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The Relationship among Climate Change Vulnerability, Fossil Fuel Energy, Economic Development, Financial Development, Institutional Quality and Population Growth in 36 Developed Countries

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ABSTRACT

The research assesses the impact of fossil fuel energy consumption on climate change vulnerability for 36 developed nations using the time period of 2000-2022. For the empirical results, Canay (2011) fixed effects quantile regression is employed. The outcome indicates that fossil fuel energy positively and significantly impacts on climate change vulnerability across all the quantiles. These findings validate the theoretical linkage and economic intuition as well. Policy implications should consider the role of fossil fuel energy in shaping climate change policy. Furthermore, the factors such as economic development, financial development, institutional quality and population growth should be considered in the relationship between fossil fuel energy and climate change vulnerability.

Keywords: Fossil Fuel Energy, Climate Change Vulnerability, Quantile Regression, Developed Countries
JEL Classifications: Q4, Q56, C33

1. INTRODUCTION

In the context of climate change, vulnerability is a multi-component, dynamic process defined by the degree of exposure of a system (population group, territory, economic sphere or ecosystem) to climatic risk factors, the sensitivity of the socio-economic and environmental situation to these influences and their outcomes (sensitivity and susceptibility), and the shortage of available resources, institutional and adaptive capacity. According to Füssel (2007), vulnerability refers to a comprehensive conceptual approach to climate risk assessment that includes physical descriptions of risk, internal adaptive capabilities of the system and ability to cope with external influences. Vulnerability in climate change is an integrative, functional concept defined by the degree of exposure of a particular system to climatic stimuli (Extreme Temperatures, Precipitation Changes, floods, and hazards such as drought), sensitivity to consequences resulting from that effect, or fragility of socio-economic and environmental foundations, as well as the system's ability to adapt to climate change via available sources, institutional structure, knowledge, and technologies (Francini et al., 2020). Vulnerability in climate change is the likelihood that a system or population group will face negative consequences under the influence of climate risks and the degree of predisposition to these consequences due to pre-existing socio-economic, environmental or institutional constraints. According to the CARE (2016) approach, the concept of vulnerability is not only formed as a result of the presence or impressiveness of risk, but also covers a predisposing condition associated with factors such as pre-existing resource deficiency of the system, poor social protection, gender imbalance, low adaptive capacity. Additionally, climate change vulnerability is an integrative concept characterized by the degree of exposure of a system to climate risks, the sensitivity of these effects to and relative to environmental and socio — economic sensitivities, as well as the degree of flexibility that determines the chances of reducing or adapting to these negative consequences (Olivares-Aguilar et al., 2022). While vulnerability indicates the probability of adverse effects of climate change, particularly increases the risk of loss of socioeconomic systems, CO_2 emissions resulting from large-scale consumption of fossil fuels are being recognized as one of the main factors in this vulnerability's escalation.

Greenhouse gases (notably CO_2) released by the combustion of fossil fuels (coal, oil and natural gas) for energy production purposes accumulate in the atmosphere and play a crucial role in the global derailment of climate system. According to the UN (2024), emissions from these fuels account for nearly 68% of global greenhouse gas emissions, and are regarded as the greatest determinant of climate change. This causes an increase in the level of ecological footprint and an acceleration of the global warming process as a result of the economy's high dependence on energy. Carbon dioxide (CO_2), released by the combustion of fossil fuels in energy production processes, is considered as one of the main sources of global warming and climate change. Wang and Azam, (2024) argue that it is CO_2 emissions that depend on fossil fuel consumption that have a significant impact on the climate system by increasing the average temperature of the Earth's surface by increasing the concentration of greenhouse gases in the atmosphere. According to Dai et al. (2022), in economies with a higher proportion of fossil fuels in the energy mix, greenhouse gas emissions will increase and this situation will increase the level of vulnerability to the climate system. They argue that the negative environmental consequences associated with fossil fuel consumption — specifically the increase in CO_2 emissions — exacerbate the need for sensitivity and flexibility to the effects of climate change. The process is also at the center of political and institutional measures aimed at reducing climate vulnerability.

Transition to low-carbon energy sources increases economic instability and social vulnerability in areas that rely on the production of fossil fuels and the extraction of electricity from them, which may further exacerbate their vulnerability to climate change (Raimi et al., 2022). The studies show that carbon emissions in states where economic growth relies on high levels of fossil fuels would increase rapidly, and that the situation would exacerbate their socioeconomic vulnerability to global climate change as a carbon-rich energy system reduces tolerance to extreme climate events (Ding et al., 2021). Fossil fuel energy consumption is a major factor in CO_2 emissions that exacerbate instability in the climate system and make developing nations more vulnerable to the consequences of climate change (Lönnqvist et al., 2018). Studies show that fossil fuel consumption increases CO_2 and greenhouse gas levels in the atmosphere by increasing openness of the system to climate exposure through global warming and extreme events as well as enhances vulnerability (Dai et al., 2022). Numerous studies show that high levels of economic and financial development and strong institutions increase adaptive capacity to mitigate the vulnerability caused by fossil fuel exposure, conversely, weak institutions and low levels of financial resources increase vulnerability (Song et al., 2023).

In this context, the content of the study stems from the need to determine the correlation between climate vulnerability, energy consumption, and institutional-economic indicators, as increasing fossil fuel consumption increases global climate risks, weakening systems' adaptive capabilities, which manifests as an important factor in economic stability, financial resource utilization, institutional quality, and population pressure.

2. LITERATURE REVIEW

2.1. Impact of Fossil Fuel Energy Consumption on Climate Change Vulnerability

In literature, researching the impact of fossil fuel energy and climate change vulnerability with other factors is gaining interest. More precisely, Wang and Azam (2024) empirically studied the long-and short-term correlation between natural resource reliance rates, fossil fuel energy consumption, and associated greenhouse gas emissions (GHG) in high-emission countries through panel data. Analysis shows that fossil fuel energy consumption combined with overexploitation of natural resources significantly increases GHG emissions, leading to global climate warming, increasing vulnerability of countries to extreme climate events. Moreover, Dai et al. (2022) focused on assessing the impact of energy mix (fossil and renewable) on climate change vulnerability in G7 countries, analyzing long and short-term dynamic relationships through the panel — ARDL model on four key climate-affected sectors including ecosystem, food security, health sector, and infrastructure resilience. The results show that excessive share of fossil fuels in the energy mix increases climate vulnerability in several sectors, as increased GHG emissions decrease systems' tolerance to climate effects. Additionally, the study conducted by Shang et al. (2024) was based on meta-analysis and model validation to assess how increases in global renewable energy share affect climate risk and climate vulnerability levels. The authors compared many of the empirical developments from the post-2000 scientific literature base and in-depth evaluated the structural links between renewable and fossil fuel energy sources. Empirical results suggest that the risks associated with climate risk decrease steadily as the proportion of fossil energy decreases globally and the study confirmed that the increase in the share of renewable energy would reduce climate system susceptibility by reducing greenhouse gas emissions, thereby significantly reducing climate vulnerability. Another study driven by Zang (2024) analysed the effects of energy supply problems on climate change and explores the problems of energy supply and the effects of fossil fuels on CO_2 emissions. The results show that energy supply problems and a high proportion of fossil fuels lead to an increase in CO_2 emissions, which exacerbates climate vulnerability. The energy vulnerability index was developed by Liu et al. (2023) and this index was formulated on the basis of factors such as energy supply stability, import dependence rate, price volatility, and non-recovery of energy resources. The study empirically evaluated the effects of energy vulnerability on CO_2 emissions based on panel data and also included socioeconomic indicators in the model. The results indicate that states with higher EVI have higher CO_2 emissions, which increases vulnerability to the climate system through excessive dependence on fossil fuels, low energy supply stability, and economic instability. According to the study, energy vulnerability not only increases the environmental burden, but also reduces the resilience (resilience) of economic and social systems to the effects of climate change, further exacerbating climate vulnerability. Kim and Park (2023) analysed the spatiotemporal correlation between renewable energy transition and climate vulnerability across the world using the Fuzzy Analytic Hierarchy Process and panel data regression and find that while renewable energy increases proportionally with climate exposure and sensitivity, many countries exhibit discrepancies between the variation in renewable energy transition and climate vulnerability. The results signify that existing renewable energy policies can exacerbate climate inequality and undermine the benefits of the transition to renewable energy by neglecting the spatial heterogeneity in climate vulnerability. Our findings provide empirical evidence for the ways in which renewable energy policy can generate spatial inequalities in climate adaptation.

2.2. Theoretical Background

The independent variables are chosen based on the theory. More precisely, the independent variables, economic development, financial development, institutional quality and population growth jointly with fossil fuel energy impact on climate change vulnerability according to the theory. Empirical research shows that CO_2 emissions increase dramatically in economies highly dependent on fossil fuel energy, exacerbating climate change vulnerability through global warming, extreme weather events, and resource deficits (Wang and Azam, 2024; Zang et al., 2024). According to Wang and Azam (2024) who researched how fossil fuel consumption and GHG emissions affect climate change vulnerability in high-emission countries and in the countries with high levels of economic development, energy consumption is usually high, often offset from fossil fuels. As a result, CO_2 emissions increase, which means that climate weakness increases. At the same time, vulnerability can be reduced if economic resources are directed towards renewable energy and energy efficiency. Shang et al., (2024) indicate that nations with high dependence on fossil fuels are considered more vulnerable to climate change. In the countries with low economic potential, mainly in the Global South, dependence on fossil energy increases climate vulnerability more strongly, since these countries have limited opportunities to invest in green energy transition and adaptation measures. Conversely, in economically developed countries, the impact of fossil fuel dependence on climate vulnerability is relatively mitigated due to high energy diversification and the ability to switch to green technologies. Therefore, the level of economic development is assessed as a buffer factor in the correlation between energy transition vulnerability and climate impact. Moreover, Khang et al. (2024) analyzed the conflict between the short-term role of fossil fuels accelerating economic growth and long-term effects on enhancing environmental degradation and climate change vulnerability. The results show that GDP growth in the early stages of economic development relies primarily on fossil energy, increases climate change vulnerability by boosting CO_2 emissions. However, economically developed countries can mitigate this negative impact by diversifying the energy system at the expense of investment potential and switching to renewable resources. Thus, economic development accelerates green transformation and manifests as a moderating factor in the correlation between fossil fuel consumption and climate change vulnerability. Additionally, uncertainty and geopolitical tensions in the energy market, while lowering the pace of economic development, exacerbate the systemic vulnerability to climate change. At the same time, institutional sustainability, green innovation and energy efficiency policies in countries with high levels of Economic Development Act as a mechanism that partially alleviates this vulnerability. This confirms the complex, bidirectional interaction between economic development and climate stability (Inglesi-Lotz et al., 2025). Another study by Al-Mubarak et al. (2024) analysed the impact of energy sources on economic stability, social welfare and environmental security in a comprehensive manner. The analysis also took into account differences in the energy structure of developed and developing countries. The results show that the increase in CO_2 emissions in low-economy developed countries with a high proportion of fossil fuels increases vulnerability to climate change. In contrast, economically sustainable countries have the potential to increase investment in renewable energy technologies and lower climate risk. Thus, the level of economic development is an important factor that determines the composition of energy sources and moderates the relationship between fossil fuel consumption and climate change vulnerability.

As to the role of financial development, Salahuddin et al. (2018) evaluated the correlation between financial development, fossil fuel energy consumption, and CO_2 emissions based on panel data. The analysis was conducted mainly on the example of developing countries. As the level of financial development increases capital flows and loans are often diverted to the fossil fuel-based energy sector resulting in increased CO_2 emissions, which in the long run may increase climate change vulnerability. That is, financial development is a risk-enhancing factor for climate vulnerability if not based on the green finance principle. Another empirical study on the example of transitional economies show that financial development initially increases CO_2 emissions by accelerating economic activity and directing credit flows into a predominantly fossil fuel-based energy sector; this increases climate change vulnerability by accelerating the global warming process due to increased atmospheric greenhouse gas concentrations. However, once the financial system reaches a mature stage, there will be a drop in emissions as capital flows are diverted to energy efficiency and renewable energy technologies, which will help reduce climate vulnerability (Tamazian and Rao, 2010). In countries with low financial development, fossil fuels will continue to control the economy for a long time, which in turn will exacerbate climate weakness. In countries with high financial development, environmental innovation is widely funded. as a result, the impact of fossil fuels decreases-which reduces climate vulnerability. Countries with low financial development, fossil fuels will continue to control the economy for a long time, which in turn will exacerbate climate weakness. Therefore, financial development is seen as a moderating factor in the relationship between fossil fuel consumption and climate vulnerability (Apeaning and Labaran, 2025). Financial development is an important factor shaping the relationship between fossil fuel consumption and climate vulnerability. Highly developed financial markets focus capital on the renewable energy sector, increasing the efficiency of adaptation and mitigation strategies. As a result, the economy's resilience to climate change is strengthened. On the contrary, if the financial system supports only the traditional energy sector, it will further exacerbate the climate weakness (Fan et al., 2025).

A study by Albahouth and Tahir (2025), using the example of GCC countries, investigated the impact of institutional quality on climate vulnerability. The study used indicators such as government efficiency, rule of law, and corruption control as measured under Worldwide Governance Indicators (WGI), and assessed climate vulnerability through the ND-GAIN Climate Vulnerability Index. The results show that improved institutional quality significantly reduces climate vulnerability, as efficient institutions mitigate climate risks by properly allocating resources, implementing environmental policies, and increasing flexibility capacity. Therefore, this study justifies the importance of institutional quality as an important moderating factor in climate risk management. According to a study by Li et al. (2022), high institutional quality is an important factor in ensuring environmental sustainability, reducing adverse environmental impacts through effective governance, control over corruption. If the economy relies heavily on fossil fuel energy, strong institutions allow mitigation of the climate change vulnerability resulting from this consumption. Hence, institutional quality can be a moderating factor that reduces the impact of fossil fuel energy consumption on vulnerability to climate change. Conversely, when institutions are weak, fossil fuel consumption can further exacerbate climate hazards. The results of the study driven by Azam et al. (2025) show that an increase in military spending, especially in countries with poor institutional quality, leads to an increase in CO_2 emissions and an increase in vulnerability to climate change. At the same time, the mechanisms of knowledge economics and Environmental Management in institutionally developed systems significantly mitigate this negative impact. Saboori et al. (2024) found that states with high institutional quality would have relatively low levels of environmental harmful factors, including fossil fuel dependence. Strong institutions create conditions for effective implementation of environmental policies, increasing the share of renewable energy, and reducing climate vulnerability. In this context, fossil fuel consumption in countries with poor institutional quality remains a major driver of climate change vulnerability. Thus, the effective operation of the institutions acts as a moderator that mitigates the negative impact of fossil fuel energy consumption on climate vulnerability.

In addition to these, we can obtain population growth as an influencing factor. As to the researches in this regard a study by Ahmed et al. (2023) investigated the effects of energy consumption, income, and population growth on CO_2 emissions. The results of the study suggest that population growth is only shown as an emission-enhancing factor in India, enhancing environmental impact in developing countries. A study by Vo and Vo (2021) cited population growth as a factor that increases energy demand and increases environmental vulnerability. The share of renewable energy, on the other hand, reduces CO_2 emissions, mitigating the negative environmental impact of population growth. Therefore, in the case of ASEAN countries, population growth acts as an amplifier that enhances the negative effects of fossil fuel consumption on climate change vulnerability. Wang and Azam (2024) identified population growth in the Chinese example as a contributing factor to fossil fuel energy consumption and resource shortages. This leads to increase in climate change vulnerability. At the same time, economic development and technological renewal serve to reduce the negative environmental impact of population growth through the management of fossil fuel dependence. The results suggest that population growth acts as a reinforcing factor in the fossil fuel consumption and climate change vulnerability relationship, additionally, it may be a solid foundation in your theoretical background section.

3. DATA AND ESTIMATION STRATEGY

3.1. Data

The study calculates the joint effect of fossil fuel energy, economic development, financial development, institutional quality and population growth on climate change vulnerability in the panel of 36 developed countries[1] over the period 2000-2022. The dependent variable is climate change vulnerability is measured in score ranging from 0 to 100, whereas the independent variables are fossil fuel energy consumption measured in terawatt hours (TWh), economic development measured as per capita GDP in USD, financial development measured as domestic credit to private sector by banks in percentage of GDP, institutional quality measured as rule of law index ranging between −2.5 and 2.5, and finally, population growth measured in percentage change. The definition and source of the variables are given in Table 1. Descriptive statistics is represented in Table 2, whereas correlation matrix is shown in Table 3.

The theoretical model which assesses the association among climate change vulnerability, fossil fuel energy, economic development, financial development, institutional quality and population growth can be described as follows:

1 Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Lithuania, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, United Kingdom, United States.

Table 1: Definition and source of the variables

Name	Definition	Abbrevation	Logarithmic transformation	Source
Climate change vulnerability	Climate change vulnerability score, ranging between 0 and 100. Higher value means high vulnerability and vica versa.	CLVUL	LOGCLVUL	Refinitive
Fossil fuel energy	Fossil fuel energy consumption, given in terawatt hours (TWh)	FFE	LOGFFE	Our World in Data
Economic development	Per capita GDP in United States Dollars	PGDP	LOGPGDP	World Bank
Financial development	Domestic credit to private sector (% of GDP)	FINDEV	-	World Bank
Institutional quality	Rule of Law index, ranging from−2.5 to 2.5. High value denotes high institutional quality	ROL	-	World Bank
Population growth	Population growth (annual %)	PG	-	World Bank

The variables that are already given in percentage or contain negative values, cannot be transformed into logarithmic form

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
CLVUL	690	0.3900145	0.1003383	0.25	0.66
FFE	713	1595.179	3926.116	44.8887	23579.9
PGDP	713	34585.1	20516.18	1621.26	109270
FINDEV	648	90.57534	41.07307	7.12522	200.399
ROL	682	1.216585	0.6233756	−0.265605	2.12476
PG	713	0.3182234	0.7450197	−3.84767	2.80996

$$LOGCLVUL_{i,t} = b_1+b_2LOGFFE_{i,t}+b_3LOGPGDP_{i,t}+b_4FINDEV_{i,t} +b_5ROL_{i,t}+b_6PG_{i,t}+\varepsilon_{i,t} \quad (1)$$

where, b_1 is an intercept, b_2, b_3, b_4, b_5 and b_6 are the coefficients, ε is an error term, i denotes a country and t means time.

3.2. Estimation Strategy

Energy markets are vulnerable to geopolitical changes (Sharipov et al., 2025). This causes heteroscedasticity in energy-related data (Kuziboev et al., 2025). Therefore, previous studies such as Kuziboev et al. (2025) employ quantile regression approach in assessing energy and environmental variables. Following previous works, this investigation also applies quantile regression in order to examine the relationship among climate change vulnerability, fossil fuel energy, economic development, financial development, institutional quality and population growth.

Koenker and Bassett (1978) introduced the quantile regression initially. The common demonstration of the quantile regression can be outlined as:

$$Q_{LOGCLVUL_{i,t}}(\tau \mid X_{it}) = \beta_0 + \beta_{1\tau}OGFFE_{i,t} +\beta_{2\tau}LOGPGDP_{i,t} + \beta_{3\tau}FINDEV_{i,t} + \beta_{4\tau}ROL_{i,t} + \beta_{4\tau}PG_{i,t} \quad (2)$$

where, $Q_{LOGCLVUL_{i,t}}(\tau \mid X_{it})$ is a conditional quantile of $LOGCLVUL$ at quantile τ.

The quantile regression given in Equation (2) is a classic quantile regression framework. Therefore, the research uses time-invariant effects quantile regression recommended by Canay (2011). Canay (2011) time-invariant impacts quantile regression permits to evaluate the influence of fossil fuel energy on climate change vulnerability at varied quantiles of climate change vulnerability controlling for unmeasured heterogeneity. Obviously, it is natural that fossil fuel consumption generates different climatic effects in each country. Therefore, when analyzing the relationship between fossil energy and vulnerability to climate change, taking into account country-specific individual factors is considered important to achieve reliable results. In order to eliminate such heterogeneity, the fixed-impact quantile regression approach proposed by Canay (2011) is used. This method consists of two stages. Initially, a simple fixed-impact regression is evaluated. A new form of the dependent variable containing fixed effects is then generated using the residues in the result of this regression. The second step is to evaluate the quantile regression based on this transformed dependent variable and analyze the distribution of effects on the different quantiles. This approach ensures the stability of results by controlling for identities not observed across countries.

4. EMPIRICAL FINDINGS

The results estimated by quantile regression are given in Table 4. According to them, an increase in fossil fuel energy causes a rise of climate change vulnerability across all the quantiles, 10-90%. This result is in line with the theoretical linkage. Moreover, CO_2 levels in the atmosphere reached 420 ppm as a result of fossil fuel consumption, increasing global temperature by 1.1°C, which increased climate weakness by 2-3 times. The result is about US $ 650 billion in economic losses each year. Therefore, reliance on fossil fuels is considered a key factor that significantly increases climate change vulnerability (Perera and Nadeau, 2022). Additionally, countries with a high proportion of fossil fuels in the energy mix have a significant increase in vulnerability to climate change. When the share of fossil fuels increased by 10%, the climate change vulnerability index increased by an average of 0.06-0.09 points. When the share of renewable energy increased by 1%, climate weakness decreased by 0.03 points. Data from 65 countries surveyed in the study from 1995-2020 show that reliance on fossil fuels has led to a weakening of food safety, infrastructure stability, and the health system (Dai et al., 2022). According to the results of another study show each additional 1 ton of CO_2 exhaust increases the global temperature to 0.0000045°C, which means an additional warming of 0.02-0.05°C at the level of large oil/gas projects. The 100 major fossil fuel projects operating through 2025 have increased the global Climate Vulnerability Index by an average of 3-4%. In the Asian and African regions in particular, each project reduced infrastructure vulnerability by 5-8% and agricultural production stability by 4% (Abram et al., 2025). Each new fossil fuel project will increase global warming and increase regional climate vulnerability, so it is necessary to evaluate them

Table 3: Correlation matrix

	LOGCLVUL	LOGFFE	LOGPGDP	FINDEV	ROL	PG
LOGCLVUL	1.0000	−0.2812	−0.2095	−0.0764	−0.0746	−0.1704
LOGFFE	−0.2812	1.0000	0.2644	0.0985	0.1934	0.2302
LOGPGDP	−0.2095	0.2644	1.0000	0.5783	0.8199	0.6493
FINDEV	−0.0764	0.0985	0.5783	1.0000	0.5863	0.4660
ROL	−0.0746	0.1934	0.8199	0.5863	1.0000	0.6714
PG	−0.1704	0.2302	0.6493	0.4660	0.6714	1.0000

Table 4: The results of Canay (2011) quantile regression

Variable	Dependent variable: LOGCLVUL								
	Quantiles								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
LOGFFE	0.044	0.042	0.041	0.409	0.040	0.040	0.039	0.038	0.039
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LOGPGDP	−0.242	−0.028	−0.031	−0.035	−0.036	−0.038	−0.038	−0.038	−0.041
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FINDEV	−0.000	−0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P-value	0.006	0.255	0.700	0.020	0.009	0.017	0.042	0.100	0.000
ROL	0.010	0.015	0.015	0.017	0.019	0.018	0.019	0.021	0.026
P-value	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PG	−0.004	−0.001	0.000	0.001	0.002	0.005	0.005	0.005	0.000
P-value	0.036	0.491	0.906	0.320	0.124	0.001	0.000	0.007	0.760
Constant	−1.028	−0.971	−0.937	−0.892	−0.878	−0.849	−0.840	−0.832	−0.809
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R-square	0.603	0.639	0.668	0.689	0.706	0.710	0.712	0.714	0.712

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

as a factor contrary to sustainable development strategies. Another study found a significant increase in vulnerability to climate change in countries that are highly dependent on natural resources, especially mineral and fossil fuel resources. When the resource reliance index increased by 1 unit, the Climate Vulnerability Index rose by an average of 0.07-0.1 points. A 10% increase in export route to Fossil fuels increased global temperature risk by 0.015°C, and regional climate vulnerability by 2.8%. Climate adaptive capacity turned out to be 20-25% lower in countries with high resource reliance (Keneck-Massil and Foudjo, 2025).

Regarding economic development, it negatively impacts on climate change vulnerability at all quantiles from 10% to 90%. Furthermore, if no additional emission cutting measures are taken, the world economy may lose 19% of its potential revenue by 2050. According to empirical estimations, this loss can range from 11% to 29%. Economic losses are estimated at around US $ 38 trillion each year. Losses are 6 times greater than the cost of limiting global warming to 2°C to reduce losses. The world economy has already suffered a significant forced loss due to climate change. These figures clearly show the negative link between economic development and climate vulnerability, and confirm the transition to a green economy as a strategic necessity not only environmentally, but also economically (Kotz et al., 2024). Empirical research shows that in countries with increased energy policy risks, energy independence levels decrease, and this in turn weakens the stability of economic development while increasing vulnerability to climate change (Pardaev et al., 2025). In developing countries, climate change weakens the agricultural sector and social infrastructure, particularly negatively affecting the population in low-income and vulnerable areas. For example, agricultural production is expected to decrease by about 1.9% by 2030, and by 4.3% by 2050, in Sub-Saharan Africa, this would reach 2.9% in 2030, and 6.8% in 2050. These figures reflect the level of climate change vulnerability for developing countries due to the lack of preparation for climate shocks and economic resources, vulnerable groups suffer greatly (Adom, 2024).

Financial development has a negative effect on climate change vulnerability at 10% quantile, whereas the effect is positive at 40%, 50%, 60%, 70% and 90%. Moreover, Trinh et al. (2024) analysed 21 countries across Europe between 2001 and 2020, found that firms would have much higher borrowing costs if they exposed to climate change at a higher rate, results show that this effect would only be significantly stronger in countries with weak financial markets and institutions. Energy policy risks in 64 countries negatively affect energy source diversification as well as the situation increases climate change vulnerability, especially in countries with weak financial institutions and limited investment flows (Mamadiyarov et al., 2025). Therefore, promoting the diversification of energy sources and increasing resilience to climate risks by improving financial development should be an integral part of the Sustainable Development. According to a study by Caporin et al., (2024a), strengthening financial development through inclusive and gender-sensitive management indirectly reduces vulnerability to climate change because it promotes clean investment, increases effective resource utilization, and reduces CO_2 emissions. By strengthening financial institutions and credit mechanisms, it is possible to reduce climate change vulnerability in the process of economic development, since a developed financial system allows firms to manage costs associated with climate shocks. As Kuziboev et al., (2023) point out, CO_2 emissions fluctuations reflect the instability of economic and investment structures in the country, which means that strengthening financial development serves to ensure environmental sustainability.

Notably, the rise in renewable energy leads to a surge in climate change vulnerability at all quantiles, 10-90%. Caijuan (2024) analyzes the global level the complex relationship between renewable energy transition and climate change vulnerability with panel regression and MMQR techniques. The results show that energy transfer at the initial stage reduces climate vulnerability, but when energy cleanability gap (ECL^2) is high, food vulnerability increases by 0.40 units. Therefore, climate vulnerability can be reduced by strengthening financial development and investment mechanisms. According to a study by Seraj and Seraj (2025), a 1% increase in the share of renewable energy transition in the world's top 15 carbon-emitting countries will reduce CO_2 emissions by 1.59%, while a 1% increase in financial development will reduce emissions by 4.51%. These results show that in order to reduce climate change vulnerability, it is necessary that the country not only be limited to the transition to green energy, but also strengthen its financial system to make this transition effective. Empirical research suggests that renewable energy transition does not always reduce climate change vulnerability. Kim and Park (2023) identified based on global panel data, renewable energy surge in some countries may increase vulnerability due to lack of territorial readiness and infrastructure. Also, a 2000-2019 analysis on Turkey shows that energy vulnerability negatively affects environmental sustainability in the long run, especially if financial development is low (Özkan et al., 2024). Thus, strengthening the financial system and investment mechanisms in the green energy transition process is an important condition for reducing climate vulnerability and implementing sustainable energy policies.

Lastly, population growth has negative effect on climate change vulnerability at 10% quantile, while the impact is positive at quantiles from 60% to 80%. Empirical results suggest that climate change is the dominant factor in increasing the world's drought-prone population by +59.5%, while having an additional impact on population growth of +9.2%. This means that in climate vulnerability mitigation strategies, not only CO_2 emissions reduction and green energy transition are important, but also measures to manage population growth and efficiently allocate resources (Smirnov et al., 2016). Strengthening infrastructure and adaptive capacity in areas with high population density can significantly reduce climate vulnerability. At the same time, the population growth rate in the 80 most climate-vulnerable countries are 2 times higher than the global average, and climate vulnerability is further exacerbated by community readiness and lack of infrastructure in these areas (Population Institute, 2023). The index of territorial weakness increases, which means that the rapid growth of the population can be an important factor reinforcing climate weakness. Hence, in strategies, it is necessary to introduce measures not only to reduce CO_2 emissions and develop green energy transition, but also to manage the growth rate of the population, efficiently allocate resources and strengthen infrastructure and community readiness. This approach serves to reduce climate vulnerability and increase adaptive capacity at the global and territorial levels. Rapid population growth and climate change in the African region can collectively reduce agrarian production by −15% and increase the Climate Vulnerability Index by +20% (Ghio et al., 2023). Therefore, in strategies to reduce climate vulnerability, it is important not only to reduce emissions from green energy transition and CO_2, but also to manage population growth, modernize agrarian systems and introduce measures to strengthen infrastructure. This approach serves to reduce climate vulnerability and increase adaptive capacity at the territorial and global levels. Additionally, rapid population growth and urbanization rates in hazardhigh areas in the United States lower the Climate Risk Readiness Index by −12%; in log point accounting, this leads to +2.9 log point per decade (+17% per decade) vulnerability, while in low hazard areas, +0.5 log point (+3% per decade) is felt (Indaco and Ortega, 2024). Population growth and urbanization management, infrastructure strengthening and increased preparedness are necessary measures to reduce climate vulnerability. Inglesi-Lotz et al., (2024) using the example of Central Asian countries found direct and marginal effects of CO_2 emissions on health care costs. As the authors point out, with urbanization and an increase in population density, energy consumption increases, which manifests itself as a demographic factor that increases environmental degradation as well as vulnerability to climate change. The results of the study by Caporin et al., (2024b) show that increasing investment in renewable energy sources in Central Asian countries, improving energy efficiency policies and introducing green technologies should be one of the main strategic directions of reducing vulnerability to climate variability.

5. CONCLUSION, POLICY IMPLICATIONS AND LIMITATIONS

The results of the study show that the results of the panel quantile regression, conducted on a sample of 36 developed countries, prove that economic, institutional, financial, population and energy factors jointly strongly influence the degree of climate change vulnerability. In particular, the consumption of fossil fuel energy has been implicated in an increase in vulnerability across all quantiles (10-90%). This result is consistent with theoretical views, and it is noted that as a result of high levels of CO_2 emission, the atmospheric carbon concentration reached 420 ppm, an increase in global temperature by 1.1°C, which increases the climate weakness by 2-3 times. In addition, the growth of economic development further increase climate vulnerability by increasing dependence on fossil fuels if it is not accompanied by energy-efficient technologies and green innovation. At the same time, while countries with high levels of financial development have the opportunity to effectively use financial resources for adaptation strategies against climate change, countries with low institutional quality do not have these resources effectively channelled. As a result, a decline in the rule of law Index or political instability leads to a weakening of environmental management systems. Population growth, in turn, increases resource utilization pressure as well as expanding ecological footprint. This situation limits the potential for adaptation to climate change, especially via the increased infrastructure load and energy demand in areas where the urbanization process is going fast. In general, the results of the study mean that an economic model based on fossil fuels cannot provide long-term stability. To reduce the vulnerability to climate change, it is necessary to increase institutional quality, redirect the financial system to the green investment projects, harmonize population policy with resource efficiency, and switch to renewable energy sources. Thus, ensuring the environmental and social stability of economic development becomes the main strategic direction of reducing climate vulnerability.

Based on the results of the study, a variety of political measures can be recommended in order to reduce vulnerability to climate change and ensure economic stability. Initially, as results of the study show that the consumption of fossil fuel energy increases climate vulnerability across all quantiles, states should accelerate the gradual transition to renewable resources (solar, wind, bioenergy) by diversifying their energy policy. It is possible to limit carbon-intensive economic activities by introducing quota systems for emissions and carbon taxes. Furthermore, the lower Rule of law Index reduces the efficiency of environmental policy. For this reason, institutional reforms that increase government accountability, anti-corruption, and enlarge environmental control play an important role in reducing climate risk. Also, the implementation of the green budgeting system serves to direct public spending to environmental priorities. The study shows that financial development is important in financing adaptation mechanisms against climate change. Thus, it is advisable to increase the environmental responsibility of the financial sector through the introduction of green bonds, sustainable finance funds and environmental risk assessment systems. Economic growth itself may not give a positive result, unless it is supported by energy efficiency and innovation, it is necessary for countries to integrate green growth model into economic strategies by expanding fiscal benefits which encourage investing in low carbon technologies. Moreover, population growth and urbanization levels increase resource consumption and climate change vulnerability. In this case, it is possible to reduce demographic pressure by developing sustainable urban infrastructure, energy-efficient housing policies, and electromobilization in the transportation system. Climate change is a problem with the exception of national borders. Therefore, it is relevant to create coordinated systems of green technology exchange, joint climate risk assessment platforms and cross-border energy policy in international level. To develop an effective strategy against climate change at the policy level, energy, finance, demographics and institutional management systems ought to work jointly and this can reduce climate vulnerability as well as strengthen economic stability in the long run.

Although this study analysed the factors that determine the vulnerability to climate change on the example of 36 developed countries, it has some scientific limitations. More precisely, the possibility of endogeneity and the fact that structural changes including, geopolitical crises, pandemics which are not taken into account can limit the results. Future researches can further explore vulnerability to climate change by covering these factors.

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