$lnREC_{it}$	0.400***	0.207***	0.075	0.221***	0.361***	0.536***	0.794***
		(0.059)	(0.034)	(0.072)	(0.058)	(0.058)	(0.072)	(0.099)
	$lnCEC_{it}$	0.401***	0.004	0.395***	0.398***	0.401***	0.404***	0.409***
		(0.069)	(0.049)	(0.088)	(0.071)	(0.067)	(0.084)	(0.129)
	$lnAEC_{it}$	-0.175***	-0.132***	-0.381***	-0.289***	-0.201***	-0.090**	-0.073*
		(0.028)	(0.013)	(0.031)	(0.028)	(0.028)	(0.036)	(0.044)
Developed	$lnGDP_{it}$	0.011	0.035	0.144***	0.219***	0.245***	0.335***	0.378***
		(0.040)	(0.028)	(0.040)	(0.034)	(0.038)	(0.053)	(0.082)
	$lnTECH_{it}$	-0.094***	-0.154***	-0.148***	-0.039*	-0.065***	-0.195***	-0.387***
		(0.023)	(0.013)	(0.026)	(0.023)	(0.023)	(0.033)	(0.042)
	$lnPOP_{it}$	0.856***	0.138***	1.073***	0.975***	0.883***	0.766***	0.595***
		(0.051)	(0.031)	(0.061)	(0.051)	(0.050)	(0.063)	(0.089)
	$Constant$	-8.216***	-0.428***	-8.887***	-8.586***	-8.299***	-7.937***	-7.406***
		(0.424)	(0.262)	(0.170)	(0.405)	(0.411)	(0.513)	(0.756)
	$lnIEC_{it}$	0.130***	0.029*	0.084***	0.105***	0.127***	0.148***	0.182***
		(0.019)	(0.012)	(0.025)	(0.021)	(0.019)	(0.022)	(0.032)
	$lnTEC_{it}$	0.059***	0.012	0.078***	0.069***	0.060***	0.051***	0.037*
		(0.012)	(0.008)	(0.025)	(0.010)	(0.011)	(0.014)	(0.021)
	$lnREC_{it}$	0.104***	0.121***	0.129***	0.134***	0.152***	0.171***	0.241***
		(0.028)	(0.020)	(0.034)	(0.028)	(0.027)	(0.035)	(0.052)
	$lnCEC_{it}$	0.218***	0.202***	0.117***	0.121***	0.131***	0.153***	0.258***
		(0.025)	(0.018)	(0.035)	(0.028)	(0.026)	(0.031)	(0.046)
	$lnAEC_{it}$	0.058***	0.107***	0.046***	0.051***	0.057***	0.062***	0.071
		(0.012)	(0.008)	(0.015)	(0.012)	(0.012)	(0.015)	(0.022)
Full Panel	$lnGDP_{it}$	0.132***	0.024*	0.170***	0.153***	0.134***	0.117***	0.089***
		(0.015)	(0.011)	(0.020)	(0.016)	(0.015)	(0.019)	(0.028)
	$lnTECH_{it}$	0.015	0.042***	-0.052**	-0.022*	-0.011	-0.042***	-0.090***
		(0.009)	(0.006)	(0.011)	(0.009)	(0.009)	(0.012)	(0.018)
	$lnPOP_{it}$	0.968***	0.051***	1.048***	1.012***	0.972***	0.935***	0.877***
		(0.017)	(0.011)	(0.021)	(0.017)	(0.017)	(0.020)	(0.029)
	$Constant$	-9.144***	0.525***	-9.980***	-9.605***	-9.193***	-8.811***	-8.205***
		(0.134)	(0.091)	(0.166)	(0.135)	(0.131)	(0.159)	(0.238)

*Standard errors are given in brackets (). ***, **, &* shows the level of significance at 1%, 5%, & 10% respectively.*

4.3.3.1 Robustness Analysis of MMQR Estimates

To ensure the robustness of the MMQR findings, this study further employs the GMM approach to examine the relationship between sectoral energy consumption and environmental degradation across developing countries, developed countries, and the full panel. The GMM estimates are largely consistent with the MMQR results, thereby reinforcing the reliability of the main findings. The detailed results are presented in Table 8.

Table 8: Results of GMM for Sectoral Energy Consumption Model for Robustness of MMQR

Panels Variables	Full Panel Coefficients	Developing Panel Coefficients	Developed Panel Coefficients
$lnEDG_{it-1}$	0.8320*** (0.0137)	0.7216*** (0.0299)	0.6551*** (0.0517)
$lnIEC_{it}$	0.0570*** (0.0043)	0.0645*** (0.0091)	0.3370*** (0.0654)
$lnTEC_{it}$	0.0241*** (0.0003)	0.0301*** (0.0032)	-0.1686*** (0.0407)
$lnREC_{it}$	0.0649*** (0.0060)	0.0281* (0.0096)	0.4818*** (0.0795)
$lnCEC_{it}$	0.0859*** (0.0059)	0.0096*** (0.0032)	0.3418*** (0.0519)
$lnAEC_{it}$	0.0019*** (0.0003)	0.0304*** (0.0045)	-0.0187* (0.0096)
$lnGDP_{it}$	0.1429*** (0.0067)	0.1329*** (0.0135)	0.2056*** (0.1144)
$lnTECH_{it}$	-0.0006*** (0.0002)	-0.0015** (0.0005)	-0.1049*** (0.0210)
$lnPOP_{it}$	0.0040*** (0.0008)	0.3625*** (0.0363)	0.0832*** (0.0259)
$Constant$	-0.0602*** (0.0076)	-2.9083*** (0.3513)	0.6707*** (0.2191)
Diagnostic Test			
No. of Obs.	2515	1394	1121
No of Countries	74	41	33
Instruments	66	35	23

AR(1)	-2.48	-3.20	-4.53
	(0.016)	(0.030)	(0.000)
AR(2)	-0.26	0.07	2.13
	(0.759)	(0.855)	(0.359)
Hansen Test	33.47	32.42	30.22
	(0.256)	(0.209)	(0.308)

*Standard errors are given in brackets (). ***, **, &* shows the level of significance at 1%, 5%, & 10% respectively. Under the diagnostic test, () shows the P-values of AR(1), AR(2), & Hansen chi-square.*

5. Conclusion and Policy Recommendation

This study takes a closer look at how energy use in different sectors contributes to environmental degradation by applying the Method of Moments Quantile Regression (MMQR). Covering the years 1990 to 2023, it separates energy consumption into five major sectors—industrial, transport, residential, commercial, and agriculture—to explore their individual effects. By examining these relationships for the overall sample, and then comparing developing and developed countries, the study provides clearer and more nuanced insights into the energy–environment relationship.

Findings show that industrial energy use continuously impacts the degradation of the environment in all quantiles and country categories. This observation indicates the energy intensive and fossil fuel reliant aspect of industrial production, especially in the developing economics where clean technologies are not as widespread. Equally, household energy consumption and commercial energy consumption contribute favorably to the environmental degradation process in almost all scenarios, which highlights the environmental impact of the household and commercial energy consumption, which in most situations, depends on the non-renewable sources.

However, contrary to this, the effect of energy consumption by the transport sector differs according to development status. Although it also leads to the rise in environmental degradation in the developing world and the entire panel, the effects in the developed world feature a negative relationship-which suggests effective adoption of cleaner technology in transportation and more efficient mass transit systems. There are also regional differences in the relationship between the use of agricultural energy and environmental degradation. In developing nations, this impact is positive, which can be explained by the inefficient and intensive farming methods. On the other hand, such negative relationship implies successful implementation of energy efficient sustainable agricultural technologies in developed countries.

Also, other macroeconomic variables like GDP and population growth are observed to have positive impacts on environmental degradation throughout the board. Such results indicate the theoretical foundations of the IPAT model, according to which environmental pressure increases with increasing wealth and population. On the other hand, technological advancement has a rather positive effect in that it diminishes environmental degradation. The impact, however, is not homogenous with respect to quantiles, and is more effective in the tails of the distribution, perhaps due to variations in the speed at which technology is diffused, and its uptake rate and integration in the sectors.

The results of this study can have an important impact on the policy formulation. Lawmakers need to develop industry-specific energy transition plans. In nations especially those which are developing, the industrial sector must focus on modernizing ways of production, adopting clean fuels, and promoting energy efficient technology. It is important in developing countries to invest in electric cars, transport infrastructure that is based on renewable energy and mass transportation. The clean mobility solutions can be encouraged through incentives to reduce the impact of transport-related emissions and to align the sector with the sustainable development objectives. They should introduce green building code, smart metering and retrofit programs that will enhance efficient energy use. Behavioral changes in terms of responsible energy consumption by households and businesses can be supported with the help of awareness campaigns and financial incentives.

There should be favorable adoption of clean and efficient farming technologies by governments. Renewable-powered irrigation, precision agriculture and sustainable land management programs that are subsidized can greatly mitigate the environmental impact of the sector in the developing regions. The ecological cost of populated growth and urban development should be minimized by focusing on sustainable use of resources, green urban infrastructure, and compact cities among the urban planning and population management policies. The government can invest in green research and development and encourage transfer of technology, particularly to the developing countries to speed up the spread of green technologies and develop local sustainable development capacity.

Some of the market mechanism through which policy makers can implement the environmental laws are green taxes, carbon pricing and emissions trading schemes. These tools are able to promote more sustainable production and consumption patterns along with internalizing environmental costs. Furthermore, distributional heterogeneity needs to be considered in environmental monitoring frameworks by including indicators that take the form of quantiles. The strategy allows the development of fair policies that would respond to both the extreme environmental effects and median environmental effects by region and income.

The results presented by the study underline the fact that a complex, context-related policy framework should be developed that considers the imbalanced distribution of environmental pollution, developmental imbalances, and sectoral energy relationships. The findings indicate the significance of clean energy adoption, development of technologies, and institutional backing in achieving sustainable environmental outcomes and fostering fair economic growth.

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