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Investigating the Impact of Multiple Factors on CO_2 Emissions: Insights from Quantile Analysis

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Abstract: This study investigates the impacts of alternative energy use, urbanization, GDP, agriculture, ICT development, and FDI on carbon dioxide (CO_2) emissions in the 14 leading CO_2-emitting countries in Asia. This research comprises various econometric techniques, including MMQR, FMOLS, DOLS, and Driscoll–Kraay, to extend the data analysis from 1996 to 2020. The findings provide significant support for an inverted U-shaped link between economic expansion and environmental deterioration, known as the environmental Kuznets curve. Moreover, this paper verifies that the GDP square, renewable energy use, and agriculture are shown to help to decrease pollution, as indicated by the research findings. On the contrary, urbanization and the GDP are demonstrated to be variables that contribute to carbon emissions. Furthermore, the panel quantile regression models validate that the impacts of each explanatory variable on CO_2 emissions vary across various quantiles. Finally, this analysis provides valuable suggestions to scholars, environmentalists, politicians, and authorities for identifying and mitigating the main cause of emissions.

Keywords: CO_2; GDP; urbanization; energy; MMQR; Asia

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1. Introduction

Over the last six decades, substantial economic advancement and a significant increase in the world's population have been accompanied by negative impacts on the environment [1]. The Fifth Assessment Report [2] provides an important framework for understanding the impacts of climate change on natural and human systems across the globe [3,4]. This urgent call for action stems from the growing scientific evidence that shows the detrimental effects of global warming and the escalating environmental damage caused by carbon dioxide (CO_2) emissions [5]. This has prompted international organizations and governments to seek solutions for reducing emissions around the globe [6]. Consequently, a sequence of accords has been established among various nations to regulate worldwide CO_2 emissions, encompassing agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement [7]. CO_2 is commonly accepted as a greenhouse gas and is a key contributor to global warming [8]. CO_2 emissions primarily originate from anthropogenic sources such as deforestation, transportation, and the combustion of carbon-emitting fuels by the industrial sector and power stations [9]. Along with other greenhouse gases such as methane and nitrous oxide, CO_2 traps heat within the Earth's atmosphere, leading to an increase in average global temperature, commonly referred to as global warming [10]. The rising international level of CO_2 emissions has become a major concern due to its role in temperature elevation and subsequent climate change [11]. According to the UN report conducted by the IPCC (Intergovernmental Panel on Climate Change), CO_2 emissions from fossil fuel consumption are the main source of CO_2 emissions.

Emerging Asia is susceptible to environmental risks due to its unique geographical characteristics and socioeconomic conditions. The changing climate is anticipated to result in heightened occurrence and intensity of cyclones, inundation, heat waves, and droughts in the area. Furthermore, the Asian continent is home to almost 70% of the world's population that might be impacted by rapidly rising sea levels [12]. Approximately one-third of the region's workforce is engaged in agriculture and fishing, two industries heavily reliant on natural resources and thus subject to climate change. If global warming continues at its current rate of acceleration, Asia's emerging economies as an entire region would see a 24% drop in the GDP by the year 2100 [13].

Despite the initial low levels of historical emissions from emerging Asia, they have shown a more rapid growth rate compared with the world average. The region's proportion of global greenhouse gas (GHG) emissions has increased twofold, from 22% in 1990 to nearly 50% in 2021 [14]. It is projected to maintain this proportion until the middle of the century, assuming existing policies stay unchanged. Given the present amount of GHG emissions, this area alone could exhaust the amount of remaining global carbon budget that is in line with the goal of reducing global warming to 1.5 degrees Celsius (°C) by 2040 [15].

In recent years, the issue of CO_2 emissions has become a pressing concern, especially in Asian countries [7]. Asian countries have emerged as major emitters of carbon dioxide, contributing significantly to the global climate change crisis [16]. According to United Nations data, China currently holds the top position as the lead emitter of carbon dioxide [17]. This is due not only to its large population but also to its rapid economic development and industrialization [18]. Furthermore, other Asian countries, such as India, Japan, South Korea, and Southeast Asian nations, have also experienced substantial growth in CO_2 emissions due to their rapid economic growth and industrial expansion [16]. These countries have seen a significant increase in their industrial sectors, including manufacturing industries, transportation, and energy production [19]. In terms of specific contributions, different industrial sectors have varying impacts on CO_2 emissions in Asian countries [20]. Additionally, the area had a carbon footprint that was about 45% greater than the global average and more than twice as high as that of North America and the European Union in 2022 [21]. When the high level of intensity is coupled with the quick economic expansion of emerging Asia, there is a possibility of a swift increase in emissions. The energy industry is responsible for 75% of the region's greenhouse gas emissions. Electricity and heat generation dominate the energy sector as the primary and rapidly expanding contributors to emissions, constituting over 40% of total emissions. Manufacturing follows closely behind, accounting for 18% of emissions. Agriculture, land use, and forestry contribute significantly to emissions, accounting for 13% of total emissions [1,14]. Manufacturing, transportation, and energy generation are some of the region's most environmentally conscious sectors, which impact both employment and productivity. Between 2015 and 2021, these industries were responsible for 42% of all jobs and 43% of the GDP. When juxtaposed with various regions of the globe, the contributions to the GDP in the area are much larger. Approximately 18% of the GDP in the US is derived from these activities, but in Europe it is roughly 23%, and in Latin America and sub-Saharan Africa it is 24%.

The environmental impact of foreign direct investment may also be felt in many ways [22]. It is possible to classify these channels into three groups: Some people think that foreign direct investment (FDI) is the root cause of "pollution havens." As a result of different countries' approaches to environmental regulation, the pollution refuge theory was put up. When compared with industrialized nations, developing economies tend to be lax or nonexistent when it comes to environmental legislation. Furthermore, trade liberalization has both positive and negative consequences. It additionally contributes to a country's economic growth but also gives rise to both ecological and climatic issues [23]. Given this, the influence of trade openness on carbon emissions has progressively emerged as a significant concern for scholars and policymakers.

According to the Urban Development Overview by the World Bank Group, the rapid growth of urbanization has been accompanied by an increase in carbon dioxide emissions. This is primarily due to the increasing energy demand of societies, which is driven by the development of industries and the expansion of urban areas [24]. Urbanization processes have a significant impact on carbon dioxide emissions in urban areas. Numerous studies have focused on the relationship between economic processes and carbon dioxide emissions in urban areas [25]; however, these studies have shown that as cities become more urbanized, there is a corresponding increase in carbon dioxide emissions [26]. However, in recent years, there has been growing concern about the impact of communication technology infrastructure on CO_2 emissions [27]. On one hand, information and communication technologies (ICTs) play a pivotal role in fostering economic expansion, serving as one of the fundamental drivers of growth [28]. The Internet, mobile phones, telephone calls, computer systems, and associated applications, collectively known as ICTs, have become the primary drivers of societal transformation, growth, and invention [29]. However, information and communication technology infrastructures are predicted to be responsible for 3% of global annual electricity usage and 2% of CO_2 emissions [30]. This level of energy consumption and carbon emissions is significant and cannot be ignored [31].

Agricultural activities continue to play a significant role in driving climate change and are responsible for approximately one-fourth of the overall human-caused greenhouse gas emissions [32]. The agricultural industry is recognized as a key contributor to greenhouse gas emissions. The sector has experienced a 13.5% increase in emissions due to heightened deforestation and the excessive utilization of synthetic inputs such as pesticides and fertilizers [33,34]. These activities account for approximately 20% of the total carbon dioxide emissions resulting from all human activities globally [35]. Urgent actions are required to address the negative environmental impacts of agriculture and reduce CO_2 emissions from the sector [36].

This study contributes to the literature in different ways. First, to the best of our knowledge, this is the first research investigating the dynamic relationships between urbanization, Internet, FDI, agriculture, and GDP on CO_2 emissions for 14 top CO_2 emitters in Asia. Second, our work also contributes methodologically to the literature on the relationship between the environment and economic development by using the innovative econometric estimate approach known as the method of moments quantile regression (MMQR) under the EKC hypothesis [37]. Consequently, we surmount the limitations of previous research stemming from mean-based linear estimation methods by employing MMQR, which reveals the influence of regressors on the conditional distribution of the dependent variable, as opposed to solely on the mean specification. Consequently, due to the varying degrees of economic development among the sample countries, this approach is especially suitable for examining the heterogeneous effects of regressors on environmental quality indicators. The applied approach is also resilient against skewness, heteroskedasticity, and other outliers. Our research also offers reliable results by utilizing alternative estimation techniques, such as FMOLS, DOLS, and Driscoll–Kraay standard error estimators. Third, the current research employs an extensive set of data spanning from 1996 to 2020. Finally, the research outcomes will provide valuable insights for the fourteen countries in Asia with the highest CO_2 emissions, facilitating them in the development and execution of environmentally friendly measures.

The rest of this research is organized as follows. The next section is the literature review and hypothesis development. The next section describes the data and methodology used, which is followed by the results. The discussion section follows, and a summary and conclusion are provided.

2. Literature Review

This section explores the various determinants that influence CO_2 emissions, providing insights into the factors driving the release of greenhouse gases. The study examined the complex interactions between human activities, socioeconomic factors, and environmental conditions that contribute to CO_2 emissions.

2.1. Urbanization: Unveiling the Urban Carbon Footprint

The primary cause of global climate change is widely acknowledged to be anthropogenic greenhouse gas emissions, with a particular emphasis on CO_2 emissions. Numerous studies have revealed that an increase in the urban population is a substantial factor in the generation of greenhouse gas emissions [38,39]. The process of global economic integration has led to the acceleration of urbanization, which in turn has had an impact on carbon emissions [40]. Recent studies have investigated the linkage between urbanization and CO_2 emissions over the past few decades. One of the recent studies examining the causal relationship between urbanization and CO_2 emissions adopted the dynamic panel threshold approach in China from 1992 to 2018 [41].

Moreover, more advancements in technology, financial systems, and government sectors are associated with greater potential for promoting urbanization to mitigate CO_2 emissions. Similarly, Ref. [42] employed spatial econometric methods to analyze the data from Chinese provincial panels to examine the impact of urbanization on CO_2 emissions, considering geographical correlations. The findings suggested that the degree of urbanization had a direct correlation with the increase in CO_2 emissions within local provinces. Ref. [43] applied the panel cointegration test and PMG-ARDL to analyze the impacts of energy consumption, economic development, and urbanization on CO_2 emissions in China from 1995 to 2020. This study incorporated urbanization into the model to evaluate its impact on GDP growth, energy consumption, and CO_2 emissions. According to the findings, urbanization did not significantly affect environmental quality in the short term.

Furthermore, another scholar studied the sustainable green economy in sub-Saharan African nations from 1990 to 2019 using quantile regression and the environmental Kuznets curve (EKC) hypothesis test to examine the relationships among urbanization, economic growth, renewable energy, trade, and CO_2 emissions [44]. This study supported the existence of the EKC in terms of the relationships between urbanization, economic growth, renewable energy, trade, and CO_2 emissions, emphasizing the importance of adhering to urbanization thresholds for sustainable goals. These studies revealed that an increase in urbanization was correlated with higher levels of CO_2 emissions.

Hypothesis 1. *Urbanization can contribute to reduce CO_2 emissions in Asian nations.*

2.2. GDP: Evaluating the Direct Relationship between GDP and CO_2 Emissions

A better understanding of the linkage between CO_2 emissions and economic growth enables nations to adopt more sustainable energy policies and methods for the development of energy resources [45]. The scholarly literature has recently extensively examined the correlation between the GDP and CO_2 emissions [46–52]. There is a stronger correlation between economic growth and CO_2 emissions in all G7 nations throughout various periods, with the relationship being particularly prominent in the short term [53]. The study revealed a bidirectional causal relationship between CO_2 emissions and the GDP per capita across different periods and frequency ranges.

Another study examined the associations between CO_2 emissions and the GDP per capita employing a mixed frequency vector autoregressive (MF-VAR) methodology across G7 nations during the period spanning from the first quarter of 1970 to the fourth quarter of 2019 [54]. The results of the MF-VAR model also demonstrated that among the G7 nations, there existed a unidirectional causal relationship between the GDP and CO_2 emissions in Canada, the United Kingdom, and the United States. Furthermore, cross-sectional dependence in the research variables was effectively mitigated by the utilization of second-generation econometric methodologies for examining the effects of CO_2 emissions, energy consumption, and GDP in different countries located in the Middle East [55]. According to the empirical findings of this study, the devised cointegration method [56] demonstrated the presence of a long-run equilibrium among desired variables. CO_2 increased because of economic growth. Ref. [57] utilized the ARDL bounds testing strategy and DOLS methodology to analyze the dynamic impacts of the GDP per capita, renewable energy consumption, urbanization, industrialization, tourism, agricultural production, and forest area on CO_2 emissions. According to their empirical findings, it was estimated that there would be a 0.97% increase in CO_2 emissions for every 1% increase in economic growth.

Hypothesis 2. *Economic growth is closely linked to increased CO_2 emissions in Asian nations.*

2.3. Renewable Energy: Energizing the Transition to a Low-Carbon Future

The environmental crisis is a long-standing issue focusing on environmental degradation and the need for planet-friendly measures. In this sense, nonrenewable resources, especially fossil fuels, are the main contributor to degradation. Ref. [58] have already emphasized a study on CO_2 emissions in 15 countries, revealing that fossil fuel consumption decreased the environment quality in the short and long terms. Similarly, Ref. [59] asserted that fossil fuels significantly contributed to increased CO_2 emissions in the long term. However, previous studies proved that moderation of renewable energy could contribute to reduced environmental degradation [60,61].

The majority of the world's coal generation is located in Asia. It is a relief to see that the construction of new coal power plants is coming to an end. In fact, the majority of countries and regions are now prioritizing investments in clean electricity over fossil fuels. Asia has made significant progress in its energy transition, rapidly catching up with other regions. Solar and wind energy in Asia has reached a level that is comparable to the global average. Asia is home to three of the world's top five wind and solar power generators. These renewable energy sources are gaining momentum in the electricity mix of Asian countries. China's wind and solar energy production stands at 14% (1241 TWh), surpassing the global average. Japan and India, on the other hand, fall slightly below the global average with 11% (107 TWh) and 9% (165 TWh), respectively. As seen in the following figure, it can also be said that the portion of the contribution of energy generation from coal is the highest. However, the portion of emissions from coal has been seen a significant rise, which alerts a specific call for Asian regions to implement environmentally friendly policies regarding CO_2 emissions.

Asia is currently witnessing a remarkable surge in electricity demand, surpassing that of any other region with an annual growth rate of approximately 5%. During the period from 2015 to 2022, clean electricity was able to meet over half (52%) of the rising electricity demand in Asia. This is a significant improvement compared with the previous seven years, where only 26% of the demand was met with clean energy. It is worth noting that a majority of the increased global electricity demand from 2015 to 2022 occurred in Asia, accounting for 84% of the rise (Figure 1).

Renewable energy is highly valued due to its environmental friendliness, resulting in minimal carbon emissions and no air or water pollution [62]. Previous studies in energy and environmental economics offer extensive data on the impact of renewable energy on environmental degradation, revealing diverse empirical findings. The empirical findings can be categorized into two parts. The first category reveals that increasing renewable energy consumption can contribute to reducing CO_2 emissions and addresses environmental issues. Refs. [63,64] employed method of moments of quantile regression and long-run estimations to examine the performance of renewable energy on CO_2 emissions in MINT countries. The empirical findings showed that renewable energy could mitigate CO_2 emissions at the lower half quantiles. Ref. [65] used the Panel ARDL model to investigate the role of the renewable energy transition on CO_2 emissions in Latin America and Caribbean countries, finding a negative relationship in both short- and long-period analyses. However, ref. [66] revealed that renewable energy could reduce CO_2 emissions in only the short term, but there was not any effect on the environment quality in the long term when employing Panel ARDL and the EKC hypothesis in ASEAN nations from 1995 to 2018. Ref. [67] concluded with a study on European countries and found a unidirectional correlation between renewable energy and CO_2 emissions by applying the GS-2SLS approach and highlighting the need for investment plans for renewable energy in CO_2 emissions reduction efforts.

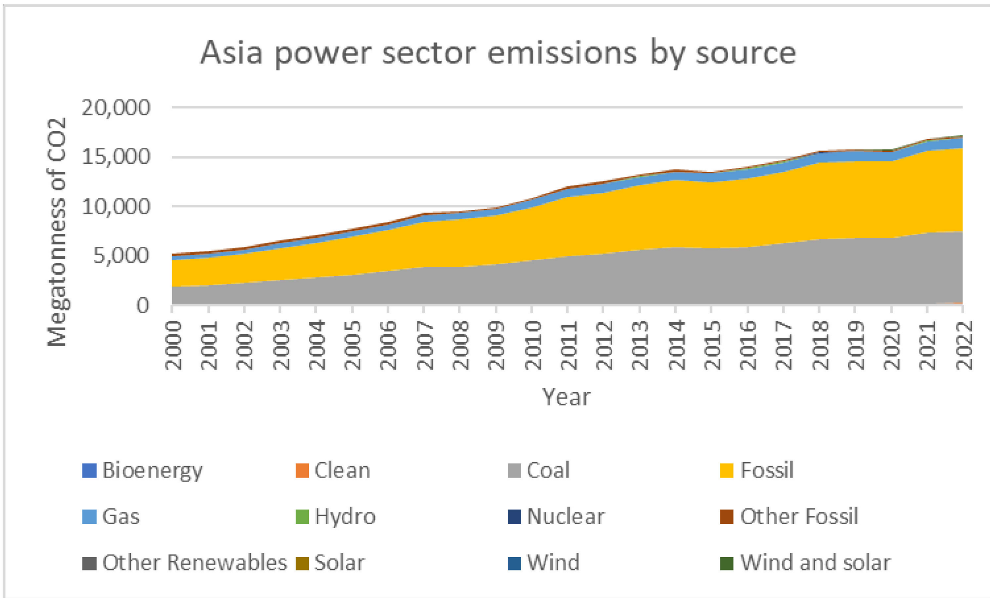

Figure 1. Asia power sector emissions by source. Source: Ember Electricity Data Explorer, ember-climate.org.

On the other hand, scholars consider that renewable energy has had an insignificant influence on environmental quality. Ref. [68] suggested that lower-income countries did not experience a significant reduction in CO_2 emissions due to renewable energy consumption, while middle- and high-income countries showed a significant decrease due to their access to financial resources, advanced scientific and technological capabilities, and infrastructure. Similarly, ref. [69] found an insignificant effect between renewable energy and CO_2 emissions across 19 sub-Saharan nations. Consequently, ref. [70] examined the relationship between non-renewable energy and renewable energy on CO_2 emissions in Pakistan using the stochastic affects by regression on population, affluence, and technology (STIRPAT) model. The study indicated that clean energy had a negative but statistically insignificant impact on CO_2 emissions in the rural sector.

Hypothesis 3. *Renewable energy can contribute to mitigate CO_2 emissions in Asian nations.*

2.4. Internet Connectivity: Unearthing the Digital Carbon Footprint

The widespread adoption and integration of Internet technology have become increasingly prevalent in various economic and societal domains amidst the current era of global technological and industrial advancements. This trend has significantly contributed to stimulating worldwide economic expansion as a notable driving force [71,72]. The proliferation of the Internet economy and the associated technological challenges have greatly contributed to improving enterprise performance, boosting productivity, and promoting sustainable economic development. Ref. [71] noted that the Internet has played a vital role in accelerating social and economic progress, providing a transformative technological platform for various industries. Additionally, the Internet has emerged as a catalyst for the advancement of the modern economy and society. However, it is important to acknowledge that the Internet also has implications for energy consumption and the natural environment. In addition, several methodologies, including life cycle assessment, the enablement method, and partial footprint analysis [73], have been employed to examine the impact of ICT on environmental degradation. Another study investigated the impact of Internet usage on CO_2

emissions in selected EU countries using panel data from 2001 to 2014. Ref. [74] employed the PMG estimator, and the findings revealed a long-term relationship between Internet usage and CO_2 emissions, indicating a negative effect on the environmental quality in EU countries. The heterogeneous panel Granger causality analysis suggested unidirectional causality from Internet usage to CO_2 emissions. These results imply that EU countries have not yet attained the desired level of environmentally sustainable ICT consumption. Nevertheless, distributed energy production via smart grids (SGs) and the Internet of Energy (IoE) are gaining popularity as means to achieve low-carbon, sustainable energy development. Automated consumption optimization, improved network efficacy, and smart administration are all made possible by the interoperability of intelligent energy systems made possible by the Web [75]. Within the framework of global Internet development and the extensive utilization of digital technologies, ref. [76] devised an assessment framework aimed at quantifying China's digital economy. This framework utilized panel data at the provincial level spanning the years 2007 to 2019. The study encompassed the development of the digital economy carrier, digital industrialization, industrial digitalization, and the digital economy development environment, and it employed the generalized method of moments to investigate the direct impact of the digital economy on low-carbon development (LCD). Subsequently, an intermediary effect model was employed to investigate the indirect transmission mechanism, accompanied by various heterogeneity analyses. The findings indicated that the digital economy was increasingly emerging as a crucial catalyst for promoting low-carbon development at the regional level.

Hypothesis 4. *ICT technology decreases the environmental quality in Asian nations.*

2.5. Agriculture: Cultivating Sustainable Practices

The examination of environmental degradation and its underlying causes has become a contentious topic of debate among governmental entities and policymakers in the past decade [77,78]. Ref. [79] investigated the influence of agricultural activities on CO_2 emissions in specific South Asian economies from 1990 to 2018. Their analysis used the FMOLS technique and variance decomposition analysis, and the findings indicated that agriculture had a mitigating effect on carbon emissions in South Asian countries. Ref. [80] employed a panel quantile regression analysis to examine the effects of agricultural development on CO_2 emissions in the 15 most densely populated developing nations from 2004 to 2020. The results indicated that agricultural value added had a positive and statistically significant relationship across all quantiles, except for the 0.3, 0.4, and 0.5 quantiles. Ref. [81] examined the symmetrical, asymmetrical, and quadratic impacts of the agricultural sector on CO_2 emissions in Saudi Arabia by applying panel ARDL during 1971–2014. The authors confirmed that both symmetrical and asymmetrical analyses revealed a negative and statistically significant effect of the agricultural sector on CO_2 emissions per capita. Ref. [82] analyzed the effect of agricultural activities on CO_2 emissions in BRIC countries from 1971 to 2016 using Fourier cointegration and causality tests. The Fourier ADL cointegration test supported the existence of a long-term relationship between the variables under consideration in Brazil and China. The results of the causality analysis demonstrated bidirectional causation between agriculture and environmental degradation. Ref. [83] investigated the relationship between the expansion of agricultural land and CO_2 emissions in Malaysia. The empirical findings indicated that the expansion of agricultural land in a country had a detrimental effect on the environmental quality. Ref. [84] investigated the dynamic relationships between crop production, livestock production, agricultural energy consumption, and CO_2 emissions in China between 1990 and 2016 using the ARDL bounds testing technique. In addition, FMOLS, CCR, and Granger causality tests were used to evaluate the robustness of the ARDL estimations. The long-term and short-term ARDL estimates confirmed that both crop and livestock production had significant positive impacts on CO_2 emissions.

Hypothesis 5. *Agriculture is one of the main factors to mitigate the effect of CO_2 emissions.*

2.6. GDP Square: Unraveling the Nonlinear Relationship with CO_2 Emissions in the Context of EKC

The EKC hypothesis has been widely researched, considering several environmental indicators like natural resources, urbanization, and financial development, with a particular focus on energy resources [85–88]. Previous studies in the literature have focused on investigating the correlation between the GDP squared and CO_2 emissions [89–91]. Analyzing data from 1962 to 2018 in China, ref. [92] employed the ARDL cointegration bound model, revealing a statistically significant negative relationship between the square of the gross domestic product and carbon dioxide emissions. In a similar vein, ref. [47] investigated the presence of the EKC hypothesis in a panel of E7 countries from 1990 to 2014, suggesting a negative correlation between CO_2 emissions and the square of the real GDP.

Examining the impact of economic growth on CO_2 emissions in Bangladesh from 1990 to 2019, ref. [93] found that the GDP squared had a substantial negative coefficient, indicating an inverted U-shaped relationship between CO_2 and economic growth in Bangladesh. Ref. [89] intricately explored the causal links among CO_2 emissions, energy consumption, GDP, and GDP square variable within Thailand's environmental Kuznets curve from 1971 to 2014. Utilizing robust methodologies like bound tests, ARDL models, and VECM, the findings highlighted that the GDP square significantly negatively impacted CO_2 emissions, contributing nuanced insights into the environmental consequences of quadratic economic growth.

Ref. [93] delved into the EKC in nine ASEAN countries (1970–2019), examining the relationships between energy consumption, GDP, CO_2, and GDP square. Their findings, exploring short- and long-run effects, underscored a reduction in carbon emissions with an increase in the square of economic growth, supporting the EKC theory and revealing the nuanced impact of the GDP and its quadratic term. A study on Turkey's environmental Kuznets curve (EKC) from 1960 to 2015 unveiled an inverted U-shaped relationship between the total energy consumption, CO_2 emissions, and income [94]. Employing the ARDL-bounds test, the findings indicated output elasticity in the long-run equilibrium, emphasizing the substantial impact of output on emissions and energy consumption. This pattern suggested an initial rise in environmental damage and energy use with income, followed by stabilization and an eventual decline [95]. Focusing on Pakistan, India, and Bangladesh, ref. [96] delved into the interaction between institutional quality, economic growth, and various variables on CO_2 emissions. Ref. [96] affirmed an inverted U-shaped environmental Kuznets curve in Pakistan and Bangladesh, while India exhibited a non-significant trend.

Hypothesis 6. *The U-shaped EKC validity or invalidity in Asian nations.*

2.7. The Relationship between FDI and CO_2

Ref. [97] analyzed panel data to evaluate the link between CO_2 emissions, energy consumption, economic development, and foreign direct investment in APEC economies from 1981:Q1 to 2021:Q1. According to Common Correlated Effect Mean Group long-run parameter calculations, FDI inflows lower the air quality, validating the pollution haven theory. Ref. [98] employed balanced annual data from 17 Asian countries from 1980 to 2014 to investigate the causal relationship between environmental pollution caused by CO_2 emissions and the net FDI, as well as other variables such as economic growth measured by real per capita income and trade openness. The FMOLS findings on the CO_2 emission model demonstrated that inbound FDI had a large beneficial influence on environmental pollution, lending credence to the pollution haven hypothesis (PHH).

Ref. [99] developed a panel data approach to compare and analyze the effects of FDI inflows on environmental protection in different Asian locales between 2000 and 2019. According to the findings, the Halo hypothesis was valid for Asian countries with high and upper-middle incomes, but the Haven pollution hypothesis applied to countries with low and lower-middle incomes. Ref. [100] evaluated the dynamic influence of governance on the connection between foreign direct investment, foreign aid, and CO_2 emissions by utilizing up-to-date data from 2001 to 2019, focusing on Asian economies and various statistical techniques, including estimated generalized least squares, two-stage least squares, system generalized method of moments, and fully modified ordinary least squares in order to estimate the regression. The empirical findings of these models indicated that the influx of FDI led to increased CO_2 emissions as a result of greater industrial expansion. By employing the GMM estimation, ref. [101] examined the moderating effects of technological innovation and institutional quality on the empirical relationship between FDI inflows and four indicator variables of CO_2 emissions in forty Asian countries from 1996 to 2016. The findings indicated that FDI inflows had a beneficial effect on CO_2 emissions (Table 1).

Hypothesis 7. *FDI has a mixed impact onCO_2emissions.*

Table 1. Recent literature review. Arrows in the table indicate increases and decreases.

Authors	Year	Country	Methodology	Empirical Findings
		Urbanization-CO2 emissions		
[39]	1960–2018	102 less-developed nations	Fixed effects model	URB ↓ CO_2 emissions
[40]	1997–2019	China	Spatial decomposition	URB ↑ CO_2 emissions
[41]	1996–2018	China	Dynamic threshold panel approach	URB ↑ CO_2 emissions
[42]	1990–2022	China	Granger causality test	URB ↑ CO_2 emissions
[43]	1995–2020	Chinese provinces	Panel PMG-ARDL	URB does not affect CO_2 emissions
[44]	1990–2019	Sub-Saharan African countries	Panel quantile regression; EKC	URB ↑ CO_2 emissions
		GDP-CO_2 emissions		
[45]	1820Q1–2021Q4	G7 countries	Panel quantile regression	GDP ↑ CO_2 emissions
[47]	1990–2014	E7 countries	Granger causality test	GDP ↑ CO_2 emissions;
[49]	1992–2018	Russia	Quantile on quantile regressions	GDP ↑ CO_2 emissions
[54]	1970Q1–2019Q4	G7 countries	VAR model	GDP → one-way causal link with CO_2 emissions
[55]	1980–2022	Middle East countries	Heterogeneity and Westerlund cointegration test	GDP ↑ CO_2 emissions
[57]	1990–2020	Thailand	ARDL bound test; DOLS	GDP ↑ CO_2 emissions
		GDP^2-CO_2 emissions (EKC hypothesis)		
[92]	1962–2018	China	ARDL, EKC	U-shaped EKC
[93]	1990–2019	Bangladesh	ARDL, EKC	Inverted U-shaped EKC
[89]	1971–2014	Thailand	Vector error correction model (VECM), EKC	The validity of EKC
[94]	1960–2015	Turkey	ARDL bound test, EKC	The validity of EKC
[95]	1971–2014	India, Pakistan, Bangladesh	VECM, EKC, ARDL	U-shaped EKC
[96]	1996Q1–2016Q4	India, Pakistan, Bangladesh	ARDL, EKC	Inverted U-shaped EKC

Table 1. *Cont.*

Authors	Year	Country	Methodology	Empirical Findings
		Renewable energy consumption-CO_2 emissions		
[62]	2000–2018	33 OECD countries	The panel smooth transition regression (PSTR)	RNEW ↓ CO_2 emissions
[63]	1995–2018	MINT countries	MMQR, EKC	RNEW ↓ CO_2 emissions; The validity of EKC
[65]	1990–2014	Latin American and Caribbean countries	Panel ARDL	RNEW ↓ CO_2 emissions in the short and long run
[66]	1995–2018	ASEAN nations	Panel ARDL	RNEW ↓ CO_2 emissions in the short but insignificant effect in the long run
[68]	1995–2015	120 global countries	FMOLS, DOLS, EKC	No significant effect between RNEW and CO_2 emissions
[69]	1990–2014	Sub-Saharan nations	Augmented mean group (AMG)	No significant effect between RNEW and CO_2 emissions
[70]	2018–2019 survey	Pakistan	STIRPAT model	RNEW ↓ CO_2 emissions
		ICT technology-CO_2 emissions		
[71]	2006–2017	China's provincial panel data	GMM estimation method	ICT ↑ CO_2 emissions
[72]	2010–2020	E7 countries	Gray relational analysis (GRA), GMM, EKC	ICT ↑ CO_2 emissions; U-shaped EKC
[73]	2000–2018	36 OECD countries	AMG and GMM	ICT ↓ CO_2 emissions
[74]	2001–2014	EU countries	Pooled mean group (PMG)	ICT ↑ CO_2 emissions
[76]	2007–2019	China	GMM	ICT ↓ CO_2 emissions
		Agriculture-CO_2 emissions		
[79]	1990–2018	South Asian countries	FMOLS, EKC	AGR ↓ CO_2 emissions
[80]	2004–2020	15 developing countries	Panel quantile regression	AGR ↑ CO_2 emissions
[81]	1971–2014	Saudi Arabia	ARDL, EKC	AGR ↓ CO_2 emissions, inverted U-shaped EKC
[82]	1971–2016	BRIC countries	Fourier cointegration and causality test	AGR ↑ CO_2 emissions
[83]	1990–2019	Malaysia	ARDL, DOLS, Granger causality test	AGR ↑ CO_2 emissions
[84]	1990–2016	China	ARDL bound test; FMOLS, CCR	AGR ↓ CO_2 emissions in the long run
		FDI-CO_2 emissions		
[97]	1981Q1–2021Q1	APEC economies	Common correlated effect mean group	FDI ↑ CO_2 emissions
[98]	1980–2014	17 Asian nations	FMOLS	FDI ↑ CO_2 emissions
[99]	2000–2014	32 Asian nations	EKC	FDI ↑ CO_2 emissions
[100]	2001–2019	Asian economies	2SLS, GLS, GMM	FDI ↑ CO_2 emissions
[101]	1996–2016	40 Asian countries	GMM	FDI ↓ CO_2 emissions

Source: Authors' own contribution.

3. Methodology

The factors influencing CO_2 emissions are intricate and diverse. However, within the scope of our analysis, we focused on urbanization, information and communication technology (ICT), renewable energy, agriculture, and economic development. Our empirical assessment was based on the following basic model:

$$co_{2it} = \alpha_0 + \alpha_1 urb_{it} + \alpha_2 agr_{it} + \alpha_3 rnew_{it} + \alpha_4 fdi_{it} + \alpha_5 ict_{it} + \alpha_6 gdp_{it} + \alpha_7 gdpsq_{it} + \varepsilon_{it}$$

where co_{2it} is the CO_2 emissions per capita; urb_{it} represents the rate of urbanization, which measures the pace at which an area is becoming more urban; gdp_{it} represents the GDP per capita, which indicates the economic output per person; $rnew_{it}$ is renewable energy consumption; fdi_{it} is foreign direct investment, net inflows (% of GDP); ict_{it} is individuals using the internet (% of population) as a proxy for ICT; agr_{it} signifies agriculture, forestry, and fishing, value added (% of GDP); $gdpsq_{it}$ is squared for GDP; and ε_{it} is the error term. All the data are in logs.

The dataset consisted of yearly panel data from 1996 to 2020, encompassing 14 Asian countries that were among the top CO_2 emitters. These countries included China, India, Indonesia, Iran, the Islamic Republic, Japan, Kazakhstan, Korea, Malaysia, the Russian Federation, Saudi Arabia, Thailand, Turkey, Uzbekistan, and Vietnam. The dataset for the variables analyzed in the study was obtained from World Development Indicators.

The approach involved six sequential steps. The first step was to assess the panel unit root and perform a cointegration analysis to determine the integration properties of the data. Second, the FMOLS and DOLS methods were employed [102]. These approaches were beneficial since they considered the presence of cross-sectional dependency and heteroscedasticity problems. Furthermore, our primary goal was to assess the impact of the independent variables under consideration on the whole distribution of the dependent variable. To do this, we implemented the MMQR approach to estimate Equation (1). Last, we implemented the Driscoll–Kraay estimator to further check the validity of the outcomes achieved by the MMQR, FMOLS, and DOLS estimation techniques.

4. Empirical Strategies

Comparable to the previous literature research investigating the link between CO_2 emissions and its main determinants, the empirical estimate involves four primary stages: (i) investigating the cross-sectional dependence features of the underlying data and determining the integration order of the variables; (ii) investigating the variables' cointegration over the long term; (iii) investigating the variables of the model that have been established for the long run in the preceding stage; and (iv) in the final stage, implementing a novel approach, quantile-regression (QR) via method of moments, to investigate the manner in which the link between each of the components runs.

4.1. Method of Moments Quantile Regression (MMQR)

Our primary approach was to utilize the MMQR to investigate whether the impacts of the factors influencing CO_2 emissions varied across the different ranges of CO_2 emissions, which represented the emission levels of major CO_2-emitting countries in Asia.

Quantile regression techniques are frequently utilized while the parameters exhibit various impacts depending on the conditional distribution of the dependent variable. Conventional mean regression models, such the OLS technique, are unable to demonstrate these diverse impacts. This is due to the investigations mainly focusing on examining how explanatory factors impact the conditional means of the dependent variable. Consequently, the mean regression places more importance on the average value of the conditional distribution, disregarding the impacts of independent variables on the whole range of values. Compared with the traditional mean regression, the MMQR estimation method provides more reliable findings since it takes into account the possible impacts of the independent variables on the dependent variable's conditional distribution and controls for distributional heterogeneity. As opposed to other panel quantile regression methods, which merely alter means, the MMQR method considers the individual effects that impact the entire distribution, allowing one to capture the conditional heterogeneous covariance effects of CO_2 emissions. Put differently, this approach determines the conditional quantile effects applying scale and location functions that have been identified with the conditional expectancies of properly described variables identifying both functions.

In accordance with [103] and other authors [104–109], the following is the expression for the conditional quantile of a random variable $Q_Y(\tau|X_{it})$:

$$Y_{it} = \alpha_i + X_{it}'\beta + \left(\delta_i + Z_{it}'\varphi\right)\mu_{it} \tag{1}$$

where Y_{it} is the dependent variable; X_{it} is an i.i.d. endogenous variable; and α, β, δ, and γ are the parameters to be examined. The probability $P\left\{\delta_i + Z_{it}' > 0\right\} = 1$. μ_{it} is an independent variable distributed across individuals and is orthogonal to X_{it}, satisfying the moment conditions [103,106,110]. $i = 1 \ldots n$ denotes the individual i fixed effects, and Z is a k-vector of known components of X [103,104,108].

Following [104,106], Equation (2) implies the following:

$$Q_Y(\tau|X_{it}) = (\alpha_i + \delta_i q(\tau)) + X_{it}'\beta + Z_{it}'\varphi q(\tau) \tag{2}$$

where $Q_Y(\tau|X_{it})$ is the quantile distribution of the dependent variable and Y_{it}. $\alpha_i + \varepsilon_i q(\tau)$ is the scalar coefficient [106], and τth is the sample quantile [103,104,106]. Z denotes a k-vector of known components of Xit, which is normalized to satisfy the moment conditions $E(U) = 0$ and $E(|U|) = 1$ [103,105,107,108].

The MMQR version of Equation (3) incorporates the appropriate variables for our framework:

$$\begin{aligned} Q_{co_{2it}}(\tau|\alpha_i, x_{it}) &= \alpha_i + \beta_{1\tau} lnurb_{it} + \beta_{2\tau} lngdp_{it} + \beta_{3\tau} lnrnew_{it} + \beta_{4\tau} lnfdi_{it} + \beta_{5\tau} lnict_{it} + \beta_{6\tau} lnagr_{it} \\ &+ \beta_{7\tau} lngdpsq_{it} \end{aligned} \tag{3}$$

4.2. Panel FMOLS and DOLS

Estimating the long-term coefficients is the next most important stage in the empirical estimation technique and is highlighted in Equation (1). This phase involves determining whether the underlying collection of data exhibits cointegration features. Both the F-MOLS technique (fully modified OLS) and the DOLS methodology (dynamic ordinary least squares method) were employed during our research. It is generally maintained in the empirical literature that the ordinary least squares (OLS) procedure for a panel may yield misleading outputs, which is why it is viewed as inefficient. Endogeneity and serial correlations are two issues that might arise if OLS algorithms are used. The FMOLS and DOLS methods, both of which are often used in the literature as panel estimating methodologies with a focus on heterogeneity [111,112], may help address these concerns.

The FMOLS approach offers a notable benefit in examining the effectiveness of a measure when confronted with mixed order integrating variables in the cointegrating structure. The measures exhibit consistency even when faced with constraints such as sample bias and endogeneity [48,113,114]. Undoubtedly, the FMOLS methods are suitable for addressing the initial levels of residual heterogeneity in long-term coefficients.

Equations (4) and (5) explain the mathematical forms of these estimators:

$$\beta_{FMOLS} = \left[N^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}\left(p_{it} - \underline{p}_i\right)^2\right]^{-1} \times \left[\sum_{t=1}^{T}\left(p_{it} - \underline{p}_i\right)S_{it} - T\Delta_{\varepsilon u}\right] \tag{4}$$

$$\beta_{DOLS} = \left[N^{-1}\sum_{i=1}^{N}\left\{\sum_{i=1}^{T} Z_{it}Z_{it}'\right\}^{-1} \times \left\{\sum_{t=1}^{T} Z_{it}S_{it}\right\}\right] \tag{5}$$

Here p is the explanatory variable, S denotes the dependent variable, and Z is the vector of regressors, where $Z = p - \overline{p}$.

Ref. [111] posits that the DOLS and FMOLS estimation methods are preferable to within-group-based estimation as they account for between-group-based estimation. The measures under consideration incorporate endogeneity concerns by accounting for temporal precedence and permitting the use of heteroskedastic standard errors. The DOLS approach is superior to the FMOLS method due to its computational simplicity and ability to minimize biases [115]. The utilization of leads and lags in the DOLS approach is advantageous for addressing issues pertaining to the order of integration and the presence or absence of cointegration.

5. Results

This section presents the initial data analyses, which include descriptive statistics and the Pearson correlation matrix of the variables under investigation. Furthermore, this section covers panel unit root and panel cointegration tests to ensure thorough screening of the variables, resulting in reliable outcomes from the model calculations and clarifications.

Table 2 presents the statistical features of the chosen variables, which include the maximum, minimum, mean, and standard deviation. The mean values of CO_2, URB, GDP, RNEW, FDI, ICT, AGR, and GDPsq were 1.58, 4.02, 8.66, 1.43, 0.42, 2.39, 2.03, and 76.07, respectively. Accordingly, a remarkable amount of standard deviation was shown for each of the variables investigated in this research, which were as follows: 0.82, 0.36, 1, 2.13, 1.18, 2.26, 0.85, and 17.36 for CO_2, URB, GDP, RNEW, FDI, ICT, and GDPsq, respectively. The descriptive properties of the factors enabled us to proceed to the unit root test.

Table 2. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
ln co_2	350	1.587216	0.8274579	−0.7604691	2.848264
lnurb	350	4.023419	0.3610731	3.116311	4.519416
lnagr	350	2.032461	0.8556259	−0.0034001	3.405278
lnrnew	350	1.432487	2.131769	−4.60517	4.136925
lnfdi	335	0.4273396	1.188987	−4.742113	2.565938
lnint	350	2.391404	2.260098	−8.911622	4.583562
lngdp	350	8.664675	1.000384	6.479981	10.49512
lnGDPsq	350	76.07451	17.36504	41.99015	110.1474

Computed by Stata 17.0.

To assess the correlation between variables, the Pearson correlation coefficient was calculated for matrix correlations, and the results are displayed in Table 3. The correlation matrix provides information on the strength and direction of the relationship between each pair of variables under investigation. A correlation coefficient that is closer to one indicates a higher degree of strength, while a negative correlation signifies a reverse correlation between two variables. The correlation matrix is symmetrical with respect to the diagonal, where the diagonal elements have a value of 1.000000, indicating that the variables are completely correlated. Table 2 shows that there was a strong positive relationship between the dependent variable (lnco_2) and the independent variables lnurb (0.8552), lngdp (0.8155), lnict (0.4306), and lngdpsq (0.7998). On the other hand, there was a clear negative relationship between the dependent variable (lnco_2) and the independent variables lnrnew (−0.7316), lnfdi (−0.1520), and lnagr (−0.7448). From these results, it was evident that there were strong and positive correlations among the variables lnco_2, lnurb, lngdp, lngdpsq, lnrnew, and lnagr, as expected.

Table 3. Correlation matrix.

	$lnco_2$	lnurb	Lnagr	lnrnew	lnfdi	lnint	lngdp	lnGDPsq
$\ln co_2$	1.0000							
lnurb	0.8552	1.0000						
lnagr	−0.7448	−0.7595	1.0000					
lnrnew	−0.7316	−0.6307	0.4347	1.0000				
lnfdi	−0.1520	−0.3733	0.3181	0.1698	1.0000			
lnint	0.4306	0.4783	−0.4867	−0.1601	−0.0130	1.0000		
lngdp	0.8155	0.8659	−0.9224	−0.5032	−0.2733	0.5769	1.0000	
lnGDPsq	0.7998	0.8546	−0.9337	−0.4991	−0.2936	0.5650	0.9978	1.0000

Computed by Stata 17.0.

Table 4 contains the findings associated with the cross-sectional analysis (CD). The CD test demonstrated that the null hypothesis should not be accepted, therefore rejecting it. This indicated the existence of cross-sectional dependence within the data. These findings provided evidence that over the course of a longer time period, the variables could become cointegrated.

Table 4. Cross-sectional dependency tests.

Tests	Statistic	*p*-Value
Breusch Pagan LM	89.384 ***	0.0000
Pesaran CD	14.259 ***	0.0000

Standard errors in parentheses: *** $p < 0.01$.

The results of the cross-sectional unit root test can be found in Table 5. The outcomes showed that all the variables examined showed evidence of stationarity when evaluated through first-order differencing. After careful analysis, the null hypothesis of the presence of a unit root could be rejected. This implied that there was proof that order integration occurred within the variables in question.

Table 5. Cross-sectional unit root test results.

	CADF		CIPS	
	I(0)	I(1)	I(0)	I(1)
$\ln co_2$	−1.948 *	−3.094 ***	−2.521	−4.397 ***
lnurb	−2.250	−3.525 ***	−0.784	−2.328 ***
lnagr	0.693	−4.664 ***	−2.163 ***	−4.618 ***
lnrnew	2.888	−1.400 **	−1.328	−3.972 ***
lnfdi	0.586	−6.049 ***	−0.598	−3.254 ***
lnict	−3.958 ***	−4.776 ***	−3.106 ***	−4.259 ***
lngdp	−1.368	−3.257***	−2.307	−3.195 ***
lnGDPsq	−1.365	−3.558 ***	−2.275 ***	−3.313 ***

Note: Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6 reveals that the probability values for the rho and ADF statistics in the "within-dimension" analysis were not significant. Nevertheless, the probability values for the v and PP statistics were deemed significant at the 5% level. Extensive research revealed that there was a significant correlation between the variables under examination over an extended period of time.

Table 6. Pedroni cointegration test results.

	Statistic	p-Value
Within		
v-statistics	−2.6975	0.0035
rho-statistics	2.4739	0.0067
PP-statistics	0.3120	0.3775
ADF-statistics	−0.2842	0.3881
	Between	
rho-statistics	3.8629	0.0001
PP-statistics	0.8535	0.1967
ADF-statistics	0.4028	0.3435

6. Discussion

While our main objective was to evaluate the influence of the factors that determined CO_2 emissions on the entire range of the dependent variable implementing the MMQR technique, we initially present the findings of three conventional estimators—FMOLS, DOLS, and the Driscoll–Kraay estimates—for the purpose of comparison. Table 7 shows the results of these tests. The results of various statistical techniques clearly demonstrated that renewable energy, agriculture, and the square of the GDP had significant and adverse influences on CO_2 emissions. According to the FMOLS calculations, a mere one percent increase in the utilization of renewable energy led to a precise decrease of 0.142% in CO_2 emissions per individual. Similarly, both the DOLS and the Driscoll–Kraay, which was implemented for a robustness check, estimating procedures had significant negative correlations. Based on these estimation techniques, a 1% rise in the usage of renewable energy led to decreases in CO_2 emissions per capita of 0.133% and 0.158%. Our outcomes were consistent with those of other studies performed in numerous nations, which also revealed that the utilization of renewable energy sources may significantly reduce carbon emissions [116–121].

Table 7. Dynamic panel data results.

	(1)	(2)	(4)
Variables	**FMOLS**	**DOLS**	**Driscoll–Kraay (FE-OLS)**
lnurb	0.793 **	0.879 **	1.296 ***
	(0.320)	(0.382)	(0.142)
lnagr	−0.428 ***	−0.430 **	−0.421 ***
	(0.159)	(0.188)	(0.0666)
lnrnew	−0.142 ***	−0.133 ***	−0.158 ***
	(0.0297)	(0.0343)	(0.0260)
lnfdi	0.0734	0.111 *	−0.00800
	(0.0461)	(0.0662)	(0.00637)
lnint	−0.0148	−0.0104	−0.00732 **
	(0.0257)	(0.0376)	(0.00323)
lngdp	2.629 ***	2.254 **	1.054 ***
	(0.892)	(1.078)	(0.314)
lnGDPsq	−0.152 ***	−0.131 **	−0.0606 ***
	(0.0521)	(0.0625)	(0.0212)
Constant	−11.76 ***	−10.43 ***	−7.023 ***
	(3.318)	(3.966)	(1.054)
Observations	334	332	335
R-squared	0.379	0.885	

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Our analysis revealed a significant and negative association between CO_2 emissions and agriculture, which aligned with the expected relationship between CO_2 emissions and the utilization of renewable energy sources. These findings were consistent across all three estimation methodologies. Based on the FMOLS and DOLS estimation methods, a 1% increase in agricultural output led to a decrease of approximately 0.428% to 0.430% in CO_2 emissions per capita. In contrast to the prior illustration, ref. [102] estimates showed that the agricultural output was negatively and statistically significantly correlated with emissions CO_2. Specifically, the estimates showed that a 1% increase in agricultural production led to a 0.421% decrease in per capita CO_2 emissions [102]. These results align with the findings of previous research [73,109,122]. Our findings showed that all the estimation techniques indicated favorable and statistically significant relationships between urbanization, the GDP, and CO_2 emissions [27,123]. The DOLS estimate was the sole indicator that showed an important and beneficial relationship between FDI and CO_2 emissions. Similarly, the Driscoll–Kraay estimate was one piece of evidence indicating a significant and adverse correlation between CO_2 emissions and ICT.

Our main goal was not to provide a conditional average of these estimations but rather to offer estimates that encompassed the many effects of various variables driving CO_2 emissions. The findings of the MMQR are presented in Table 8. First, the favorable effect of urbanization on CO_2 could be verified. The evidence clearly demonstrated that urbanization had a substantial impact on an upsurge in CO_2 levels, with values varying from 0.312 to 1.177 across all quantiles. With the increase in population, there was a corresponding increase in the need for energy. Due to their cost-effectiveness and easy availability, fossil fuels are heavily relied upon for energy generation, considering the high demand. Urbanization is a contributing factor to the increase in CO_2 emissions. Moreover, it is intriguing to explore the relationship between the GDP and CO_2 emissions. The table provides a clear and comprehensible explanation of the substantial increase in CO_2 emissions attributed to the GDP. The frequency of the rise varied from 3.205 to 2.050 as the quantile increased. In the initial stages of economic expansion, the rate of primary production slowly increased, which eventually transitioned to a more rapid acceleration. Consequently, a rise in these economic activities led to a beneficial effect on carbon emissions. Conversely, the square of the GDP had a significant and harmful impact on CO_2 emissions at all levels, as demonstrated by statistical research. Moreover, the EKC theory was valid for all quantiles. Our analysis suggested that the selected economies achieved a specific degree of economic advancement, as demonstrated by the validity of the inverted U-shaped EKC. Presently, there is a movement toward achieving economic growth that is both ecologically friendly and capable of being maintained over time [37]. Moreover, the increase in economic growth stimulates technical progress, promotes the emergence of alternative energy sources, amplifies the production of renewable energy, and accelerates the expansion of the tertiary and service sectors. These endeavors have successfully contributed to the decrease in CO_2 emissions.

The findings demonstrated a robust and negative correlation between the utilization of renewable energy and environmental deterioration across all levels of quantiles (Table 8). The negative repercussions of REC may result in a direct outcome; specifically, technological developments, especially in the realm of renewable energy generation, are essential for improving production quality and lowering production costs. Furthermore, it effectively counteracts environmental contaminants. Similarly, agriculture had a detrimental effect on CO_2 emissions at all levels of assessment. By incorporating technical advancements in machinery and improving energy efficiency in farm buildings, farmers may greatly reduce fuel usage and emissions while also enjoying financial advantages.

The results indicated a strong and positive relationship between FDI and environmental deterioration across the 25th to 95th quantiles. FDI had multiple impacts on the carbon footprint of the host nation. First, it increased the overall size of economic activity. Second, it altered the structure of economic activity. Last, it introduced new manufacturing processes. When considered independently, the scale effect was anticipated to amplify carbon emissions since a larger economy signified greater output and, hence, higher emissions. Conversely, ICT had a detrimental impact on CO_2 emissions in higher quantiles, whereas this connection was favorable and was statistically significant at the fifth quantile. Digital technology directly or indirectly contributed to the reduction in carbon emissions by fostering the development of environmentally friendly technical advancements and decreasing energy consumption. It additionally served a crucial role in the implementation of carbon emission trading regulations and extensive national large-scale data pilot regions aimed at lowering carbon emissions.

Ultimately, Figure 2 displays graphical plots of MMQR. It demonstrates the interconnectedness of the variables at various quantiles.

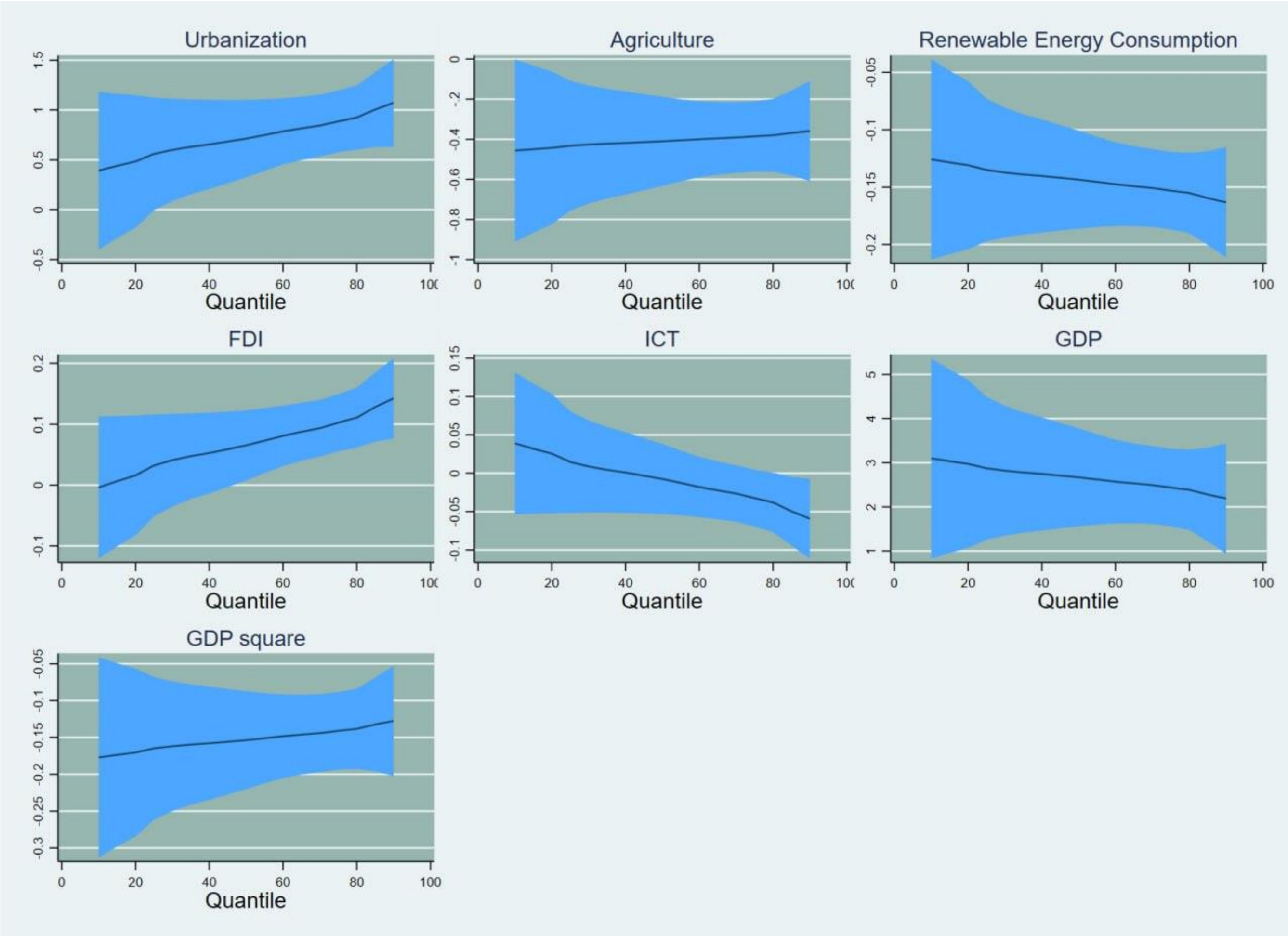

Figure 2. Graphical summary of the impacts of the determinants of CO_2 emissions. Computed by Stata 17.0.

Table 8. Quantile regression via method of moments.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Location**	**Scale**	**qtile_5**	**qtile_25**	**qtile_50**	**qtile_75**	**qtile_95**
lnurb	0.723 ***	0.206 ***	0.312 *	0.560 ***	0.713 ***	0.886 ***	1.177 ***
	(0.111)	(0.0649)	(0.176)	(0.118)	(0.112)	(0.131)	(0.187)
lnagr	−0.409 ***	0.0295	−0.467 ***	−0.432 ***	−0.410 ***	−0.385 ***	−0.344 ***
	(0.0508)	(0.0296)	(0.0721)	(0.0531)	(0.0506)	(0.0590)	(0.0878)
lnrnew	−0.144 ***	−0.0113 **	−0.121 ***	−0.135 ***	−0.143 ***	−0.153 ***	−0.169 ***
	(0.0137)	(0.00569)	(0.0205)	(0.0163)	(0.0138)	(0.0125)	(0.0139)

Table 8. *Cont.*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Location**	**Scale**	**qtile_5**	**qtile_25**	**qtile_50**	**qtile_75**	**qtile_95**
lnfdi	0.0673 ***	0.0444 ***	−0.0212	0.0322 *	0.0652 ***	0.103 ***	0.165 ***
	(0.0152)	(0.00907)	(0.0219)	(0.0173)	(0.0156)	(0.0187)	(0.0270)
lnint	−0.00882	−0.0297 ***	0.0504 ***	0.0147	−0.00743	−0.0324 ***	−0.0743 ***
	(0.0115)	(0.00443)	(0.0145)	(0.0133)	(0.0120)	(0.0124)	(0.0140)
lngdp	2.656 ***	−0.275	3.205 ***	2.874 ***	2.669 ***	2.438 ***	2.050 ***
	(0.295)	(0.180)	(0.329)	(0.257)	(0.291)	(0.392)	(0.598)
lnGDPsq	−0.153 ***	0.0150	−0.183 ***	−0.165 ***	−0.154 ***	−0.141 ***	−0.120 ***
	(0.0174)	(0.0101)	(0.0198)	(0.0158)	(0.0172)	(0.0224)	(0.0336)
Constant	−11.65 ***	0.651	−12.95 ***	−12.17 ***	−11.68 ***	−11.14 ***	−10.22 ***
	(1.072)	(0.646)	(1.354)	(1.025)	(1.063)	(1.344)	(2.039)
Observations	335	335	335	335	335	335	335

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

7. Conclusions and Policy Implications

Concerns regarding the environment continue to be popular and widely discussed in academic circles due to the ongoing shifts in climate change and the rising amount of carbon emissions. Numerous research efforts have explored the factors that contribute to pollution, but most of them rely on aggregate use of energy or traditional panel estimation techniques for their analysis. With regard to the top 14 CO_2-emitting economies in Asia, the primary purpose of this research was to investigate the impacts that factors such as consumption of renewable energy, urbanization, gross domestic product, agricultural production, information and communication technology development, and foreign direct investment had on CO_2 emissions. Applying the innovative method of moments quantile regression (MMQR) from 1996 to 2020, the current research intended to investigate, for the first time, the impact of renewable energy consumption, urbanization, the GDP, agriculture, ICT development, and FDI on CO_2 emissions in all countries under consideration. To gain an understanding of the characteristics of the dataset, this study used several preliminary analyses and panel sensitivity tests. Additionally, it utilized several panel estimation approaches in conjunction with quantile regression to assess the robustness of the dataset.

Research findings indicated that certain factors, such as REC and agriculture, were shown to reduce pollution. Furthermore, we revealed evidence for the EKC hypothesis and found that the GDP had an inverted U-shaped effect on CO_2 emissions based on the relationship between the GDP squared and CO_2 emissions. On the other hand, urbanization and the GDP were found to contribute to carbon emissions. These findings supported the validity of the EKC hypothesis. According to the findings, a 1% increase in REC resulted in decreases in carbon emissions by 0.142%, 0.133%, and 0.158% for FMOLS, DOLS, and the Driscoll–Kraay methods, respectively. On the other hand, a 1% growth in agriculture led to an increase in CO_2 emissions by 0.428% for FMOLS, 0.430% for DOLS, and 0.421% for the Driscoll–Kraay method. In addition, a 1% increase in the GDP square led to corresponding rises in CO_2 emissions of 0.152%, 0.131%, and 0.060% for FM-OLS, DOLS, and the Driscoll–Kraay method, respectively. The presence of EKC in Asian countries was confirmed by the negative and significant signs of coefficients of the GDP square in all three methods. On the other hand, the results of the study showed that a 1% increase in urbanization was associated with rises in carbon emissions of 0.793%, 0.879%, and 1.296% using the FMOLS, DOLS, and Driscoll–Kraay methods, respectively. However, a 1% growth in the GDP led to an increase in CO_2 emissions of 2.629% using FMOLS, 2.254% using DOLS, and 1.054% using the Driscoll–Kraay method. Regarding the relationship between foreign direct investment and carbon dioxide emissions, the DOLS estimate was the only one that showed a significant and positive correlation. Comparably, the lone estimation that showed a significant but unfavorable correlation between CO_2 emissions and ICT was the Driscoll–Kraay estimate.

The outcome of the MMQR revealed that urbanization, the GDP, and FDI all had a beneficial impact on carbon emissions across all quantiles, from the 5th to the 95th. However, it is worth noting that REC, ICT, agriculture, and the square of the GDP all had a detrimental effect on pollution levels across all quantiles. Therefore, the results confirmed the presence of the EKC hypothesis across all quantiles.

Additionally, we developed the graphical representation of the findings of our empirical analysis. Figure 3 compares the estimated coefficients for all methods employed, including MMQR, FE-OLS, DOLS, and FMOLS. As opposed to the DOLS, FMOLS, and FE-OLS coefficients, which were all fixed, the MMQR coefficients were variable and provided a lively picture throughout all quantiles.

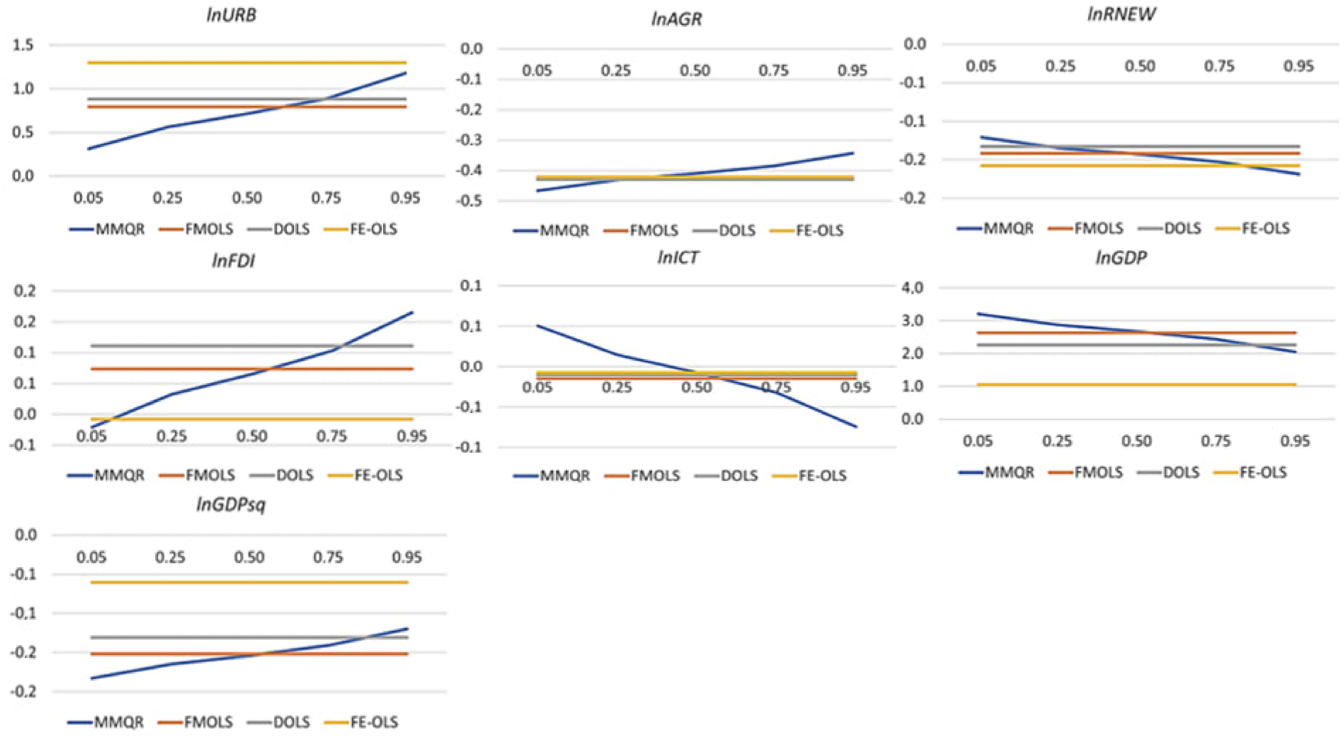

Figure 3. Graphical summary of the empirical results.

Based on these results, the present study proposes several policy recommendations for the selected sample.

First, economic development is a crucial instrument in addressing climate change. According to the inverted U-shaped EKC theory, it is postulated that as development in the economy continues, there will be a point at which a specific income level is attained, leading to a drop in CO_2 emissions. From this standpoint, it is essential to promote economic development.

Second, policymakers in the Asian countries that produce the most carbon dioxide should prioritize expanding the use of renewable energy sources to power agricultural expansion while simultaneously decreasing reliance on fossil fuels. To attain a consistent and enduring expansion in the utilization of energy from renewable sources, authorities must formulate and execute favorable legislation that incentivizes investments for enhancing the newly developed renewable energy facilities.

Third, to address the heat and electricity issues and lessen reliance on non-renewable energy sources, it would be beneficial to promote the construction by agricultural businesses of small biogas plants and power stations that are powered by wind and sun. Furthermore, it is essential for the legislative bodies of the aforementioned countries to enhance their laws and regulations, such as by implementing tax incentives, feed-in tariffs, tax refunds, and investment subsidies, in order to promote the adoption of renewable energy in the agriculture industry.

Fourth, it is crucial to boost FDI in industries characterized by low levels of CO_2 emissions, while reducing FDI in sectors associated with substantial carbon emissions. Hence, it is essential to enact relevant regulations to bolster FDI, expedite the dissemination of state-of-the-art global technology, and optimize the advantages of environmental enhancement resulting from technological spillovers. Successful implementation of these measures would ultimately enable Asian nations with the highest CO_2 emissions to achieve both a low-carbon economy and economic growth. In such a situation, it is imperative to gradually modify the worldwide trade and FDI structure while conducting "supply-side reform" in sectors that have a limited emphasis on carbon emissions. In addition, concurrent research and development efforts are underway to create new technologies aimed at safeguarding the environment and establishing an eco-friendly industrial setting.

Fifth, governments should prioritize the development and use of environmentally friendly types of ICT so that these advancements may support their endeavors to create a sustainable environment.

Last, it is advisable to implement initiatives aimed at slowing down the rate of urbanization in these nations. This might be achieved if governments focus on improving rural income initiatives. Furthermore, the association between the urban areas in Asian countries that have the highest levels of CO_2 emissions and the increased demand for energy and environmental degradation highlights the crucial significance of strategic planning in the design, development, and management processes. This planning is essential in addressing urban expansion while simultaneously promoting higher urban density. Urban density has many benefits, including less environmental harm and a well-developed transportation network and infrastructure, especially public transportation, which enhances accessibility. Additionally, urban density promotes efficient energy supply and good water management systems.

The shortcomings of the current investigation highlight the need to explore prospective areas of investigation that ought to be explored in the future. Nevertheless, although factors such as institutional quality, research and development, and technological innovation are anticipated to exert an influence on the pollution haven and halo hypothesis, the theoretical framework fails to include these specific attributes. These issues, as well as similar ones, might potentially be the focus of future study. In the near future, researchers who seek to highlight the practical consequences of their findings could gain from a specialized terminology that elucidates the interplay between institutional quality and natural resources.

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References

1. United Nations Conference on Trade and Development (UNCTAD). UNCTAD Handbook of Statistics 2021. In *Handbook of Statistics*; UNCTAD: Geneva, Switzerland, 2022. [CrossRef]
2. IPCC. Climate Change 2014: Synthesis Report. In *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Core Writing Team, Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014; 151p.
3. Kinski, L.; Ripoll Servent, A. Framing Climate Policy Ambition in the European Parliament. *Politics Gov.* **2022**, *10*, 251–263. [CrossRef]
4. Saranya, M.S.; Nair Vinish, V. Evaluation and Selection of CORDEX-SA Datasets and Bias Correction Methods for a Hydrological Impact Study in a Humid Tropical River Basin, Kerala. *J. Water Clim. Change* **2021**, *12*, 3688–3713. [CrossRef]
5. Tangsathitkulchai, C.; Naksusuk, S.; Wongkoblap, A.; Phadungbut, P.; Borisut, P. Equilibrium and Kinetics of CO_2 Adsorption by Coconut Shell Activated Carbon Impregnated with Sodium Hydroxide. *Processes* **2021**, *9*, 201. [CrossRef]
6. Nchofoung, T.N.; Asongu, S.A. ICT for Sustainable Development: Global Comparative Evidence of Globalisation Thresholds. *Telecommun. Policy* **2022**, *46*, 102296. [CrossRef]
7. Mushtaq, A.; Chen, Z.; Ud Din, N.; Ahmad, B.; Zhang, X. Income Inequality, Innovation and Carbon Emission: Perspectives on Sustainable Growth. *Econ. Res.-Ekon. Istraživanja* **2020**, *33*, 769–787. [CrossRef]
8. Lazzerini, G.; Migliorini, P.; Moschini, V.; Pacini, C.; Merante, P.; Vazzana, C. A Simplified Method for the Assessment of Carbon Balance in Agriculture: An Application in Organic and Conventional Micro-Agroecosystems in a Long-Term Experiment in Tuscany, Italy. *Ital. J. Agron.* **2014**, *9*, 55. [CrossRef]
9. Zulkurnai, N.Z.; Md Ali, U.F.; Ibrahim, N.; Abdul Manan, N.S. Carbon Dioxide Capture by Deep Eutectic Solvent Impregnated Sea Mango Activated Carbon. *E3S Web Conf.* **2018**, *34*, 02030. [CrossRef]
10. Karaduman, H.A.; Karaman-Akgül, A.; Çağlar, M.; Akbaş, H.E. The Relationship between Logistics Performance and Carbon Emissions: An Empirical Investigation on Balkan Countries. *Int. J. Clim. Chang. Strateg. Manag.* **2020**, *12*, 449–461. [CrossRef]
11. Mitić, P.; Fedajev, A.; Kojić, M. Exploring the Economy–Environment Interactions in the Western Balkans. *Econ. Anal.* **2023**, *56*, 43–56. [CrossRef]
12. Rahaman, M.A.; Hossain, M.A.; Chen, S. The Impact of Foreign Direct Investment, Tourism, Electricity Consumption, and Economic Development on CO_2 Emissions in Bangladesh. *Environ. Sci. Pollut. Res.* **2022**, *29*, 37344–37358. [CrossRef]
13. Jin Kang, S. *Asia's Low-Carbon Transition: Opportunities and Challenges for Trade*; Asian Development Bank: Mandaluyong, Philippines, 2023. [CrossRef]
14. ESCAP. 2023 Review of Climate Ambition in Asia and the Pacific Just Transition Towards Regional Net-Zero Climate Resilient Development. 2023. Available online: https://www.unescap.org/kp/2023/2023-review-climate-ambition-asia-and-pacific-just-transition-towards-regional-net-zero (accessed on 18 December 2023).
15. Ekins, P. *Stopping Climate Change: Policies for Real Zero*; Taylor & Francis: Abingdon, UK, 2023; Available online: https://www.routledge.com/Stopping-Climate-Change-Policies-for-Real-Zero/Ekins/p/book/9781032571416 (accessed on 18 December 2023).
16. Shaari, M.S.; Abidin, N.Z.; Ridzuan, A.R.; Meo, M.S. The impacts of rural population growth, energy use and economic growth on co_2 emissions. *Int. J. Energy Econ. Policy* **2021**, *11*, 553–561. [CrossRef]
17. Romana, H.K.; Singh, R.P.; Shukla, D.P. Long Term Air Quality Analysis in Reference to Thermal Power Plants Using Satellite Data in Singrauli Region, India. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2020**, 829–834. [CrossRef]
18. Dong, K.; Dong, X.; Dong, C. Determinants of the Global and Regional CO_2 Emissions: What Causes What and Where? *Appl. Econ.* **2019**, *51*, 5031–5044. [CrossRef]
19. Lorenzo, T.E.; Kinzig, A.P. Double Exposures: Future Water Security across Urban Southeast Asia. *Water* **2019**, *12*, 116. [CrossRef]
20. Wenlong, Z.; Tien, N.H.; Sibghatullah, A.; Asih, D.; Soelton, M.; Ramli, Y. Impact of Energy Efficiency, Technology Innovation, Institutional Quality, and Trade Openness on Greenhouse Gas Emissions in Ten Asian Economies. *Environ. Sci. Pollut. Res.* **2022**, *30*, 43024–43039. [CrossRef]
21. Khan, M.T.; Imran, M. Unveiling the Carbon Footprint of Europe and Central Asia: Insights into the Impact of Key Factors on CO_2 Emissions. *Zenodo* **2023**, *1*, 52–66. [CrossRef]
22. Xie, Q.; Wang, X.; Cong, X. How Does Foreign Direct Investment Affect CO_2 Emissions in Emerging Countries? New Findings from a Nonlinear Panel Analysis. *J. Clean. Prod.* **2020**, *249*, 119422. [CrossRef]
23. Dauda, L.; Long, X.; Mensah, C.N.; Salman, M.; Boamah, K.B.; Ampon-Wireko, S.; Kofi Dogbe, C.S. Innovation, Trade Openness and CO_2 Emissions in Selected Countries in Africa. *J. Clean. Prod.* **2021**, *281*, 125143. [CrossRef]
24. Kurnia, A.; Rustiadi, E.; Pravitasari, A. Characterizing Industrial-Dominated Suburban Formation Using Quantitative Zoning Method: The Case of Bekasi Regency, Indonesia. *Sustainability* **2020**, *12*, 8094. [CrossRef]
25. Ding, Y.; Yang, Q.; Cao, L. Examining the Impacts of Economic, Social, and Environmental Factors on the Relationship between Urbanization and CO_2 Emissions. *Energies* **2021**, *14*, 7430. [CrossRef]
26. Huang, C.; Qu, Y.; Huang, L.; Meng, X.; Chen, Y.; Pan, P. Quantifying the Impact of Urban Form and Socio-Economic Development on China's Carbon Emissions. *Int. J. Environ. Res. Public Health* **2022**, *19*, 2976. [CrossRef] [PubMed]
27. Zhang, Y.; Zhang, B.; Mu, Y.; Song, K.; Gao, J.; Liu, Y. CMBF-Based Dynamic Selection for Heterogeneous Massive MIMO Systems. *EURASIP J. Wirel. Commun. Netw.* **2020**, *2020*, 70. [CrossRef]

28. O'Mahony, M.; Vecchi, M. Quantifying the Impact of ICT Capital on Output Growth: A Heterogeneous Dynamic Panel Approach. *Economica* **2005**, *72*, 615–633. [CrossRef]
29. Awan, A.; Abbasi, K.R.; Rej, S.; Bandyopadhyay, A.; Lv, K. The Impact of Renewable Energy, Internet Use and Foreign Direct Investment on Carbon Dioxide Emissions: A Method of Moments Quantile Analysis. *Renew. Energy* **2022**, *189*, 454–466. [CrossRef]
30. Daas, M.J.; Jubran, M.; Hussein, M. Energy Management Framework for 5G Ultra-Dense Networks Using Graph Theory. *IEEE Access* **2019**, *7*, 175313–175323. [CrossRef]
31. Dai, L.; Jia, R.; Wang, X. Relationship between Economic Growth and Energy Consumption from the Perspective of Sustainable Development. *J. Environ. Public Health* **2022**, *2022*, 6884273. [CrossRef]
32. Bogdanski, A. Integrated Food–Energy Systems for Climate-Smart Agriculture. *Agric. Food Secur.* **2012**, *1*, 9. [CrossRef]
33. Lenka, S.; Lenka, N.K.; Sejian, V.; Mohanty, M. Contribution of Agriculture Sector to Climate Change. *Clim. Chang. Impact Livest. Adapt. Mitig.* **2015**, 37–48. [CrossRef]
34. Bonou-zin, R.D.C.; Allali, K.; Fadlaoui, A. Environmental Efficiency of Organic and Conventional Cotton in Benin. *Sustainability* **2019**, *11*, 3044. [CrossRef]
35. Bulut, S.; Gökalp, Z. Agriculture and Environment Interaction. *Curr. Trends Nat. Sci.* **2022**, *11*, 372–380. [CrossRef]
36. Campbell, B.M.; Hansen, J.; Rioux, J.; Stirling, C.M.; Twomlow, S.; (Lini) Wollenberg, E. Urgent Action to Combat Climate Change and Its Impacts (SDG 13): Transforming Agriculture and Food Systems. *Curr. Opin. Environ. Sustain.* **2018**, *34*, 13–20. [CrossRef]
37. Grossman, G.; Krueger, A. *Environmental Impacts of a North American Free Trade Agreement*; National Bureau of Economic Research: Cambridge, MA, USA, 1991. [CrossRef]
38. Jorgenson, A.K.; Clark, B. Are the Economy and the Environment Decoupling? A Comparative International Study, 1960–2005. *Am. J. Sociol.* **2012**, *118*, 1–44. [CrossRef]
39. McGee, J.A.; York, R. Asymmetric Relationship of Urbanization and CO_2 Emissions in Less Developed Countries. *PLoS ONE* **2018**, *13*, e0208388. [CrossRef] [PubMed]
40. Chen, L.; Xu, L.; Xia, L.; Wang, Y.; Yang, Z. Decomposition of Residential Electricity-Related CO_2 Emissions in China, a Spatial-Temporal Study. *J. Environ. Manag.* **2022**, *320*, 115754. [CrossRef] [PubMed]
41. Lee, C.-C.; Zhou, B.; Yang, T.-Y.; Yu, C.-H.; Zhao, J. The Impact of Urbanization on CO_2 Emissions in China: The Key Role of Foreign Direct Investment. *Emerg. Mark. Financ. Trade* **2022**, *59*, 451–462. [CrossRef]
42. Chen, X.H.; Tee, K.; Elnahass, M.; Ahmed, R. Assessing the Environmental Impacts of Renewable Energy Sources: A Case Study on Air Pollution and Carbon Emissions in China. *J. Environ. Manag.* **2023**, *345*, 118525. [CrossRef]
43. Liu, H.; Wong, W.-K.; The Cong, P.; Nassani, A.A.; Haffar, M.; Abu-Rumman, A. Linkage among Urbanization, Energy Consumption, Economic Growth and Carbon Emissions. Panel Data Analysis for China Using ARDL Model. *Fuel* **2023**, *332*, 126122. [CrossRef]
44. Abdulqadir, I.A. Urbanization, Renewable Energy, and Carbon Dioxide Emissions: A Pathway to Achieving Sustainable Development Goals (SDGs) in Sub-Saharan Africa. *Int. J. Energy Sect. Manag.* **2023**, *18*, 248–270. [CrossRef]
45. Jebabli, I.; Lahiani, A.; Mefteh-Wali, S. Quantile Connectedness between CO_2 Emissions and Economic Growth in G7 Countries. *Resour. Policy* **2023**, *81*, 103348. [CrossRef]
46. Mardani, A.; Streimikiene, D.; Cavallaro, F.; Loganathan, N.; Khoshnoudi, M. Carbon Dioxide (CO_2) Emissions and Economic Growth: A Systematic Review of Two Decades of Research from 1995 to 2017. *Sci. Total Environ.* **2019**, *649*, 31–49. [CrossRef]
47. Aydoğan, B.; Vardar, G. Evaluating the Role of Renewable Energy, Economic Growth and Agriculture on CO_2 Emission in E7 Countries. *Int. J. Sustain. Energy* **2019**, *39*, 335–348. [CrossRef]
48. Gyamfi, B.A.; Ozturk, I.; Bein, M.A.; Bekun, F.V. An Investigation into the Anthropogenic Effect of Biomass Energy Utilization and Economic Sustainability on Environmental Degradation in E7 Economies. *Biofuels Bioprod. Biorefining* **2021**, *15*, 840–851. [CrossRef]
49. Adebayo, T.S.; Bekun, F.V.; Rjoub, H.; Agboola, M.O.; Agyekum, E.B.; Gyamfi, B.A. Another Look at the Nexus between Economic Growth Trajectory and Emission within the Context of Developing Country: Fresh Insights from a Nonparametric Causality-in-Quantiles Test. *Environ. Dev. Sustain.* **2022**, *25*, 11397–11419. [CrossRef]
50. Jeon, H. CO_2 Emissions, Renewable Energy and Economic Growth in the US. *Electr. J.* **2022**, *35*, 107170. [CrossRef]
51. Zuo, Y.; Zhi, K.; Pei, Y.; Zhuang, W.; Chen, Y. Combining the Role of Natural Resources Development and Trade Openness on Economic Growth: New Evidence from Linear and Asymmetric Analysis. *Resour. Policy* **2023**, *83*, 103538. [CrossRef]
52. Ayhan, F.; Kartal, M.T.; Kılıç Depren, S.; Depren, Ö. Asymmetric Effect of Economic Policy Uncertainty, Political Stability, Energy Consumption, and Economic Growth on CO_2 Emissions: Evidence from G-7 Countries. *Environ. Sci. Pollut. Res.* **2023**, *30*, 47422–47437. [CrossRef] [PubMed]
53. Khalfaoui, R.; Tiwari, A.K.; Khalid, U.; Shahbaz, M. Nexus between Carbon Dioxide Emissions and Economic Growth in G7 Countries: Fresh Insights via Wavelet Coherence Analysis. *J. Environ. Plan. Manag.* **2021**, *66*, 31–66. [CrossRef]
54. Jia, L.; Chang, T.; Wang, M.-C. Revisit Economic Growth and CO_2 Emission Nexus in G7 Countries: Mixed Frequency VAR Model. *Environ. Sci. Pollut. Res.* **2022**, *30*, 5540–5579. [CrossRef] [PubMed]
55. Alkasasbeh, O.M.; Alassuli, A.; Alzghoul, A. Energy Consumption, Economic Growth and CO_2 Emissions in Middle East. *Int. J. Energy Econ. Policy* **2023**, *13*, 322–327. [CrossRef]
56. Westerlund, J.; Edgerton, D.L. A Simple Test for Cointegration in Dependent Panels with Structural Breaks*. *Oxf. Bull. Econ. Stat.* **2008**, *70*, 665–704. [CrossRef]

57. Raihan, A.; Muhtasim, D.A.; Farhana, S.; Rahman, M.; Hasan, M.A.U.; Paul, A.; Faruk, O. Dynamic Linkages between Environmental Factors and Carbon Emissions in Thailand. *Environ. Process.* **2023**, *10*, 5. [CrossRef]
58. Khan, S.A.R.; Zia-Ul-Haq, H.M.; Ponce, P.; Janjua, L. Re-Investigating the Impact of Non-Renewable and Renewable Energy on Environmental Quality: A Roadmap towards Sustainable Development. *Resour. Policy* **2023**, *81*, 103411. [CrossRef]
59. Naseem, S.; Guang Ji, T.; Kashif, U. Asymmetrical ARDL Correlation between Fossil Fuel Energy, Food Security, and Carbon Emission: Providing Fresh Information from Pakistan. *Environ. Sci. Pollut. Res.* **2020**, *27*, 31369–31382. [CrossRef] [PubMed]
60. Saidi, K.; Omri, A. Reducing CO_2 Emissions in OECD Countries: Do Renewable and Nuclear Energy Matter? *Prog. Nucl. Energy* **2020**, *126*, 103425. [CrossRef]
61. Vo, D.H.; Vo, A.T.; Ho, C.M.; Nguyen, H.M. The Role of Renewable Energy, Alternative and Nuclear Energy in Mitigating Carbon Emissions in the CPTPP Countries. *Renew. Energy* **2020**, *161*, 278–292. [CrossRef]
62. Nan, S.; Huang, J.; Wu, J.; Li, C. Does Globalization Change the Renewable Energy Consumption and CO_2 Emissions Nexus for OECD Countries? New Evidence Based on the Nonlinear PSTR Model. *Energy Strategy Rev.* **2022**, *44*, 100995. [CrossRef]
63. Aziz, N.; Sharif, A.; Raza, A.; Jermsittiparsert, K. The Role of Natural Resources, Globalization, and Renewable Energy in Testing the EKC Hypothesis in MINT Countries: New Evidence from Method of Moments Quantile Regression Approach. *Environ. Sci. Pollut. Res.* **2020**, *28*, 13454–13468. [CrossRef]
64. Saidmamatov, O.; Rudenko, I.; Baier, U.; Khodjaniyazov, E. Challenges and Solutions for Biogas Production from Agriculture Waste in the Aral Sea Basin. *Processes* **2021**, *9*, 199. [CrossRef]
65. Koengkan, M.; Fuinhas, J.A. Exploring the Effect of the Renewable Energy Transition on CO_2 Emissions of Latin American & Caribbean Countries. *Int. J. Sustain. Energy* **2020**, *39*, 515–538. [CrossRef]
66. Pata, U.K.; Dam, M.M.; Kaya, F. How Effective Are Renewable Energy, Tourism, Trade Openness, and Foreign Direct Investment on CO_2 Emissions? An EKC Analysis for ASEAN Countries. *Environ. Sci. Pollut. Res.* **2022**, *30*, 14821–14837. [CrossRef]
67. Radmehr, R.; Shayanmehr, S.; Ali, E.B.; Ofori, E.K.; Jasińska, E.; Jasiński, M. Exploring the Nexus of Renewable Energy, Ecological Footprint, and Economic Growth through Globalization and Human Capital in G7 Economics. *Sustainability* **2022**, *14*, 12227. [CrossRef]
68. Dong, K.; Dong, X.; Jiang, Q. How Renewable Energy Consumption Lower Global CO_2 Emissions? Evidence from Countries with Different Income Levels. *World Econ.* **2019**, *43*, 1665–1698. [CrossRef]
69. Nathaniel, S.P.; Iheonu, C.O. Carbon Dioxide Abatement in Africa: The Role of Renewable and Non-Renewable Energy Consumption. *Sci. Total Environ.* **2019**, *679*, 337–345. [CrossRef]
70. Amin, A.; bte Mohamed Yusoff, N.Y.; Yousaf, H.; Peng, S.; Işık, C.; Akbar, M.; Abbas, S. The Influence of Renewable and Non-Renewable Energy on Carbon Emissions in Pakistan: Evidence from Stochastic Impacts by Regression on Population, Affluence, and Technology Model. *Front. Environ. Sci.* **2023**, *11*, 1182055. [CrossRef]
71. Wang, J.; Dong, K.; Sha, Y.; Yan, C. Envisaging the Carbon Emissions Efficiency of Digitalization: The Case of the Internet Economy for China. *Technol. Forecast. Soc. Chang.* **2022**, *184*, 121965. [CrossRef]
72. Xu, L.; Xu, C. Does Green Finance and Energy Policy Paradox Demonstrate Green Economic Recovery: Role of Social Capital and Public Health. *Front. Public Health* **2022**, *10*, 951527. [CrossRef] [PubMed]
73. Balsalobre-Lorente, D.; Abbas, J.; He, C.; Pilař, L.; Shah, S.A.R. Tourism, Urbanization and Natural Resources Rents Matter for Environmental Sustainability: The Leading Role of AI and ICT on Sustainable Development Goals in the Digital Era. *Resour. Policy* **2023**, *82*, 103445. [CrossRef]
74. Park, Y.; Meng, F.; Baloch, M.A. The Effect of ICT, Financial Development, Growth, and Trade Openness on CO_2 Emissions: An Empirical Analysis. *Environ. Sci. Pollut. Res.* **2018**, *25*, 30708–30719. [CrossRef] [PubMed]
75. Ghiasi, M.; Wang, Z.; Mehrandezh, M.; Jalilian, S.; Ghadimi, N. Evolution of Smart Grids towards the Internet of Energy: Concept and Essential Components for Deep Decarbonisation. *IET Smart Grid* **2022**, *6*, 86–102. [CrossRef]
76. Zhang, J.; Lyu, Y.; Li, Y.; Geng, Y. Digital Economy: An Innovation Driving Factor for Low-Carbon Development. *Environ. Impact Assess. Rev.* **2022**, *96*, 106821. [CrossRef]
77. Usman, O. Renewable Energy and CO_2 Emissions in G7 Countries: Does the Level of Expenditure on Green Energy Technologies Matter? *Environ. Sci. Pollut. Res.* **2022**, *30*, 26050–26062. [CrossRef] [PubMed]
78. Usman, M.; Anwar, S.; Yaseen, M.R.; Makhdum, M.S.A.; Kousar, R.; Jahanger, A. Unveiling the Dynamic Relationship between Agriculture Value Addition, Energy Utilization, Tourism and Environmental Degradation in South Asia. *J. Public Aff.* **2021**, *22*, e2712. [CrossRef]
79. Cai, Y.; Xu, J.; Ahmad, P.; Anwar, A. What Drives Carbon Emissions in the Long-Run? The Role of Renewable Energy and Agriculture in Achieving the Sustainable Development Goals. *Econ. Res.-Ekon. Istraživanja* **2021**, *35*, 4603–4624. [CrossRef]
80. Karimi Alavijeh, N.; Salehnia, N.; Salehnia, N.; Koengkan, M. The effects of agricultural development on CO_2 emissions: Empirical evidence from the most populous developing countries. *Environ. Dev. Sustain.* **2022**, *25*, 12011–12031. [CrossRef]
81. Mahmood, H.; Alkhateeb, T.T.Y.; Al-Qahtani, M.M.Z.; Allam, Z.; Ahmad, N.; Furqan, M. Agriculture Development and CO_2 Emissions Nexus in Saudi Arabia. *PLoS ONE* **2019**, *14*, e0225865. [CrossRef] [PubMed]
82. Pata, U.K. Linking Renewable Energy, Globalization, Agriculture, CO_2 Emissions and Ecological Footprint in BRIC Countries: A Sustainability Perspective. *Renew. Energy* **2021**, *173*, 197–208. [CrossRef]
83. Raihan, A.; Begum, R.A.; Nizam, M.; Said, M.; Pereira, J.J. Dynamic Impacts of Energy Use, Agricultural Land Expansion, and Deforestation on CO_2 Emissions in Malaysia. *Environ. Ecol. Stat.* **2022**, *29*, 477–507. [CrossRef]

84. Chandio, A.A.; Akram, W.; Ahmad, F.; Ahmad, M. Dynamic Relationship among Agriculture-Energy-Forestry and Carbon Dioxide (CO_2) Emissions: Empirical Evidence from China. *Environ. Sci. Pollut. Res.* **2020**, *27*, 34078–34089. [CrossRef]
85. Danish; Ulucak, R.; Khan, S.U.-D. Determinants of the Ecological Footprint: Role of Renewable Energy, Natural Resources, and Urbanization. *Sustain. Cities Soc.* **2020**, *54*, 101996. [CrossRef]
86. Aziz, N.; Mihardjo, L.W.; Sharif, A.; Jermsittiparsert, K. The Role of Tourism and Renewable Energy in Testing the Environmental Kuznets Curve in the BRICS Countries: Fresh Evidence from Methods of Moments Quantile Regression. *Environ. Sci. Pollut. Res.* **2020**, *27*, 39427–39441. [CrossRef]
87. Jahanger, A.; Usman, M.; Murshed, M.; Mahmood, H.; Balsalobre-Lorente, D. The Linkages between Natural Resources, Human Capital, Globalization, Economic Growth, Financial Development, and Ecological Footprint: The Moderating Role of Technological Innovations. *Resour. Policy* **2022**, *76*, 102569. [CrossRef]
88. Destek, M.A.; Sarkodie, S.A. Investigation of Environmental Kuznets Curve for Ecological Footprint: The Role of Energy and Financial Development. *Sci. Total Environ.* **2019**, *650*, 2483–2489. [CrossRef] [PubMed]
89. Bunnag, T. Analyzing Short-Run and Long-Run Causality Relationship among CO_2 Emission, Energy Consumption, GDP, Square of GDP, and Foreign Direct Investment in Environmental Kuznets Curve for Thailand. *Int. J. Energy Econ. Policy* **2023**, *13*, 341–348. [CrossRef]
90. Sadiq, M.; Kannaiah, D.; Yahya Khan, G.; Shabbir, M.S.; Bilal, K.; Zamir, A. Does Sustainable Environmental Agenda Matter? The Role of Globalization toward Energy Consumption, Economic Growth, and Carbon Dioxide Emissions in South Asian Countries. *Environ. Dev. Sustain.* **2022**, *25*, 76–95. [CrossRef]
91. Sultana, T.; Hossain, M.S.; Voumik, L.C.; Raihan, A. Does Globalization Escalate the Carbon Emissions? Empirical Evidence from Selected next-11 Countries. *Energy Rep.* **2023**, *10*, 86–98. [CrossRef]
92. Aslam, B.; Hu, J.; Shahab, S.; Ahmad, A.; Saleem, M.; Shah, S.S.A.; Javed, M.S.; Aslam, M.K.; Hussain, S.; Hassan, M. The Nexus of Industrialization, GDP per Capita and CO_2 Emission in China. *Environ. Technol. Amp; Innov.* **2021**, *23*, 101674. [CrossRef]
93. Gillani, S.; Sultana, B. Empirical Relationship between Economic Growth, Energy Consumption and CO_2 Emissions: Evidence from ASEAN Countries. *Irasd J. Energy Environ.* **2020**, *1*, 83–93. [CrossRef]
94. Beşer, M.K.; Hızarcı Beşer, B. The Relationship between Energy Consumption, CO_2 Emissions and GDP per Capita: A Revisit of the Evidence from Turkey. *Alphanumeric J.* **2017**, *5*, 353–368. [CrossRef]
95. Uzair Ali, M.; Gong, Z.; Ali, M.U.; Asmi, F.; Muhammad, R. CO_2 Emission, Economic Development, Fossil Fuel Consumption and Population Density in India, Pakistan and Bangladesh: A Panel Investigation. *Int. J. Finance Econ.* **2020**, *27*, 18–31. [CrossRef]
96. Mehmood, U.; Tariq, S.; Ul-Haq, Z.; Meo, M.S. Does the Modifying Role of Institutional Quality Remains Homogeneous in GDP-CO_2 Emission Nexus? New Evidence from ARDL Approach. *Environ. Sci. Pollut. Res.* **2020**, *28*, 10167–10174. [CrossRef]
97. Balli, E.; Sigeze, C.; Ugur, M.S.; Çatık, A.N. The Relationship between FDI, CO_2 Emissions, and Energy Consumption in Asia-Pacific Economic Cooperation Countries. *Environ. Sci. Pollut. Res.* **2021**, *30*, 42845–42862. [CrossRef]
98. Khan, M.A.; Ozturk, I. Examining Foreign Direct Investment and Environmental Pollution Linkage in Asia. *Environ. Sci. Pollut. Res.* **2019**, *27*, 7244–7255. [CrossRef]
99. Nhuong, B.H.; Quang, P.T. Are FDI Inflows Crucial for Environmental Protection in Various Asian Regions? *J. Environ. Assess. Policy Manag.* **2022**, *24*, 2250028. [CrossRef]
100. Farooq, U. Foreign Direct Investment, Foreign Aid, and CO_2 Emissions in Asian Economies: Does Governance Matter? *Environ. Sci. Pollut. Res.* **2021**, *29*, 7532–7547. [CrossRef]
101. Bakhsh, S.; Yin, H.; Shabir, M. Foreign Investment and CO_2 Emissions: Do Technological Innovation and Institutional Quality Matter? Evidence from System GMM Approach. *Environ. Sci. Pollut. Res.* **2021**, *28*, 19424–19438. [CrossRef]
102. Kraay, A.; Driscoll, J. *Spatial Correlations in Panel Data*; The World Bank: Washington, DC, USA, 1999. [CrossRef]
103. Machado, J.A.F.; Santos Silva, J.M.C. Quantiles via Moments. *J. Econom.* **2019**, *213*, 145–173. [CrossRef]
104. Amegavi, G.B. The Heterogeneous Effects of Government Size and Press Freedom on Corruption in Sub-Saharan Africa: Method of Moment Quantile Regression Approach. *Int. J. Press/Politics* **2021**, *27*, 439–459. [CrossRef]
105. Anwar, A.; Malik, S.; Ahmad, P. Cogitating the Role of Technological Innovation and Institutional Quality in Formulating the Sustainable Development Goal Policies for E7 Countries: Evidence from Quantile Regression. *Glob. Bus. Rev.* **2022**, 097215092110726. [CrossRef]
106. Ike, G.N.; Usman, O.; Sarkodie, S.A. Testing the Role of Oil Production in the Environmental Kuznets Curve of Oil Producing Countries: New Insights from Method of Moments Quantile Regression. *Sci. Total Environ.* **2020**, *711*, 135208. [CrossRef] [PubMed]
107. Koengkan, M.; Fuinhas, J.A. Heterogeneous Effect of "Eco-Friendly" Dwellings on Transaction Prices in Real Estate Market in Portugal. *Energies* **2022**, *15*, 6784. [CrossRef]
108. Koengkan, M.; Fuinhas, J.A.; Silva, N. Exploring the Capacity of Renewable Energy Consumption to Reduce Outdoor Air Pollution Death Rate in Latin America and the Caribbean Region. *Environ. Sci. Pollut. Res.* **2020**, *28*, 1656–1674. [CrossRef] [PubMed]
109. Sarkodie, S.A.; Strezov, V. Economic, Social and Governance Adaptation Readiness for Mitigation of Climate Change Vulnerability: Evidence from 192 Countries. *Sci. Total Environ.* **2019**, *656*, 150–164. [CrossRef] [PubMed]
110. Xu, B.; Lin, B. Investigating Drivers of CO_2 Emission in China's Heavy Industry: A Quantile Regression Analysis. *Energy* **2020**, *206*, 118159. [CrossRef]

111. Pedroni, P. Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. *Oxf. Bull. Econ. Stat.* **1999**, *61*, 653–670. [CrossRef]
112. Phillips, P.C.B.; Hansen, B.E. Statistical Inference in Instrumental Variables Regression with I(1) Processes. *Rev. Econ. Stud.* **1990**, *57*, 99. [CrossRef]
113. Doğan, B.; Driha, O.M.; Balsalobre Lorente, D.; Shahzad, U. The Mitigating Effects of Economic Complexity and Renewable Energy on Carbon Emissions in Developed Countries. *Sustain. Dev.* **2020**, *29*, 1–12. [CrossRef]
114. Pattak, D.C.; Tahrim, F.; Salehi, M.; Voumik, L.C.; Akter, S.; Ridwan, M.; Sadowska, B.; Zimon, G. The Driving Factors of Italy's CO_2 Emissions Based on the STIRPAT Model: ARDL, FMOLS, DOLS, and CCR Approaches. *Energies* **2023**, *16*, 5845. [CrossRef]
115. Kao, C. Spurious Regression and Residual-Based Tests for Cointegration in Panel Data. *J. Econom.* **1999**, *90*, 1–44. [CrossRef]
116. Acheampong, A.O.; Adams, S.; Boateng, E. Do Globalization and Renewable Energy Contribute to Carbon Emissions Mitigation in Sub-Saharan Africa? *Sci. Total Environ.* **2019**, *677*, 436–446. [CrossRef]
117. Alola, A.A.; Yalçiner, K.; Alola, U.V.; Akadiri, S.S. The Role of Renewable Energy, Immigration and Real Income in Environmental Sustainability Target. Evidence from Europe Largest States. *Sci. Total Environ.* **2019**, *674*, 307–315. [CrossRef]
118. Bashir, M.A.; Dengfeng, Z.; Shahzadi, I.; Bashir, M.F. Does Geothermal Energy and Natural Resources Affect Environmental Sustainability? Evidence in the Lens of Sustainable Development. *Environ. Sci. Pollut. Res.* **2022**, *30*, 21769–21780. [CrossRef] [PubMed]
119. Hao, L.-N.; Umar, M.; Khan, Z.; Ali, W. Green Growth and Low Carbon Emission in G7 Countries: How Critical the Network of Environmental Taxes, Renewable Energy and Human Capital Is? *Sci. Total Environ.* **2021**, *752*, 141853. [CrossRef] [PubMed]
120. Inglesi-Lotz, R.; Dogan, E. The Role of Renewable versus Non-Renewable Energy to the Level of CO_2 Emissions a Panel Analysis of Sub- Saharan Africa's Big 10 Electricity Generators. *Renew. Energy* **2018**, *123*, 36–43. [CrossRef]
121. Sharif, A.; Mishra, S.; Sinha, A.; Jiao, Z.; Shahbaz, M.; Afshan, S. The Renewable Energy Consumption-Environmental Degradation Nexus in Top-10 Polluted Countries: Fresh Insights from Quantile-on-Quantile Regression Approach. *Renew. Energy* **2020**, *150*, 670–690. [CrossRef]
122. Prastiyo, S.E.; Irham; Hardyastuti, S.; Jamhari, F. How Agriculture, Manufacture, and Urbanization Induced Carbon Emission? The Case of Indonesia. *Environ. Sci. Pollut. Res.* **2020**, *27*, 42092–42103. [CrossRef]
123. Rauf, A.; Liu, X.; Amin, W.; Ozturk, I.; Rehman, O.U.; Hafeez, M. Testing EKC Hypothesis with Energy and Sustainable Development Challenges: A Fresh Evidence from Belt and Road Initiative Economies. *Environ. Sci. Pollut. Res.* **2018**, *25*, 32066–32080. [CrossRef]