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Exploring the Effects of Greenhouse Gases and Particulate Emissions on Quality of Life: A Country-Level Empirical Study

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Abstract: This study explores the relationship between greenhouse gases (GHGs) and particulate emissions and quality of life. The aim is to understand how emissions affect quality of life globally—across countries, regions, and the global population. Statistical methods were used to examine the impact of various emissions' indicators on different aspects of quality of life. The study highlights the urgent need for climate change action and encourages policymakers to take strategic steps. Climate change adversely affects numerous aspects of daily life, leading to significant consequences that must be addressed through policy changes and global governance recommendations. Key findings include that higher CO_2 and methane emissions and air pollution negatively impact quality of life. CO_2 emissions are positively associated with electricity while air pollution is positively associated with GDP and negatively with unemployment. Air pollution has an adverse effect on all three aspects of the children's welfare dimension of quality of life. These results provide timely and convincing insights for policy- and decision-making aimed at mitigating the impact of emissions on quality of life.

Keywords: access to electricity; air pollution; climate change; CO_2 emission; freshwater withdrawal; GDP; greenhouse gas emission (GHG); immunization rate; methane emission; mortality rate; quality of life; school enrollment; unemployment

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1. Introduction

The purpose of this exploratory work is to examine the association between greenhouse gas and other emissions (GHGs) and quality of life (QoL) at the macro-level. When we talk about the macro-level, we are referring to the impact on QoL that arises out of the adverse effects of emissions at the country level [1–7]. Prior research has mostly focused on narrative or large case studies and hardly any empirical studies have been conducted. In this paper, we develop a framework for conceptualizing and studying the association between emission factors and QoL indicators at the country level. Our research is motivated by various propositions that climate change factors such as CO_2 emissions, PM2.5 air pollution, methane emissions, annual freshwater withdrawals, and others have the potential to adversely impact QoL indicators such as access to electricity, GDP growth, mortality rates, unemployment, school enrollment, and the percentage of measles immunization at the country level [8–13]. By identifying the specific associations, policymakers may implement targeted solutions to prevent or reduce emissions (and thereby climate change) and mitigate its adverse effects on QoL [3,6–9]. This study addresses relationships empirically using statistical analysis. Although studies in past decades have examined and generally confirmed the negative association between emissions and QoL, very few have conducted empirical studies; most are anecdotal or case studies or descriptive in nature. Hence, the causal or associative relation between the two is not well understood. Unlike many of the others, our study is data-driven and provides empirical evidence upon which country leaders and policymakers can base decisions to allocate their limited resources to prevent or mitigate climate change by reducing emissions to improve QoL.

In this study, GGE climate change is characterized by several world development indicators (WDIs) that collectively specify the climate change in a country (https://datatopics.worldbank.org/world-development-indicators/, accessed on 2 October 2024). The World Bank has already pre-classified several key indicators as characterizing climate change and, therefore, is an established and recognized source of climate change variables. Quality of life is represented by a set of variables from historical research [2] and the data drawn from the WDI database. We believe that important insights can be derived from studying potential associations between GHG and other emissions and quality of life. This study makes several contributions. First, we introduce the contemporary literature on climate change, emissions, and QoL. Second, we develop an initial framework of the relationship between emissions and QoL. Third, we empirically examine the relationship with a large dataset, so the generalizability of the conclusions is possible. Fourth, by studying the macro-effects, countries can develop preventive and mitigation strategies for climate change to promote a higher quality of life.

The balance of the paper is organized as follows: we first provide background information with respect to climate change and emissions and quality of life. We then outline the conceptual framework of the association between emissions and QoL and develop the hypotheses. Fourth, we describe the methods and results. Fifth, we discuss the results of our statistical analysis and implications. We then identify the scope and limitations. This is followed by a discussion of the key contributions, conclusions, and directions for future research.

2. Research Background

Global climate change is a serious threat to quality of life as it affects many aspects of human well-being [1–5]. This research examines country-level data to examine how one aspect of climate variability, namely, GHG and other emissions, correlates with quality of life variables. By leveraging data analytics, the goal is to gain a better understanding of how GHGs impact living standards. These insights are vital for policymakers and researchers in creating strategies to improve resiliency and quality of life amidst environmental changes [3,6–9]. The investigation focused on the effects of indicators such as CO_2 and methane emissions, PM2.5 air pollution, annual freshwater withdrawals, and others on quality of life variables including mortality rates, immunization against measles, school enrollment, GDP growth and unemployment, and others [8,10–13]. This analysis of direct impacts helps identify vulnerable populations and critical areas requiring immediate attention. Beyond direct effects, climate change triggers a series of indirect consequences through environmental degradation [14,15]. These include, for example, increased greenhouse gas emissions which affect public health and socio-economic stability [3,16–22]. Understanding these chain reactions is essential for developing holistic and sustained climate resilience strategies [23,24]. The concept of quality of life encompasses many aspects of human experience, including economic, physical, and social well-being [25–31]. Climate change will have a profound impact on these aspects: climate policies, for example, that aim to reduce CO_2 emissions may have an impact on access to electricity due to the use of fossil fuels in the generation of electricity [3]. Climate change could make it more difficult to achieve adequate immunization because of the spread of diseases [10,32–38]. Climate-related food- and water-borne disease risks could increase mortality rates, especially for children under five [39,40]. The number of students enrolled in school may be affected if families prioritize short-term survival over educational opportunities [41]. Climate change could also have a significant impact on food production [3]. The study provides critical insights into how climate change affects quality of life variables across different countries and regions. By studying various socio-economic factors such as health, education, and economic stability, researchers can gain an understanding of the broader economic and social impacts [42–45]. A key assumption is that GHGs indeed have an adverse effect on quality of life. Key to this research, therefore, is the question of whether there is an association between GHGs and quality of life: are GHGs directly associated with quality of life? If so, which variables are significant?

As the study is data-driven and experiments and control groups are not appropriate in this study, we can at best examine association. Additionally, our study is limited to the emission aspect of climate change. The insights gained from this research can be used to shape strategies by governments and non-governmental organizations to increase resilience against climate impacts on quality of life. This research contributes significantly to academic discourse and practical discussion on sustainable development. It offers new perspectives for adapting to climate change and fighting it. Understanding the interdependencies between climate change and quality of life is pivotal for crafting resilient economic, education, environmental, and public health policies while simultaneously reducing climate change [46,47]. Unpacking the association between climate change and quality of life data informs sustainable economic growth models and global climate agreements [48–50]. Identifying which quality of life variables are most sensitive to climate change helps prioritize resource allocation and international aid [37,51].

Climate change refers to long-term alterations in temperature and weather patterns. While these changes can occur naturally, such as through variations in solar activity or significant volcanic eruptions, human activities have been the dominant cause since the 1800s. This is largely due to the burning of fossil fuels, including coal, oil, and gas [3,4,18]. Burning fossil fuels releases greenhouse gasses that function like a blanket around the Earth, trapping heat from the sun and causing temperatures to rise. The primary greenhouse gases driving climate change are carbon dioxide and methane [5,8]. These emissions result from activities like using gasoline to power vehicles or burning coal to heat buildings, clearing land, and deforestation [23,36,49]. The primary sectors responsible for greenhouse gases include energy, industry, transportation, buildings, agriculture, and land use [1,3,9].

The indirect impacts from climate change extend to an individual's quality of life along the lines of economic stability and social, physical, and mental well-being. Quality of life (QoL) is defined by the World Health Organization (WHO) as an individual's perception of their position in life, taking into account the cultural and value systems that one is embedded in, as well as the goals, standards, expectations, and concerns (https://www.who.int/toolkits/whoqol accessed on 2 October 2024). The concept of QoL addresses the overall well-being, inclusive of positive and negative aspects at a point in time [52–55]. Indicators to study QoL include those that are relevant to material living conditions (such as food, clothing, and shelter) as well as to quality of life (such as environment, education, community, health, governance, life satisfaction, safety, and work–life balance) [56–58]. Traditionally, quality of life was assessed using GDP. However, in recent years, this view has been considered myopic, as it does not cover aspects of a person's current and future living conditions [59–62]. While GDP and economic growth remain key for well-being, the goals and aspirations of people are equally important in considering the overall quality of life for a sustainable society [56,63–66].

Climate change has a detrimental socio-economic impact on the quality of life of the population [4,9,27,43]. Environmental effects such as rising sea levels and saltwater intrusion have forced communities to relocate, while droughts have exposed people to famine. Extreme weather conditions have exacerbated the incidence of food scarcity, droughts, and displacement worldwide [15,45,50]. The number of people facing acute food scarcity worldwide has increased from 149 million prior to 2019 (pre-COVID-19) to 333 million in 2023 (post COVID-19) in countries monitored by the World Food Program. Between 2010 and 2020, the death toll from climate change events was 15 times higher in highly vulnerable regions [7]. The negative impacts of climate change on health range from heat-related or vector-borne diseases to water-borne infections, allergies, malnutrition, respiratory issues, and mental health challenges [10,34,37,44,46]. These environmental and health threats cover a wide array of civil, political, economic, social, and cultural rights, including the rights to life, water, food, shelter, health, security, and cultural preservation [4,18,50].

At the national and local levels, the groups most vulnerable to the environmental and health impacts of climate change include poor and minority communities, women, children, people with chronic illnesses and disabilities, and those living in regions that are prone to extreme weather and climates [13,15,17,44,45]. At the global level, there is also a significant disparity in the effects of climate change on the quality of life. Despite being the lowest contributors to climate change, low-income countries suffer the most impacts, while high-income countries which are the highest contributors suffer less severe consequences [36]. This is because of the inequality in the capacity to adapt to the challenges posed by climate change [4]. As an example, the per capita GHG emissions in 2004 in developed nations such as the United States, Canada, and Australia approached 6 metric tons, and those in Japan and Western European countries ranged from 2 to 5 metric tons. In contrast, annual per capita GHG emissions in developing countries overall approximate 0.6 metric tons, and more than 50 developing countries have annual per capita GHG emissions less than 0.2 metric tons [4].

As global temperature increases, rich countries' economies continue to prosper, but the economic growth of poor countries is seriously impaired more than previously estimated [23,24]. The consequences for economic growth in poor countries will be substantial if we continue down a "business-as-usual" path of increasing carbon dioxide concentrations and rapid climate change, with poor countries' mean annual growth rate decreasing from 3.2% to 2.6%. 27 Poor countries are likely to suffer a greater negative effect than rich countries from climate change since they more often experience high temperatures [4,43]. Additionally, their economic growth depends very much on agriculture, natural resource extraction, and other sectors exposed to extreme weather fluctuations. Furthermore, air conditioning, insurance, and other risk management alternatives are less available in poor countries than in rich countries [4]. Considering the major adverse effects of Greenhouse Gas and other emissions on various dimensions of QoL, this study undertakes to shed light on the association between the two and find out the significant variables and linkages. Below, we next outline the conceptual framework and hypotheses.

3. Conceptual Framework and Hypotheses

Based on the background discussion above, we draw broadly from the literature in several disciplines, including the conceptual basis for climate change [3,23], quality of life [61,62,66], and the association between the two [49,51], global development [36,49,53], and the substantive number of publications at the UN, World Bank, IPCC, and others, to develop the conceptual framework for this study shown in Figure 1 below.

The independent variables reflecting climate change include CO_2 emissions, PM2.5 air pollution, annual freshwater withdrawals, and methane emissions. These are drawn from the World Bank's 'climate change' world development indicators [67–71]. The dependent variables characterizing QoL include access to electricity, GDP growth, mortality rates, unemployment, school enrollment, and the percentage of measles immunization. The six dependent variables are categorized into two dimensions: three variables relating to economic growth (access to electricity, GDP growth, and unemployment) and three variables relating to the education and health welfare of children (mortality rate, school enrollment, and immunization rate). These are drawn from the QoL literature and data retrieved from the WDI database [72–77]. Inflation and population are used as control variables. CO_2 emissions are mainly caused by the burning of coal, oil, and natural gas for energy production and transportation. Other significant sources include industrial processes, deforestation, and certain agricultural practices. Increased CO_2 emissions could indicate economic growth and the expansion of manufacturing industries. Therefore, we hypothesize that there may be a positive relationship between CO_2 emissions and the economic growth dimension of quality of life. However, CO_2 emissions will also lead to climate change and adversely affect the children's welfare dimension of quality of life. PM2.5 air pollution has a similar impact on the quality of life as CO_2 emissions. Annual water withdrawals will benefit both the economic growth and children's welfare dimensions of quality of life in the short term. Methane emissions are mainly caused by agricultural activities and the burning of organic materials. While highly industrialized regions can also have high methane emissions due to activities such as fossil fuel extraction and waste management, for the purpose of this analysis, we are theorizing that high methane emissions correlate with the levels of industrialization. Therefore, methane emissions are influenced by a variety of factors, and high emissions do not necessarily correlate with the level of industrialization. In other words, methane emissions are negatively related to both dimensions of quality of life. Table 1 presents the hypotheses tested in this study.

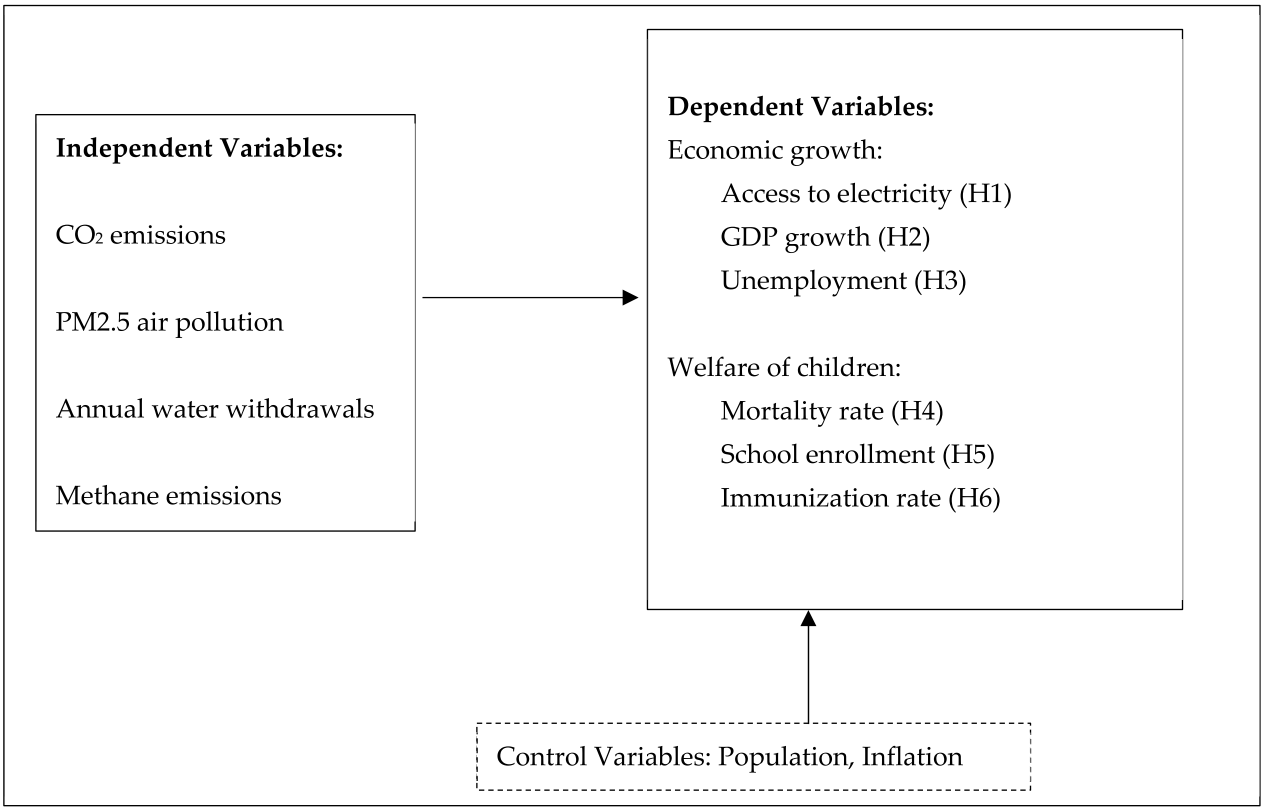

Figure 1. Conceptual framework.

Table 1. Hypotheses of the study.

H1: CO_2 emissions have a positive impact on the economic growth dimension of quality of life.	H1.1: CO_2 emissions are positively related to access to electricity. H1.2: CO_2 emissions are positively related to GDP growth. H1.3: CO_2 emissions are negatively related to unemployment.
H2: CO_2 emissions have a negative impact on the children's welfare dimension of quality of life.	H2.1: CO_2 emissions are positively related to the mortality rate. H2.2: CO_2 emissions are negatively related to school enrollment. H2.3: CO_2 emissions are negatively related to the measles immunization rate.
H3: PM2.5 air pollution has a positive impact on the economic growth dimension of quality of life.	H3.1: PM2.5 air pollution is positively related to access to electricity. H3.2: PM2.5 air pollution is positively related to GDP growth. H3.3: PM2.5 air pollution is negatively related to unemployment.
H4: PM2.5 air pollution has a negative impact on the children's welfare dimension of quality of life.	H4.1: PM2.5 air pollution is positively related to the mortality rate. H4.2: PM2.5 air pollution is negatively related to school enrollment. H4.3: PM2.5 air pollution is negatively related to the measles immunization rate.
H5: Annual water withdrawals have a positive impact on the economic growth dimension of quality of life.	H5.1: Annual water withdrawals are positively related to access to electricity. H5.2: Annual water withdrawals are positively related to GDP growth. H5.3: Annual water withdrawals are negatively related to unemployment.

Table 1. *Cont.*

H6: Annual water withdrawals have a positive impact on the children's welfare dimension of quality of life.	H6.1: Annual water withdrawals are negatively related to the mortality rate. H6.2: Annual water withdrawals are positively related to school enrollment. H6.3: Annual water withdrawals are positively related to the measles immunization rate.
H7: Methane emissions have a negative impact on the economic growth dimension of quality of life.	H7.1: Methane emissions are negatively related to access to electricity. H7.2: Methane emissions are negatively related to GDP growth. H7.3: Methane emissions are positively related to unemployment.
H8: Methane emissions have a negative impact on the children's welfare dimension of quality of life.	H8.1: Methane emissions are positively related to the mortality rate. H8.2: Methane emissions are negatively related to school enrollment. H8.3: Methane emissions are negatively related to the measles immunization rate.

4. Methods

4.1. Data

Data were collected at the country level for the period 2010–2019 for 217 countries. The sample size was 767, providing a robust dataset with sufficient variation for our analysis. Due to the significant differences in data magnitudes, all data were normalized. The collection period spanned ten years, capturing a wide range of economic, social, and environmental variables across different regions and development stages. The process of normalization was crucial to ensure comparability across diverse variables. Normalization involved adjusting the values measured on different scales to a common scale without distorting differences in the ranges of values. This procedure helps in minimizing the impact of scale differences and allows for a more straightforward interpretation of results. Table 2 shows how each variable was measured. This detailed table provides clear definitions and measurements for each variable, ensuring that the data are well understood and accurately interpreted in subsequent analyses. By defining each variable explicitly, we can ensure consistency and reliability in the analysis, allowing for meaningful comparisons and robust conclusions.

Table 2. Measurement of variables.

Variables	Measurement
Population total	Total number of people living in a specific area such as a country
Inflation	Annual percentage change in the cost of goods and services
CO_2 emissions	Average emissions of CO_2 per person measured in metric tons
PM2.5 air pollution	Average concentration of particulate matter smaller than 2.5 microns in the air
Annual water withdrawals	Percentage of country's available water resources used per year
Methane emissions	Total weight of methane gas emissions measured in kt of CO_2 equivalent
Access to electricity	Proportion of population with access to electricity
GDP growth	Yearly percentage increase in national economic output
Mortality rate	Annual deaths of children under five per 1000 live births
Unemployment	Proportion of the labor force that is jobless but seeking employment
School enrollment	Percent of children enrolled in secondary education
Immunization	Proportion of children between 12 and 32 months who have received the measles vaccine

4.2. Results

Table 3 represents the correlation matrix of the variables that were identified in the research framework.

Table 3. Correlation matrix.

	Popu	Infl	CO_2	PM2.5	Water	Metha	Elec	GDP	Mort	Unem	School	Immu
Population	1											
Inflation	0.113 **	1										
CO_2	0.018	−0.188 **	1									
PM2.5	0.150 **	0.179 **	−0.234 **	1								
Water withdrawals	0.029	0.112 **	0.265 **	0.344 **	1							
Methane	0.797 **	0.083 *	0.184 **	−0.032	0.004	1						
Electricity	0.055	−0.223 **	0.460 **	−0.458 **	0.073 *	0.113 **	1					
GDP growth	0.048	0.052	−0.154 **	0.247 **	0.024	−0.032	−0.224 **	1				
Mortality	0.030	0.193 **	−0.523 **	0.604 **	−0.051	−0.059	−0.871 **	0.269 **	1			
Unemployment	−0.078 *	−0.075*	−0.034	−0.181 **	−0.056	−0.061	0.200 **	−0.290 **	−0.228 **	1		
School enrollment	−0.022	−0.220 **	0.598 **	−0.572 **	0.062	0.082 *	0.867 **	−0.292 **	−0.895 **	0.251 **	1	
Immunization	−0.074 *	−0.073 *	0.380 **	−0.334 **	0.080 *	0.007	0.535 **	−0.101 **	−0.652 **	0.206 **	0.594 **	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

We tested our hypotheses by conducting regression analyses. The regression model is shown as below:

$$\text{Dependent Variable} = \beta_0 + \beta_1{*}CO_2 \text{ emissions} + \beta_2{*}\text{PM2.5 air pollution} + \beta_3{*}\text{Annual water withdrawals} + \beta_4{*}\text{Methane emissions} + \beta_5{*}\text{Population} + \beta_6{*}\text{Inflation} + \text{Year Indicators} + \varepsilon$$

A particularly important control variable in our regression was population. Since data were collected from multiple countries over approximately ten years, the analysis needed to consider the fixed effects of country and time. To account for the fixed effects of country, we included population in the regression model. This allowed us to control for variations across different countries. Additionally, to address the fixed effects of time, we incorporated the year variable into the regression model. The year helped control for any potential time-specific effects that could influence the results. By including these control variables and fixed effects, we aim to isolate the impact of the independent variables on the dependent variables, providing a more accurate and reliable analysis of the data. This approach helps ensure that the results are robust and not biased by unobserved heterogeneity across countries and over time. In summary, our regression analysis framework was designed to rigorously test the relationships between GHG and other emissions' variables (such as CO_2 emissions, PM2.5 air pollution, annual water withdrawals, and methane emissions) and quality of life or economic growth variables (such as access to electricity, GDP growth, mortality rates, unemployment, school enrollment, and the percentage of measles immunization). By accounting for country and time fixed effects, we strive to provide a comprehensive and nuanced understanding of these relationships.

Tables 4 and 5 represent the results of the regression analysis. Standardized regression coefficients and their significance levels are summarized in the tables.

Table 4. The impact of emissions on economic growth dependent variables.

	Dependent Variable		
	Access to Elec.	**GDP Growth**	**Unemployment**
CO_2 emissions	0.312 ***	−0.083 **	−0.101 ***
PM2.5 air pollution	−0.456 ***	0.228 ***	−0.211 ***
Annual water withdrawals	0.154 ***	−0.034	0.051
Methane emissions	−0.136***	−0.061	−0.036
Population	0.234 ***	0.065	−0.010
Inflation	−0.115 ***	−0.003	−0.058
R-Square	0.396	0.095	0.057
p-value of overall model	<0.001	<0.001	<0.01

*** $p < 0.01$. ** $p < 0.05$.

Table 5. The impact of emissions on the welfare of children dependent variables.

	Dependent Variable		
	Mortality Rate	**School Enrollment**	**Measles Immunization**
CO_2 emissions	−0.361 ***	0.454 ***	0.300 ***
PM2.5 air pollution	0.604 ***	−0.529 ***	−0.311 ***
Annual water withdrawals	−0.163***	0.126 ***	0.104 ***
Methane emissions	0.182 ***	−0.150 ***	−0.081
Population	−0.199 ***	0.172 ***	0.026
Inflation	0.043	−0.061 **	0.031
R-Square	0.563	0.588	0.229
p-value of overall model	<0.001	<0.001	<0.001

*** $p < 0.01$. ** $p < 0.05$.

Table 6 presents the results of the hypotheses tested through our regression analyses. Each hypothesis is evaluated based on the direction and significance of the estimated coefficients. The results are categorized as either supported or rejected, with specific notes on the nature of the rejection, such as the sign being opposite to the hypothesis or the result being statistically insignificant.

Table 6. Hypotheses' results based on the data analysis.

Hypothesis		**Support/Reject**
H1	H1.1	Support
	H1.2	Reject (the opposite sign)
	H1.3	Support
H2	H2.1	Reject (the opposite sign)
	H2.2	Reject (the opposite sign)
	H2.3	Reject (the opposite sign)
H3	H3.1	Reject (the opposite sign)
	H3.2	Support
	H3.3	Support
H4	H4.1	Support
	H4.2	Support
	H4.3	Support
H5	H5.1	Support
	H5.2	Reject (insignificant)
	H5.3	Reject (insignificant)
H6	H6.1	Support
	H6.2	Support
	H6.3	Support
H7	H7.1	Support
	H7.2	Reject (insignificant)
	H7.3	Reject (insignificant)
H8	H8.1	Support
	H8.2	Support
	H8.3	Reject (insignificant)

5. Discussion

The results paint a complicated picture of the association between climate change and human development. Among the key findings, higher CO_2 emission is associated with higher access to electricity. Electricity generation mainly depends on coal and its products, which has led to the increase in CO_2 emissions. By proxy, higher CO_2 emissions imply more demand for electricity thereby resulting in a higher production of electricity utilizing fossil fuels. While electricity itself is good, its production from fossil fuels is indicated in the positive association. On the other hand, higher CO_2 emissions act as a catalyst to the increased use of electricity as society moves towards alternative and clean energies. However, higher CO_2 emission is not associated with higher GDP growth; on the contrary, higher CO_2 is negatively correlated with GDP growth, which means higher CO_2 is associated with lower GDP growth. This paradoxical result needs to be further studied from a reverse causality perspective applying the Granger Causality Test. Historically, causality results confirmed the unidirectional causality running from economic growth to CO_2 emissions but not vice versa. Higher CO_2 emission is associated with lower unemployment. This finding suggests higher CO_2 emission because of rapid industrialization is associated with reduced unemployment. As countries strive for sustainable development and poverty alleviation, emissions are collateral damage resulting in environmental degradation and climate change. A careful balance between economic growth, increased job creation, and higher emissions needs to be achieved. As a contrary indication, higher CO_2 emission is not associated with a higher mortality rate; on the contrary, higher CO_2 emission is associated with a lower mortality rate. A plausible explanation is that CO_2 emission is a consequence of economic growth; simultaneously, health quality improves with higher economic growth. Similarly, higher CO_2 emission is not associated with lower school enrollment; on the contrary, higher CO_2 emission is associated with higher school enrollment. This too is likely due to economic growth. Higher CO_2 emission is not associated with a lower measles immunization rate; on the contrary, higher CO_2 emission is associated with a higher measles immunization rate. Relating to healthcare, economic growth (resulting in increased CO_2 emission) may result in better quality healthcare, with a higher immunization rate being a good indicator of quality healthcare. Overall, the results show that CO_2 emissions have a mixed impact on the economic growth dimension of quality of life. The results also show that CO_2 emissions have a positive impact on the children's welfare dimension of quality of life, which is different from how we hypothesized the relationships.

Addressing air pollution, higher PM2.5 air pollution is not associated with higher access to electricity; on the contrary, higher PM2.5 air pollution is associated with lower access to electricity. This empirical result is quite counterintuitive and presents an interesting research question for future studies. One possible explanation is that lower access to electricity is often a sign of underdevelopment, where the infrastructure for modern, cleaner energy sources may be lacking. In such places, people may rely on cheaper but dirtier fossil fuels. Therefore, when the dataset includes multiple countries at different stages of development, more polluted nations are associated with lower access to electricity. The next two findings are reflecting reality as higher PM2.5 air pollution is associated with higher GDP growth and lower unemployment. One of the key findings of this study relates to the association between air pollution and children's welfare as a proxy for quality of life (health). Higher PM2.5 air pollution is associated with a higher mortality rate, lower school enrollment, and a lower measles immunization rate. It is obvious air pollutions results in premature deaths, may prevent children from attending school (e.g., 'smog' days), and declining immunizations (difficulty in access to immunization due to bad-quality air) [78,79]. In summary, higher PM2.5 air pollution also shows some mixed impacts on the economic growth dimension of quality of life. But in general, the relationships are consistent with what we have hypothesized. PM2.5 air pollution is a more direct measure of climate change and the negative consequences of the change.

Regarding annual freshwater withdrawal and its effects, higher annual freshwater withdrawal is associated with higher access to electricity. This reflects the reality as hydroelectric projects associated with electricity generation result in more consumption (access) of electricity. Contrary to initial expectations, the analysis found no significant correlation between annual freshwater withdrawal and GDP growth. Likewise, the relationship between freshwater withdrawal and unemployment rates is statistically insignificant. This suggests that variations in water usage do not meaningfully affect GDP growth or employment levels. These empirical results do not confirm the hypothesized connections between water usage and key economic indicators, implying that other variables may play a more influential role in these outcomes. Consequently, further research is necessary to explore alternative factors. Concerning the children's dimension of QoL, higher annual freshwater withdrawal is associated with a lower mortality rate. Again, the implication is greater withdrawal means better economic growth resulting in a reduced mortality rate. Likewise, higher annual freshwater withdrawal is associated with higher school enrollment (availability of food, water, and affordability with economic growth). Additionally, higher annual freshwater withdrawal is associated with a higher measles immunization rate. Of course, the rapid depletion of freshwater itself has negative effects so freshwater must be managed efficiently.

Next, in examining the effect of methane emission, higher methane emission is associated with lower access to electricity. It is conceivable that water resources needed for electricity generation are diverted to farming and agricultural activities resulting in higher methane emission but lower electricity production. Further studies are warranted. However, the analysis indicates that there is no significant relationship between methane emissions and GDP growth, nor between methane emissions and unemployment rates. This suggests that methane emissions are not a meaningful indicator of economic growth or employment opportunities. Furthermore, when assessing the welfare dimension related to children's quality of life, higher methane emissions are linked to increased mortality rates and lower school enrollment, but there is no significant connection with measles immunization rates. Methane results in poor air quality by contributing to the formation of ground-level ozone and particulate pollution. Exposure to ozone and particulate pollution damages airways, aggravates lung diseases, causes asthma attacks, increases rates of preterm birth, cardiovascular morbidity, and mortality, and heightens stroke risk. This warrants attention. To summarize, CO_2 and methane emissions do impact some of the economic aspects of QoL. Air pollution is associated with some of the dimensions of economic growth while having a negative impact on the children's welfare component of QoL. These are two of the key findings.

6. Scope and Limitations

While our study is constrained by data availability in terms of the time and number of countries, it has other limitations. For example, the number of countries included is limited, and because the data source is the world development indicators (WDIs) of the World Bank, there is a reporting lag that resulted in numerous missing values. Additionally, being an exploratory study, we considered only a limited set of key variables from the climate change category and key variables from QoL to scope our study. A more comprehensive study could include a wider range of variables from diverse sources, cover more countries, and extend over a longer period. To gain a macro-perspective on the climate change–QoL association, we also incorporated additional control variables. However, there may be additional intervening or compounding variables influencing the adverse relationship with QoL. Furthermore, while our study examines associations and relationships between variables, it does not investigate causality. The study is data-driven and experiments or control groups are not suitable. Lastly, this is an exploratory predictive analytic study; more advanced analytical methods including the Granger Causality Test could be applied in future research.

7. Conclusions and Future Research

Our exploratory study demonstrates that climate change has a negative impact on quality of life. Both climate change and QoL are critical to the health and well-being of individuals and society. To conceptualize these phenomena, it is essential to extend the focus beyond the individual context and incorporate the broader cultural, social, and structural context in which these relationships occur. Furthermore, the ethical, geographical, legal and regulatory, and political contexts must be considered. This requires a multi-dimensional approach, including interdisciplinary research, diverse data sources, and innovative frameworks. Given the ever-increasing disparities in the economy, health, and the environment, new policy and research initiatives are needed to address the adverse effects of climate change on QoL and vice versa.

When identifying and developing action research and policies and strategies, governments and stakeholders must consider the dual role of QoL as both a facilitator of improvement in the human condition and a contributor to climate change, especially through rapid industrialization. Addressing these large-scale disparities requires interventions at the highest levels. Activists, government and non-profit entities, policymakers, researchers, and other stakeholders' policies must work together in this effort: researchers should investigate and share insights and recommendations with policymakers, while policymakers need to communicate the challenges and needs of the economic and human welfare dimensions to researchers. Researchers can leverage variations in national cultural, political, and societal systems to explore how different forms of governance impact the relationship between climate change and QoL. Due to constraints in budgets and time, nations need to prioritize specific aspects of climate change to advance key aspects of QoL. Education plays a crucial role in enabling informed decisions to mitigate the negative impacts of climate change. Additionally, new models and empirical studies are needed to capture the nuances of this relationship and validate the largely anecdotal and case study evidence currently available.

Our study also presents several opportunities for future research. Future research could integrate additional cultural, regional, and social variables—such as population demographics, local cultural and religious beliefs, governance structures, and historical context—for a more comprehensive analysis. Further, incorporating data from other sources could expand the study to include more countries and variables, particularly a more precise classification of income levels, geographic regions, population size, and other factors, thereby broadening the scope of the analysis. Additionally, case studies and action research can complement empirical studies. Methodologically, future research can deploy predictive analytics meta-regression analysis and reverse causal studies to assess the relationships between climate change and QoL variables. Future studies should also move beyond country-level factors to explore the broader social context in which climate change and QoL occur, such as gender inequality, impacts on children and the elderly, and other societal dimensions. This approach will generate insights that can inform effective policies and interventions to address disparities in climate change and QoL. Additionally, ensuring adequate funding, political commitment, technology transfer, and fostering partnerships are essential for more effective emission mitigation and QoL efforts. Although the study of the relationship between emissions and QoL is still in the nascent phase, further empirical research and case studies can help accelerate its maturing process.

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