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The growth impacts of agriculture value-added, energy utilization, and environmental degradation in Pakistan: Causality in continuous wavelet transform approach

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Abstract

Considering the increasing challenge to Pakistan's sustainable economic growth and development, the current study posits a fresh perspective on the dimension of attainable sustainable economic growth in the country. Based on this, a more innovative Granger causality of wavelet coherence and frequency domain approaches are employed to proffer inference for the relationship between economic growth, agriculture value-added, energy utilization, urbanization, and environmental degradation via carbon dioxide (CO_2) emissions over the period 1965 to 2021. The result reveals that economic growth in Pakistan is positively related to the aforementioned variables with a significant dimension. Moreover, with a statistically significant degree of evidence, there is bidirectional causality between energy utilization and economic expansion. Similarly, there is a significant bidirectional causality between environmental degradation (as captured by carbon emission) and economic expansion. This better translates that historical information of energy utilization and carbon emissions could explain the future dimension of economic growth in Pakistan and vice versa. Expectedly, increasing urbanization and value-added from the agricultural sector of the economy both Granger causes economic growth in Pakistan. The implication for the policymaker is that as much as economic growth is a vital indicator of sustainable development, the policy initiatives should reflect environmental, energy development, agricultural sector, and urban activities dimensions.

KEYWORDS
agricultural activities, economic growth, energy usage, environmental factor, Pakistan

1 | INTRODUCTION

In most nations across the world, the fundamental goal of economic policy is to achieve sustainable economic growth. Economic development with the appropriate policy mix, on the other hand, may influence climate change and global warming, which are major worldwide challenges and issues. Greenhouse gas (GHG) emission levels in the atmosphere have increased significantly due to economic growth and civilization (Mutascu et al., 2022; Usman et al., 2020).The connection between economic growth, CO_2 emissions, energy usage, and economic output has overwhelmingly been explored in the literature. This viewpoint implies that energy, like the resource input of production such as labor, capital, and entrepreneurship, is critical to economic output. As a result, energy utilization impacts the economy. According to this perspective, economic growth and energy consumption (in)directly influence the level of CO_2 emissions, which is the primary source of GHG emissions (Ozturk & Acaravci, 2016).

Considering its bright economic prospects, Pakistan's economy is susceptible to environmental deterioration from both domestic and global influences. The economy's progress is not without some drawbacks, particularly the perennial flooding within the country and spillovers of external influence arising from global climate change issues. The temperature pattern from the 19th century to the present reveals that Pakistan has been steadily warming, at a constant, consistent, and fast rate (Chandio et al., 2021). Since it was observed that the climate was warming which proves that its rises were attributable to an upsurge in anthropogenic GHGs emissions, this issue has piqued the scientific community's attention. Variations in global weather patterns due to climate change owing to GHGs emissions, including carbon dioxide, methane, and nitrogen oxide, among others, are thought to be the cause of the continual growth and intensity of these heatwaves (Ojekemi et al., 2022; Su et al., 2023). Various economic sectors, such as oil and gas, transportation, manufacturing and industries, and agriculture, all contribute to GHGs emissions.

Why Pakistan? Oil and natural gas constitute the majority of Pakistan's primary energy (See Figure 1). Hydropower is the nation's primary renewable energy source, but solar photovoltaic (PV) and wind are slightly gaining more interest (see Figure 1). Over 40 million people still do not have access to electricity, and most do not have access to safe cooking facilities (Enerdata, 2023). After a period of considerable growth between 2013 and 2018 (4.5 percent/year), overall consumption in the nation fell by 1% in 2019, to 110 Mtoe, after a period of steady growth between 2008 and 2013 (1.5%/year). Pakistan contributes less than 1% of global emissions while being one of the most susceptible nations to the effects of climate change (Enerdata, 2023). According to the Germanwatch (2023), Pakistan ranks 7th with 523.1 deaths yearly: 10,462 deaths in 20 years and $3.8 billion in economic losses. Pakistan has had 141 severe weather events (cyclones, storms, floods, glacial lake outburst floods [GLOFs], heatwaves, and so on) throughout this time.

These repeated occurrences have an economic impact on Pakistan by damaging infrastructure and changing planting patterns, which has consequences for food security in many of the nation's agricultural regions. The agriculture and energy sectors account for 90% of the nation's total GHGs emissions, according to the nation's

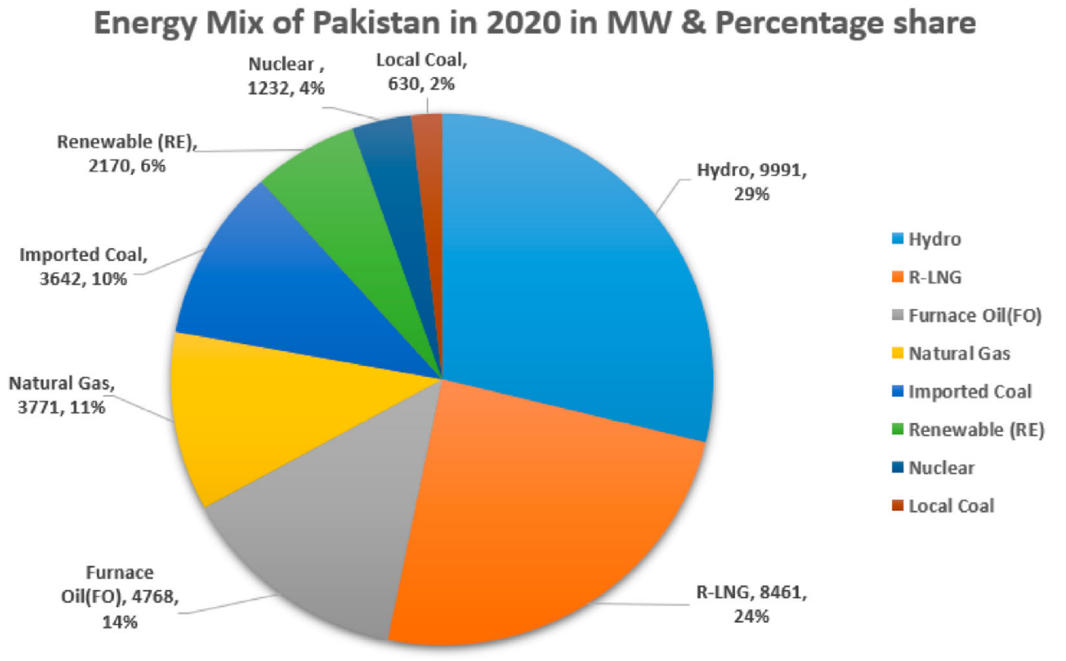

FIGURE 1 Pakistan energy mix in 2020.

emission pattern[1]. Pakistan's overall GHGs emissions have grown by 123% in 21 years (1994 to 2015), per the Intended Nationally Determined Contribution (INDC). The nation's total emissions are predicted to increase by nearly 300% over the projected timeframe, owing to GDP growth objectives established in Vision 2025 and the China-Pakistan Economic Corridor's (CPEC) investment, infrastructure development, and energy consumption. Statistics like these should encourage nations like Pakistan to take the Paris Agreement earnestly. Its execution necessitates that all key stakeholders (nations and other entities) collaborate to develop policies and mobilize resources promoting climate change action.

Given these elaborate facts about Pakistan's economy, the present research tends to assess the influence of agriculture, urbanization, CO_2 emissions, and energy utilization on Pakistan's economic performance between 1965 and 2019. The structure of the Pakistani economy influences the approach utilized in this research. This is centered on the industrial and productive sectors (to accommodate rising consumption and investment) and is prone to high energy utilization. A detailed examination of the Pakistani economy's sustainability in light of empirical results will assist us in developing sustainable strategies to handle questions such as the following: (i) Is it possible for Pakistan to diversify its energy mix policies by embracing green energy to boost its green economy? (ii) Can Pakistan adopt new strategies to reduce emissions without jeopardizing the country's economic progress?

Over the years, numerous studies have been conducted to create awareness about the influence of CO_2 emission, energy utilization, urbanization, and agriculture on economic growth. Nevertheless, their findings are often constrained to traditional empirical methodologies and generalized steps measures. Recognizing these concerns, Sharif et al., 2021 and Polanco-Martínez et al., 2020 stated that methodologies are critical in producing impartial analysis results and emphasized the importance of employing novel econometric techniques. Based on this information, this research utilizes an innovative time-frequency approach to assess the effect of agriculture, urbanization, CO_2 emissions, and energy utilization on economic growth in Pakistan. These techniques' major advantage is that they distinguish between long-, medium-, and short-run dynamics over the sample period. Furthermore, this technique establishes correlation, lead/lag, and causal association between series.

The remaining sections of this research are compiled as follows: a synopsis of past studies is presented in Section 2. Section 3 presents the data and methods. Section 4 presents the findings and discussion, and the conclusion is presented in Section 5.

2 | LITERATURE REVIEW

The sustainability of numerous nations' growth is compromised by their excessive emphasis on pro-growth policies, neglecting the crucial ecological dimension. Therefore, it is imperative to examine the influence of CO_2 emissions, energy consumption, and urbanization on this growth trajectory. This research segment delves into previous studies conducted on the interplay between economic growth and carbon emissions, agriculture, urbanization, and energy usage. To ensure clarity and organization, this section is subsequently subdivided into four subsections as outlined below:

2.1 | Relationship between economic growth, energy consumption, and CO_2 emissions

The intricate and nuanced relationship between economic expansion, CO_2, and energy use presents a complex scenario. As the economy expands, energy consumption tends to increase to support critical sectors such as manufacturing, transportation, and other economic operations. However, it is crucial to recognize that CO_2 resulting from energy production and usage play a significant role in climate change and various environmental challenges. As stated by Samour et al. (2022), striking a balance between promoting economic development and embracing sustainable environmental practices remains a formidable challenge for both businesses and policymakers. Extensive research suggests a correlation between the upward trajectory of energy use and economic development. Increased energy consumption often becomes a prerequisite for sustaining economic growth and facilitating overall development. Nevertheless, the relationship between economic expansion and CO_2 is multifaceted and warrants a comprehensive understanding to effectively address its complexities. Economic development has shown potential for reducing emissions, whereas economic expansion has the potential to increase CO_2 levels. This trend can be attributed to the inclination of nations to transition towards greener and more efficient energy sources as their economies grow (Shahbaz et al. 2017). It is important to recognize that the relationship between economic growth, CO_2, and energy consumption varies across different nations and regions. Wealthier nations tend to exhibit higher energy consumption and CO_2 compared to developing nations, which often have lower energy consumption and emissions. However, it is worth noting that poorer nations may face challenges in achieving sustainable economic growth as they are often more vulnerable to the impacts of climate change.

Over the years, numerous scholars have conducted extensive research on the dynamic relationship between energy utilization, economic growth, and CO_2 emissions, employing diverse methodologies, focusing on different countries, and spanning various timeframes. It is widely recognized that energy plays a pivotal role in fostering economic development. However, the consumption of energy, if not environmentally friendly, can contribute to both economic growth and environmental degradation. This perspective is reinforced by the study conducted by Udemba et al. (2020) in India, utilizing data from 1990Q2 to 2015Q4. Their empirical findings revealed a positive correlation between increased CO_2 emissions and energy consumption with economic expansion. Similarly, the research conducted by Balcilar et al. (2019) in Pakistan, spanning the period from 1970 to 2014, provided additional support to this viewpoint. Their study demonstrated that both CO_2 emissions and energy utilization stimulated GDP growth, while the Granger causality test results indicated that CO_2 emissions and energy consumption could serve as predictors of economic expansion in Pakistan. Moreover, a comprehensive examination carried out by Awosusi et al. (2021) in South Korea applied novel wavelet coherence and autoregressive distributed lag (ARDL) approaches to assess the impact of CO_2 emissions and energy utilization on GDP. Their findings revealed a positive relationship between CO_2, energy consumption, and economic growth. Furthermore, Ali et al. (2016) examined the GDP and energy connection in Nigeria using FMOLS and DOLS methodologies and a dataset spanning from 1971 to 2014. Their empirical results disclosed a positive correlation between GDP and energy consumption.

Moreover, Xu et al. (2022) conducted an investigation on the drivers of growth in Brazil, utilizing data spanning from 1965 to 2019. The study employed the autoregressive distributed lag (ARDL) approach and revealed that both CO_2 and energy consumption (EC) contribute to economic expansion in Brazil. Ahmed et al. (2022) explored the determinants of growth using the nonlinear autoregressive distributed lag (NARDL) model, finding that an increase in economic growth leads to higher CO_2. In a study by Umar et al. (2021) focusing on EU member countries, the impact of GDP and renewable energy on CO_2 emissions was assessed. The findings indicated a positive relationship between GDP and CO_2 emissions, while renewable energy utilization was found to mitigate environmental degradation. Ojekemi et al. (2022) investigated the growth drivers in EU countries between 1997 and 2014, employing FMOLS and DOLS. Their findings demonstrated that both energy consumption and economic expansion contribute to environmental degradation. Similarly, Pata et al. (2022) examined the association between energy utilization, CO_2, and growth drivers in Thailand. Their study revealed that both GDP and energy consumption contribute to CO_2. Lastly, Zang et al. (2023) conducted a study highlighting the positive impact of nonrenewable energy consumption and GDP on CO_2, thereby contributing to environmental degradation. These studies provide valuable insights into the complex relationship between economic growth, CO2 emissions, and energy consumption, emphasizing the need for sustainable strategies to address environmental challenges.

2.2 | Relationship between economic growth and urbanization

Numerous previous studies have consistently shown a robust correlation between urbanization and per capita GDP. It is widely recognized that economic growth fosters the expansion of modern industries and leads to an increase in the urban population. Conversely, urbanization also acts as a catalyst for economic growth. For example, Abbas et al. (2021) investigated the urbanization-growth nexus in Pakistan using data spanning from 1972 to 2018. By employing the dynamic autoregressive distributed lag (ARDL) approach, the researchers found a positive impact of urbanization on GDP, indicating that an increase in the urban population is associated with higher GDP. Similarly, in India, Rahman and Vu (2020) examined the relationship between growth and urbanization using the conventional Granger causality approach. Their empirical findings revealed that urbanization Granger causes GDP, implying that the urban population can predict real growth in India. In Angola, Shahbaz et al. (2013) analyzed the drivers of growth using data from 1971 to 2009 and employed the vector error correction model (VECM). Their results demonstrated that the urban population stimulates real growth. Likewise, Udemba et al. (2020) investigated the determinants of real growth in India using ARDL and Granger causality tests. Their empirical analysis indicated a positive influence of the urban population on real GDP, with the Granger causality test revealing one-way causality from urbanization to GDP. Furthermore, Faisal et al. (2021) explored the connection between GDP growth and urban population in Iceland, utilizing data from 1965 to 2013. Applying both the VECM and ARDL approaches, they found a positive association between the urban population and GDP. Conversely, Ali et al. (2016) conducted a study in Nigeria revealing a negative association between urbanization and real growth. Taken together, these studies underscore the significant relationship between urbanization and per capita GDP, shedding light on the intricate dynamics between urban development and economic progress across different countries.

2.3 | Nexus between economic growth and agriculture-related factor

Agriculture plays a crucial role in fostering economic prosperity by bolstering overall production within the sector. Through advancements in technology, improved farming techniques, and better access to necessary resources, agricultural productivity is elevated, resulting in higher yields and increased output. This, in turn, stimulates farmer income and drives economic activity across the entire agricultural value chain, encompassing distribution, processing, and marketing. Agriculture is widely acknowledged for its significant potential to contribute to economic growth through increased agricultural output and job creation, thereby playing a crucial role in poverty reduction and overall economic development. This association is evident in the study conducted by Umarbeyli et al. (2021) in Indonesia, which established a positive connection between agricultural activities (AGRIC) and GDP. This implies that an increase in agricultural output leads to a corresponding increase in GDP. Similar findings were observed in the research conducted by Saeed and Awan (2020) in Pakistan, providing further support to the positive relationship between agriculture and economic growth. The study by Sertoglu et al. (2017) also examined the association between agriculture and GDP, revealing a positive connection and suggesting that agricultural expansion stimulates economic growth in Nigeria. In Nigeria, Udemba et al. (2020) investigated the nexus between agriculture and real GDP using ARDL, Granger causality, and other approaches. Their empirical findings demonstrated the significant role of agriculture in intensifying real growth, with the causality test indicating a unidirectional causality from agriculture to real growth. Similarly, Matthew and Ben (2016) assessed the linkage between agriculture and real growth in Nigeria from 1981 to 2014, utilizing Johansen cointegration and vector error correction model (VECM) approaches. Their results revealed a positive connection between agriculture and economic growth, highlighting the growth-enhancing role of agriculture. Collectively, these studies underscore the important contribution of agriculture to economic growth, emphasizing its potential to drive development and alleviate poverty.

2.4 | Contribution to the literature

Despite the considerable body of research on the nexus between economic growth, energy use, agriculture, and CO_2 emissions, there remains a dearth of evidence pertaining to the analysis of economic growth-energy-income relationships across diverse frequencies and timeframes. This knowledge gap leads to inconsistent policy recommendations. However, amidst this limited research landscape, noteworthy studies conducted by Sharif et al. (2021) and Adebayo (2023) stand out as valuable contributions. These studies examine the interconnections between economic growth, energy use, agriculture, and CO2 emissions, considering various frequencies and timeframes, thereby adding depth and nuance to the existing literature. As previously said, the appropriate role of energy usage, urbanization, CO_2 emissions, and agriculture on economic growth in time and frequency is scarce in the existing research. To this purpose, this research makes the following contributions to the body of existing literature: First, the SDGs agenda—which has relatively few goals for Pakistan—is what drives and strengthens the present research variable model. Secondly, the present research makes use of modern, cutting-edge econometric modeling methods such as wavelet coherence in conjunction with Rua (2013) cohesion and (Olayeni, 2016) wavelet-based causality to circumvent for the shortcomings of time domain techniques such as dynamic ARDL, dynamic OLS, VAR, VECM, quantile regression, method of moments quantile regression, and autoregressive distributed lag (ARDL). The wavelet coherence, unlike the highlighted techniques, can identify correlation as well as the lead/lag nexus between series. Furthermore, the (Olayeni, 2016) wavelet-based causality employed can identify the causality in time and frequency between the investigation variables. This all-encompassing strategy is thought to be able to add to the body of literature.

3 | THEORETICAL CONCEPT, DATA, AND METHODOLOGY

3.1 | Theoretical underpinning

The current economic policies of Pakistan are pro-growth, and as a result, environmental issues are taking a backseat on the policy agenda. Continuing on this path of growth is eventually harming the economic growth trend itself. As a result, it is reasonable to believe that Pakistan's economic growth trajectory can be traced back to the traditional growth and environmental quality trade-off argument (Azam et al., 2023; Tauseef Hassan et al., 2023). The World Bank's study on assessing Pakistan's environmental impact reveals this discourse. The present research emphasizes the labor force's health effects due to environmental destruction induced by current manufacturing practices. The OECD Global Forum on Environment reintroduced this concern, describing the depletion of natural resources and the health risks posed by ambient air pollution as important impediments of growth in the economy. Even though NITI Adebayo (2023) anticipated that the introduction and financial channelization of SDGs might aid in resolving ecological issues and maintaining the trajectory of the economic expansion, the study of (Abbasi et al., 2021; Liu et al., 2022; Liu et al., 2023) on the disrupters and drivers of economic growth found that environmental degradation is still a major disrupter of economic growth in Pakistan, and upsurge CO_2 emissions are a major contributor (Balcilar et al., 2019).

In line with this debate, it is likely that, due to policy myopia, Pakistan's real growth will be highly dependent on CO_2 emissions, endangering the pillars of sustainable development. At the same time, urban-centered industrial expansion is driving Pakistan's economic growth. People begin migrating from rural to urban areas as industrial growth and work possibilities increase in metropolitan areas. Demand for products and services is created due to increased urbanization, which contributes to economic growth (Ahmad et al., 2023; Liu et al., 2023). More demand for services and goods, therefore, necessitates increased production, which requires increased utilization of energy. Thus, economic expansion is accompanied by an upsurge in energy utilization. Finally, increased agricultural productivity boosts economic growth by increasing demand for (domestic) industrial products (Ali et al., 2016). Therefore, an upsurge in agricultural productivity is expected to trigger economic growth. Following the illustrations mentioned earlier, this research's theoretical model is formulated as follows:

$$\mathbf{GDP_t} = \mathbf{f}(\mathbf{CO_{2t}}, \mathbf{URB_t}, \mathbf{EC_t}, \mathbf{AGRIC_t}) \tag{1}$$

where **GDP**, **EC**, **CO_2**, **URB**, and **EC** stand for economic growth, energy utilization, carbon emissions, urbanization, and agriculture, respectively. The period of study is depicted by *t*.

3.2 | Data

The present research assesses the influence of carbon emissions (CO_2) on economic growth (GDP) as well as the role of urbanization (URB), agriculture (AGRIC), and energy utilization (EC). The research utilizes data stretching between 1965 and 2021. The availability of data limits time duration. Table 1 presents the variables of interest description and source of data. CO_2 and EC are sourced from the British petroleum database and AGRIC, URB, and GDP are gathered from the World Development Indicators database. Moreover, all the variables are transformed into their natural log to guarantee normal distribution in the data and resolve heteroscedasticity.

3.3 | Methodology

3.3.1 | Wavelet coherence

Since the Fourier analysis can completely reflect and decompose stationary time series, wavelets may be used to research nonstationary time series. Wavelets often encourage time conservation for localized information, allowing

TABLE 1 Variable unit and source.

Indicators	Description	Units	Source
CO_2	CO_2 emissions	Metric tones per capita	OWD
GDP	Economic Growth	GDP per capita	WDI
EC	Energy Consumption	Energy consumption per capita (Twh)	OWD
URB	Urbanization	Urban Population	WDI
AGRIC	Agriculture	Agriculture, forestry, and fishing, value added (constant 2010 US$)	WDI

co-movement to be calculated in time-frequency space. Time series analysis is the primary focus of Wavelet Coherence. Using a novel technique, this research work contributes to the environmental literature by extending the investigation on Israel. This study detects the time-frequency dependence between GDP and its regressors. For this purpose, the study employed the wavelet coherency that includes phase differences developed by Goupillaud et al. (1984) and Torrence and Compo (1998). The wavelet analysis reveals the spectral nature of the time series, especially in a manner in which several periodic features of the time series change over time. The wavelet transformation tool permits the time series decomposition into different frequencies. This study employed the Morlet wavelet function because it offers an adequate balance between time and frequency, the major components of any wavelet analysis. The Morlet wavelet function has the following form:

$$\varpi(t)\pi^{-\frac{1}{4}}e^{-i\varpi t}e^{-\frac{1}{2}t^2} \tag{2}$$

where i is $\sqrt{-1}$, and e depicts the non-dimensional frequency. Tiwari et al. (2020) argued that the use of continuous wavelet transformation is good for extracting the time series features. Furthermore, Aguiar-Conraria and Soares (2014) concluded that the continuous wavelet transform helps the cross-wavelet analysis to discover the time-frequency interaction between two-time series. The CWT for a discrete-time series is defined as

$$\varpi_{k,f}(s)=\frac{\rho t}{\sqrt{s}}\sum_{n'=0}^{N-1}x_{n'}\varpi^{*}\left((n'-m)\frac{\rho t}{s}\right),\text{with}\, m=0,1,2,.,.,.,.,N-1 \tag{3}$$

$|W_n^x(s)|^2$ depicts the wavelet power spectrum, which reveals the variance of the time series. A cone of impact shows the effects of the observations. The process of generating data is the null hypothesis, in which the stationary process has a power spectrum background. The power spectrum is formed as follows:

$$D\left(\frac{|W_n^x(s)|^2}{\theta_x^2}<p\right)=\frac{1}{2}P_fX_v^2, \tag{4}$$

where Fourier frequency depicts with the scale of the mean spectrum (P_f). θ represents variance, and X^2 illustrates the two series. p is less than P_f, when 1 is real wavelets and 2 is the complex wavelets for v. The co-movement of the two time series (p, q) was investigated using the wavelet coherence:

$$R_n(s)=\frac{|S(s^{-1}W_n^{pq}(s))|^2}{S\left(s^{-1}|W_n^p)|^{\frac{1}{2}}\right)S\left(s^{-1}|W_n^q|^{\frac{1}{2}}\right)} \tag{5}$$

where S depicts the smoothing operator for time and scale. The phase difference (ϕ_{pq}) of series (p, q) is investigated in the wavelet coherence:

$$\phi_{pq} = \tan^{-1}\left(\frac{L\{W_n^{pq}\}}{O\{W_n^{pq}\}}\right) \text{and } \phi_{pq} \in [-\pi, \pi], \tag{6}$$

where the imaginary and real component operators are denoted by O and L respectively. p leads q, when $\phi_{pq} \in \left[0, \frac{\pi}{2}\right]$ but q leads p, when $\phi_{pq} \in \left[-\frac{\pi}{2}, 0\right]$ correspondingly. Alternatively, the anti-phase difference also occurs for the series, where p leads q, when$\phi_{pq} \in \left[-\pi, -\frac{\pi}{2}\right]$ but q leads p, when $\phi_{pq} \in \left[\frac{\pi}{2}, \pi\right]$ correspondingly.

3.3.2 | Causality in continuous wavelet transform

The current investigation further explores the causality between economic growth and the regressors (CO_2 emissions, agriculture, urbanisation, and energy consumption). In doing so, the causality test initiated by Olayeni (2016) which is a more holistic causality approach is used. This causality approach improves (Rua, 2013) causality.

$$G_{y\to x}(\tau,s) = \frac{\zeta\left\{s^{-1}\left|\Re\left(W_{xy}^{m}(\tau,s)\right)I_{y\to x}(\tau,s)\right|\right\}}{\zeta\left\{s^{-1}\sqrt{\left|W_x^m(\tau,s)\right|^2}\right\}\cdot\zeta\left\{s^{-1}\sqrt{\left|W_y^m(\tau,s)\right|^2}\right\}}, \tag{7}$$

where $W_x^m(\tau,s), W_y^m(\tau,s)$, and $W_{xy}^m(\tau,s)$ are the wavelet transfiguration of x, and $I_{y\to x}(\tau,s)$ is the series function:

$$I_{y\to x}(\tau,s) = \begin{cases} 1, \text{if } \phi_{xy}(\tau,s) \in \left(0, \frac{\pi}{2}\right) \cup \left(-\pi, -\frac{\pi}{2}\right) \\ 0, \text{otherwise} \end{cases}, \text{and } \phi_{xy}(\tau,s) = \tan^{-1}\left(\frac{\Im\left\{W_{xy}^m(\tau,s)\right\}}{\Re\left\{W_{xy}^m(\tau,s)\right\}}\right) \tag{8}$$

4 | FINDINGS AND DISCUSSIONS

4.1 | Pre-estimation tests

Figure 2 depicts the flow of the analysis, which is conveyed for clarification. Understanding the series of statistical information is critical before further analyses are conducted. Table 2 presents the statistical information of the indicators such as mean, median, kurtosis, minimum and maximum, and skewness. The Jarque–Bera disclosed that AGRIC, UB, and GDP align with normal distribution, while CO_2 and EC do not conform to normal distribution. Moreover, Figure 3 presents the box plot of the study variables. The study applied the BDS test initiated by Brooke et al. (1996) to assess the nonlinearity characteristics of series. The BDS outcomes are presented in Table 3. The outcomes of the BDS test confirm the null hypothesis of nonlinearity of the series. Therefore, utilizing linear technique will produce misleading outcomes. In addition, we utilized ADF, KPSS, and PP tests to catch the series stationarity series. The outcomes of the tests are presented in Table 4, and the outcomes disclosed mixed order of integration, i.e., I (0) and I (1). While stationary assumption is not vital when utilizing the wavelet technique, it provides a benchmark by which non-stationarity may be detected.

4.2 | Wavelet coherence outcome

We utilized wavelet coherence (WTC) to capture the connection and causality between economic growth (GDP) and agriculture (AGRIC), urbanization (URB), energy utilization (EC), and carbon emissions (CO_2). The WTC test is used to

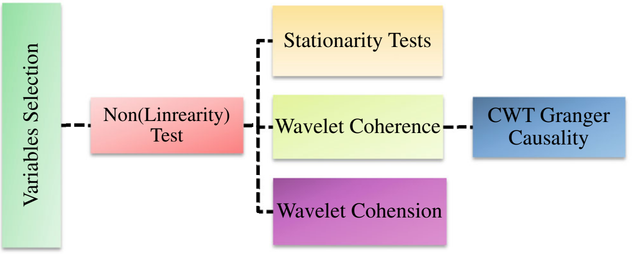

FIGURE 2 Flow of the analysis.

TABLE 2 Descriptive statistics.

	AGRIC	CO_2	EC	GDP	UB
Mean	23.284	−0.5867	5.7541	6.7552	3.4234
Median	23.165	−0.4865	5.9304	6.8242	3.4445
Maximum	25.092	−0.0010	6.9766	7.2956	3.6227
Minimum	21.451	−1.1959	4.4094	6.1532	3.1574
Std. dev.	1.1091	0.3764	0.8286	0.3213	0.1361
Skewness	0.0770	−0.2243	−0.2230	−0.1485	−0.3856
Kurtosis	1.8591	1.6480	1.6329	1.9654	1.9732
Jarque–Bera	3.1474	4.8189	4.9106	2.7514	3.9169
Probability	0.2072	0.0898	0.0858	0.2526	0.1410

determine the existence of coherence between GDP and the independent variables. This approach is crafted from mathematics and is utilized to acquire previously unnoticed information. As a result, the study looks at the association between GDP and the regressors at different frequencies. The white cone where discourse occurs in the WTC is known as the cone of influence (COI). The thick black boundary depicts a significance level predicated on Monte Carlo simulations. The short, medium, and long periods are illustrated by 0–4, 4–8, and 8–16, respectively, in Figure 4. Furthermore, the figure's horizontal and vertical axes represent time and frequency. The colors blue and yellow represent low and high interdependence between the series. The leftward and rightward arrows represent out-of-phase and in-phase connections, respectively. Moreover, the rightward-down (leftward-up) signifies that the first series leads (cause) the second series, whereas the rightward-up (leftward-down) signifies that the second series leads (cause) the first series.

Figure 4a portrays Pakistan's WTC between GDP and CO_2 between 1965 and 2021. At different frequencies, between 1970 and 2019 (0–16 years of scale), the majority of the arrows are rightward, suggesting that GDP and CO_2 are in-phase (positive association). The results show that both economic growth and CO_2 emissions move in the same direction which is as expected owing to the fact that Pakistan is an emerging nation where the focus is centered on economic growth. At the same time, insignificant attention is paid to environmental quality. Thus, it can be inferred that Pakistan's economy is at its scale effect phase. Figure 4b depicts the WTC between GDP and EC from 1965 to 2021. In all frequencies, at scales 0–8, between 1969 and 2019, EC and GDP are in-phase (positive connection). The economic growth in any nation is dependent on energy use. Thus, increased energy use is expected to impact economic growth positively. This implies that the growth trend of Pakistan's economy is energy-driven. However, care is needed to ensure that these energies are sustainable. Sustainable energy is expected to promote the Pakistani economy's growth and ecological quality.

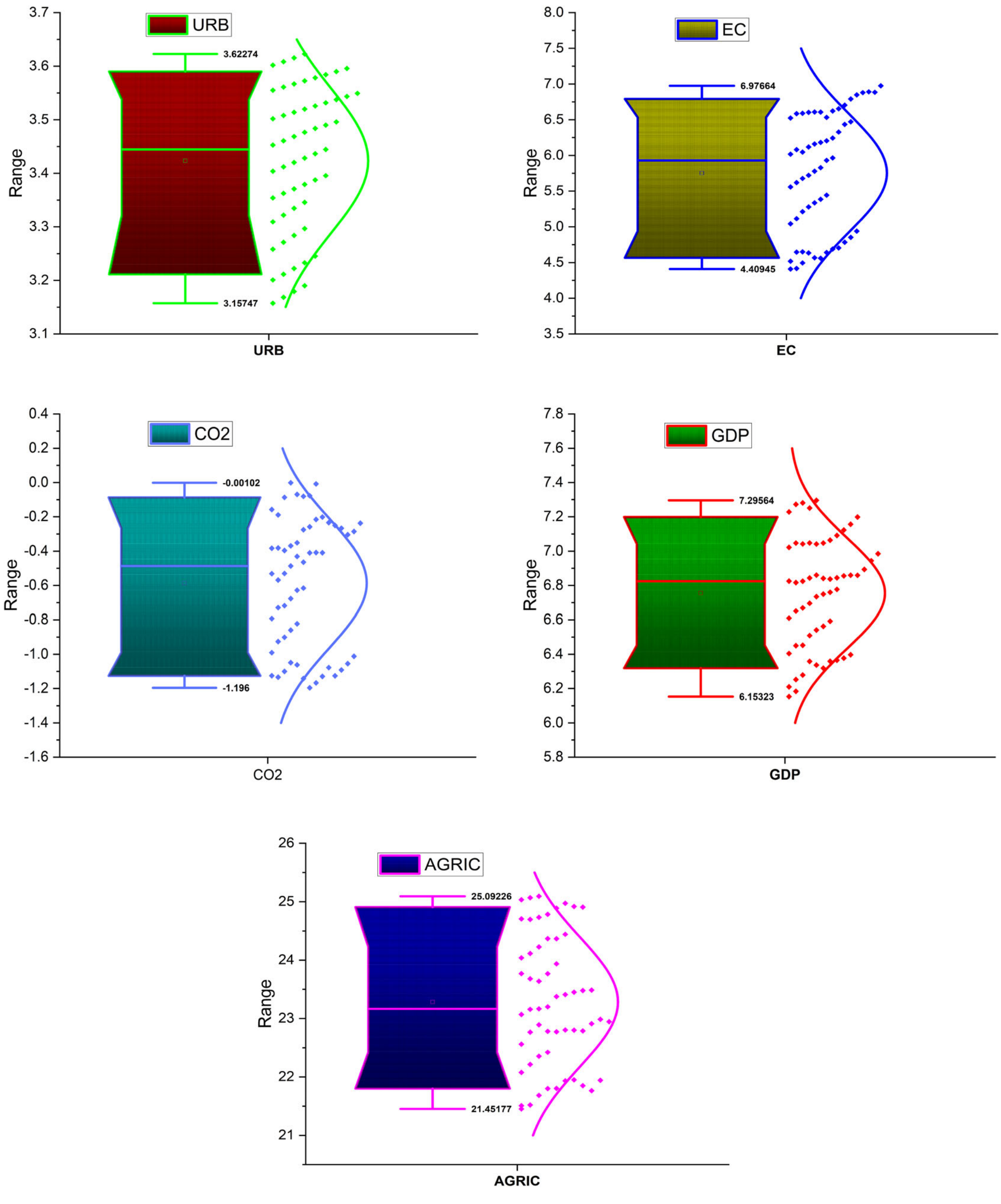

FIGURE 3 Scatter plot.

Figure 4c shows the WTC between URB and GDP from 1965 to 2021. At different frequencies, at a period of scale 0–16, from 1970 to 2019, the majority of the arrows point right which signifies positive coherence between URB and GDP. Urbanization spurs economic expansion by generating job possibilities. Based on results, we argue that Pakistan's expanding population benefits the country's economic progress. Policymakers should exercise prudence when combining metropolitan infrastructure and facilities with rural locations. Given that most government officials prioritize the development of urban rather than rural regions, this is done to prevent migration to urban areas. Otherwise, the municipal infrastructure may become overburdened and may eventually inhibit economic progress. Additionally, it results in improvements in communication, transportation, technology, and infrastructure.

Lastly, Figure 2d shows the WTC between GDP and AGRIC between 1965 and 2019. At different frequencies and scale periods 0–16 between 1980 and 2019, the series are in-phase (positive association) between AGRIC and GDP. It is clear that the growth of Pakistan's economy is influenced by agriculture. Agriculture influences economic progress by indirectly and directly adding to Pakistan's gross domestic product (GDP). It does so through forestry, farm production, textile mills, products, fishing activities, apparel and service, manufacturing, and food and beverage sales.

4.3 | Robustness check (wavelet cohesion)

The study further used the wavelet cohesion (WC) suggested by Rua (2013). The WC also captures the correlation between the series, which is similar to wavelet coherence. However, it does not identify the lead/lag connection between series. Figure 5 presents the results of WC between GDP and the independent variables for the case of Pakistan. Figure 5a depicts Pakistan's WC between GDP and CO_2 from 1965 to 2021. It is clear that the correlation between GDP and CO_2 is positive across all frequencies, which is similar to the wavelet coherence results (see Figure 4a). In addition, in Figure 5b, we noticed positive co-movement between GDP and EC between 1965 and 2021 in Pakistan. This result is also similar to the result gathered from the WTC between EC and GDP (see Figure 4b).

Figure 5c shows the WC between UB and GDP in Pakistan from 1965 to 2021. In all frequencies, we observed that UB and GDP move in the same direction, suggesting that an increase in UB leads to an increase in GDP. This result is also comparable with the results gathered from Figure 4c. Lastly, Figure 5d shows the WC between GDP and AGRIC in Pakistan from 1965 to 2021. This shows that both AGRIC and GDP move together on the same path,

TABLE 3 BDS test.

Dimension	GDP	EC	CO_2	URB	AGRIC
2	32.064***	30.180*	25.546*	35.616*	29.953*
3	34.055***	31.630*	26.172*	37.539*	31.337*
4	36.646***	33.889*	27.313*	40.238*	33.222*
5	40.663***	37.357*	30.277*	44.412*	36.297*
6	46.203****	42.081*	34.813*	50.261*	40.672*

Note: *$p < .01$, ** $p < .05$, * **$p < .1$.

TABLE 4 Unit root tests.

	ADF		PP		KPSS	
Variables	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
GDP	−1.8123	−6.4091***	−1.9791	−6.4158***	0.1933**	0.0539
CO_2	−1.8970	−5.5465***	−2.2360	−5.6194***	0.1785**	0.0832
EC	−1.7751	−6.6823***	−2.0425	−6.7315***	0.1641**	0.0803
URB	−2.8623*	−2.6444	−5.0734***	−2.3779	0.2291***	0.1756**
AGRIC	−1.7829	−9.3744*	−1.4913	−9.5965***	0.1672**	0.1263*

***$p < .01$; **$p < .05$; *$p < .1$.

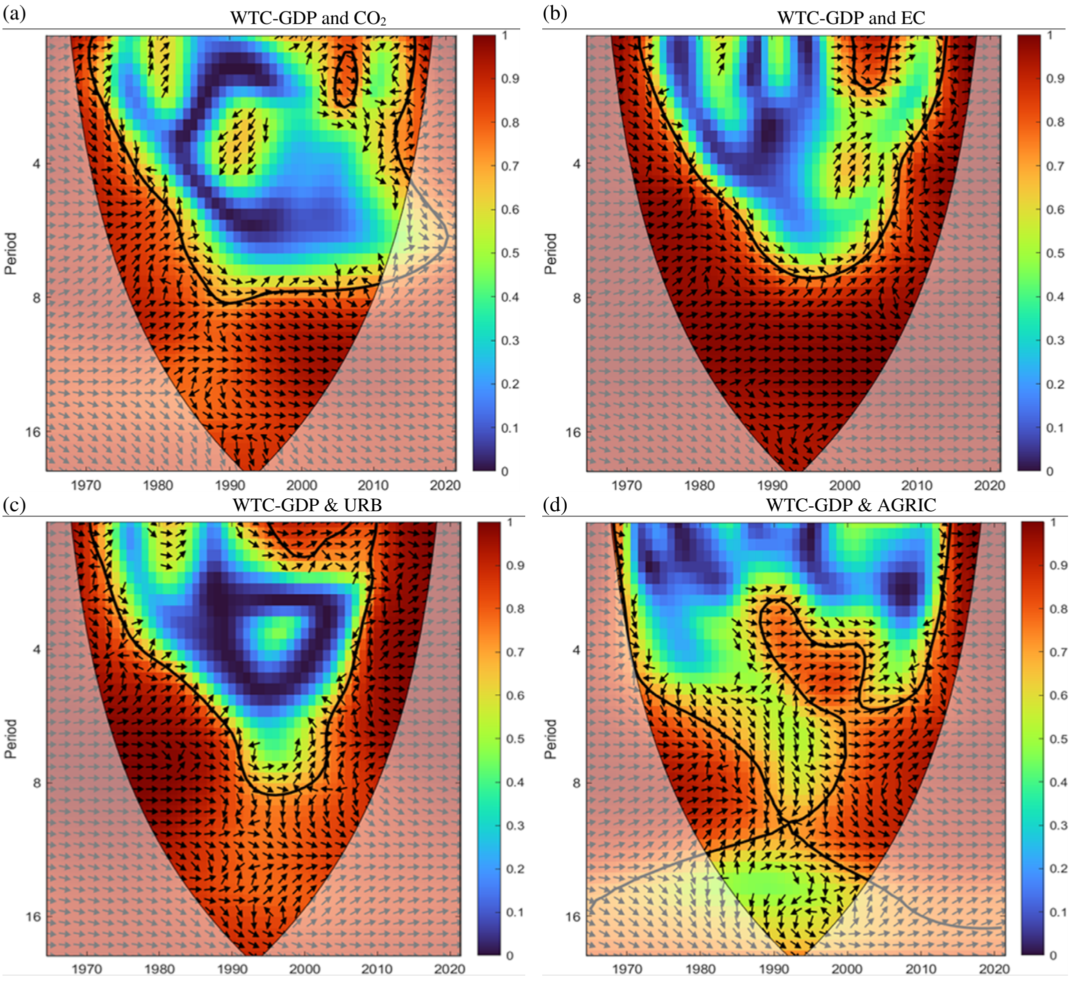

FIGURE 4 Wavelet coherence between economic growth and CO_2 emissions, energy consumption, urbanization, and agriculture.

suggesting that an upsurge in agriculture contributes to an upsurge in economic growth. These results are similar to the results obtained from Figure 4d.

4.4 | Causality in continuous wavelet transform results

The unique time-frequency causality Olayeni (2016) developed has been used in the present investigation. This method avoids the need for minimal phase transfer functions and can correctly determine causality in time-frequency. This method assesses the causal interrelationship between economic growth and the regressors (CO_2 emissions, energy consumption, urbanization, and agriculture). Contour graphs with three scales—frequency, magnitude, and time of the connection—are used to depict the causal linkage. The horizontal (vertical) axes show the time (frequency). A color scale that ranges from no causality (blue color) to strong causality (red color) is used to represent the degree of the causal linkage between variables (see Figure 6). As a result, the Granger causality correlations that are statistically significant at the 5% and 10% levels are shown by the red and white borders. In order to determine

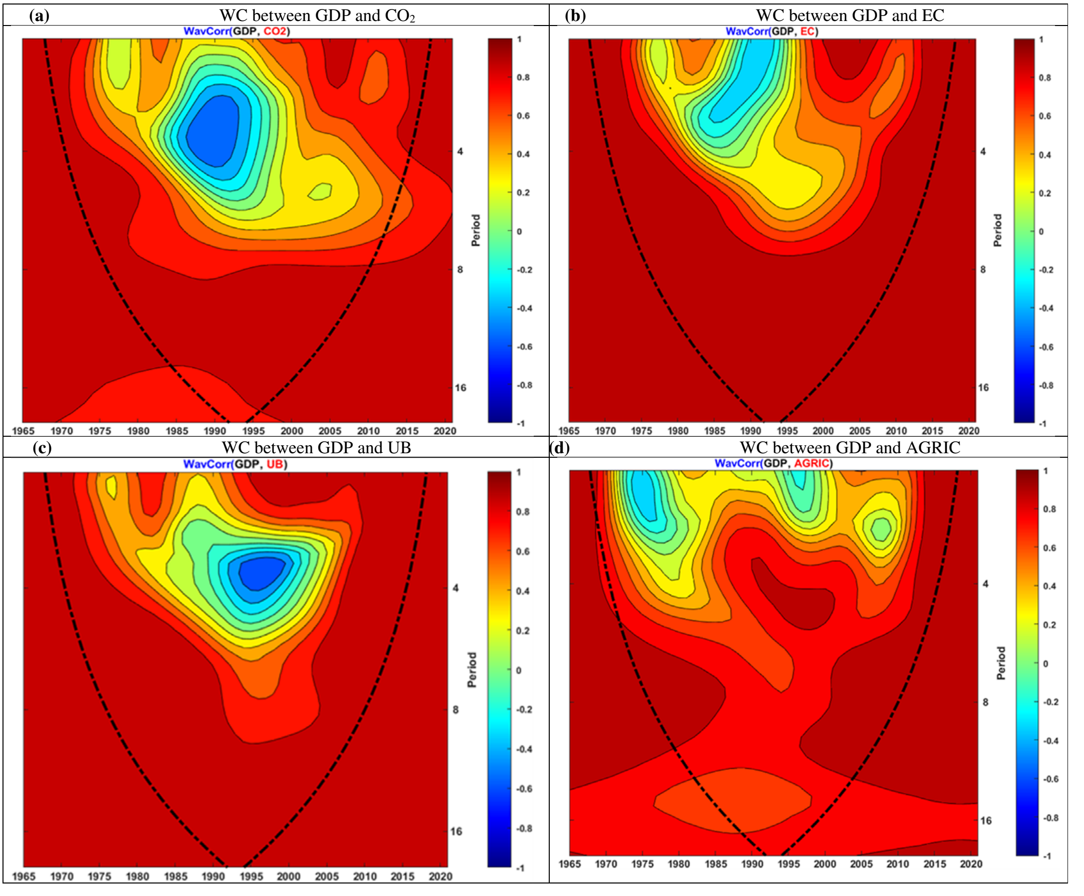

FIGURE 5 Wavelet cohesion between economic growth and CO_2 emissions, energy consumption, urbanization, and agriculture.

the significance threshold, 1000 Markov bootstrapped series are employed. The broken black line, or cone of effect, depicts the area untouched by edge impacts.

Figure 6a presents the causality between GDP and CO_2 emissions in Pakistan from 1965 to 2021. In the short term, from 1970 to 1980 and from 2005 to 2010, GDP Granger caused CO_2. In addition, in the long-term, specifically from 1980 to 2010, GDP Granger caused CO_2. Conversely, in the medium and long terms, specifically, from 1970 to 1990 and from 2000 to 2010, CO_2 Granger caused GDP. This implies feedback causality between CO_2 and GDP, suggesting that changes on CO_2 affect GDP and vice versa.

Figure 6b depicts the causality between GDP and EC between 1965 and 2021 in Pakistan. In all frequencies, specifically from 1970 to 1980 and from 2000 to 2015, GDP could significantly forecast EC. On the other hand, particularly in the medium term, from 1970 to 1990, EC could predict GDP. In summary, feedback causality exists between GDP and EC, though the time and frequency of the causality differs.

Figure 6c presents the causality between GDP and UB emissions in Pakistan from 1965 to 2021. In the medium and long terms, from 1970 to 2015, GDP Granger caused UB. Conversely, in the short and medium terms, specifically from 1970 to 1990 and from 2000 to 2015, UB Granger caused GDP. This implies feedback causality between UB and GDP, suggesting that changes in UB affect GDP and vice versa.

Figure 6d depicts the causality between GDP and AGRIC between 1965 and 2021 in Pakistan. In the short and medium terms, specifically from 1970 to 1980 and from 2000 to 2015, GDP could significantly forecast AGRIC. On

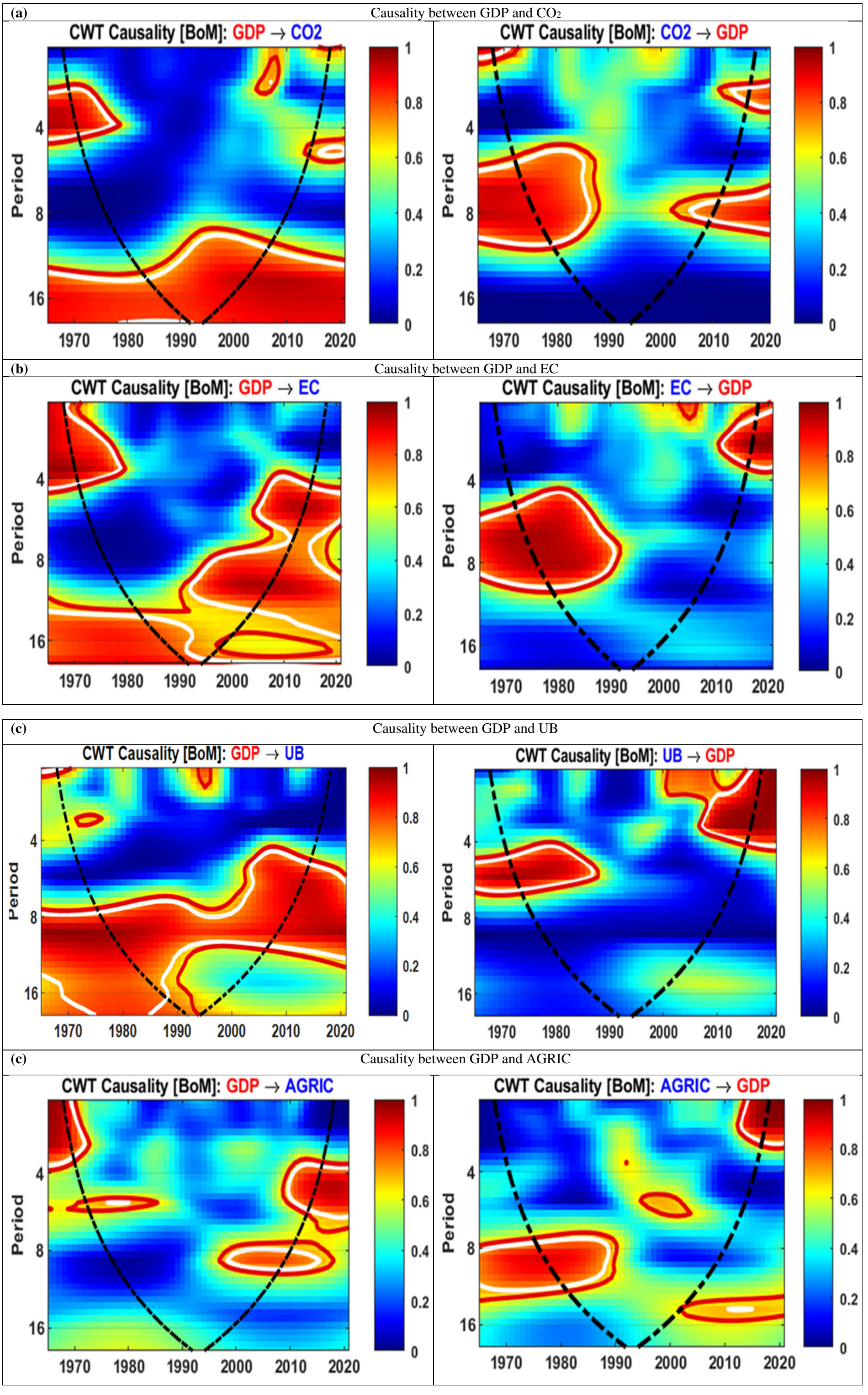

FIGURE 6 Causality between economic growth and CO_2 emissions, energy consumption, urbanization and agriculture.

the other hand, particularly in the medium and long term, from 1970 to 1990, EC could predict GDP. In summary, bidirectional causality exists between AGRIC and GDP.

4.5 | Discussion of findings

This section of the paper discusses the empirical findings above. The study applied the novel wavelet coherence test to capture the co-movement between GDP and the regressors (CO_2 emissions, agriculture, urbanization, and energy utilization). The findings from the WTC disclosed an in-phase connection (positive coherence) between CO_2 and GDP at all frequencies. This demonstrates that an upsurge in CO_2 emissions in Pakistan is followed by an upsurge in GDP. The major reason is that positive coherence in Pakistan is that increasing pollution levels are inevitable as a result of economic expansion. Higher output necessitates increased input, resulting in the utilization of more natural resources and an upsurge in levels of pollution. Pollution is expected to rise to scale with economic expansion (Ali et al., 2022; Sarkodie & Strezov, 2018). Moreover, this illustrates that the economic growth trajectory of Pakistan is driven by CO_2. This empirical outcome disclosed that Pakistan is still on the scale effect phase-suggesting that an upsurge in environmental deterioration accompanies an economic expansion. The economic structure of Pakistan could be another possible cause for this result. The Pakistani economy is built to largely rely on fossil fuels, accounting for 64% of the country's energy mix. The China Power Hub Generation Company (CPHGC) coal-fired power station in the Balochistan area of the nation, which has a capacity of 1320 MW, is a current example of fossil fuel-powered developments in the nation. This necessitates a more proactive approach from policymakers and stakeholders in order to reorganize Pakistan's economy. This outcome complies with the studies of Balcilar et al. (2019) and Magazzino et al. (2021).

Furthermore, we observed positive coherence between urbanization and economic growth at middle and low frequencies. We make the assertion based on factual evidence that Pakistan's rising population benefits the country's economic path. Nonetheless, authorities must exercise caution when attempting to duplicate metropolitan infrastructure and services in rural areas. This is to avert a stampede to metropolitan regions, as most government officials favor urban development over rural development. Otherwise, metropolitan infrastructure might be overburdened, stifling long-term economic progress. This association is supported by the studies of Udemba et al. (2020) for India, Ali et al. (2020) for Nigeria, and Agboola and Bekun (2019) for Pakistan; however, contradicts the study of Ali et al. (2020) for Nigeria. Also, there is proof of in-phase (positive relationship) between GDP and energy utilization at different frequencies; however, the in-phase association is strong in the middle and lower frequencies. The major reason for this interconnection is that as for developing economies such as Pakistan, energy utilization increases as the economy grows. This is a strong indicator that the intensity of energy is a significant indicator in the economic growth of Pakistan. This outcome corroborates the study of Matar et al. (2021). In Pakistan's current scenario, this is a major problem affecting the country's economic development.

Moreover, there is an in-phase (positive interconnection) between agriculture and economic growth in Pakistan at different frequencies. Agriculture plays a crucial role in fostering economic prosperity of Pakistan by bolstering overall production within the sector. Through advancements in technology, improved farming techniques, and better access to necessary resources, agricultural productivity is elevated, resulting in higher yields and increased output. This, in turn, stimulates farmer income and drives economic activity across the entire agricultural value chain, encompassing distribution, processing, and marketing. Particularly in developing economies where a significant proportion of the population is engaged in agricultural pursuits, agriculture serves as a substantial source of employment. The expansion of the agricultural sector creates employment opportunities, reduces unemployment rates, and injects financial resources into rural areas. The subsequent rise in disposable income, fueled by increased employment, promotes consumer spending, thus fostering broader economic growth. The probable reason for this positive connection is that agriculture is the backbone of an economy, without which the economy can neither function nor survive, so Pakistan must give importance to agriculture. Pakistan's economy relies heavily on agriculture. Another likely reason for the positive coherence between GDP and agriculture is that Pakistan's agricultural share of GDP is 21%, with a 2.7% annual growth rate. Furthermore, agriculture employs % of the working force, while 62% rely on it for living in rural areas Agboola and Bekun (2019). This outcome is consistent with Sertoglu et al. (2017) and Umarbeyli et al. (2021).

The study further applied the wavelet causality initiated by Olayeni (2016) to catch the causal linkage between economic growth and the regressors (CO_2 emissions, agriculture, urbanization, and energy use) in Pakistan from 1965 to 2021. The main novelty of this approach is that it can capture causal linkage between series at different frequencies and timeframe. The test outcomes disclosed a bidirectional causal linkage between GDP and economic growth, suggesting that economic growth can predict CO_2 and vice versa. Furthermore, there is evidence of a two-way causal linkage between energy utilization and economic growth. In addition, there is a feedback causal connection between GDP and urbanization and agriculture. This suggests that both urbanization and agriculture can predict Pakistan's economic growth. As a result, fossil fuels influence the economic performance of Pakistan. This is because the economy is heavily reliant on industrial and productive activities. This outcome also establishes the linkages between economic growth and the selected variables; hence, growth is caused by urbanization, agriculture, energy utilization, and CO_2 emissions. Additionally, this indicates that Pakistan is sacrificing the quality of the environment in order to achieve economic growth. This is the perspective of the present state of the Pakistani economy, which is one of the globe's most populated nations, with economic growth and populace as the major drivers of energy consumption and emissions. This has ramifications for Pakistan's economic growth in light of the country's fast population increase, since spending will be directed largely toward the impoverished people, with the promise of improved welfare. Policymakers in Pakistan should create policies in this area following the nation's diversification of its energy portfolio.

Policy formulation and execution should be centered on how energy consumption and economic growth could be regulated in order to preserve economic momentum while reducing Pakistan's high CO_2 emissions. Government officials should consider energy security and diversification as viable choices that open up new pathways for improving energy efficiency and reducing negative energy impacts. Furthermore, because Pakistan is one of the globe's most populated countries, energy usage and population has substantial financial consequences. Pakistan intends to generate 5–6% on-grid electricity from renewable sources by 2030 (except big hydropower). At the end of 2016, the total installed power capacity was 26 GW, with renewable energy accounting for 4.2% (Enerdata, 2023). Pakistan has a lot of renewable energy resources, but only big hydropower projects and a few solar and wind projects have harnessed this prospective. Wind, Solar PV, and biomass-based power plants account for 1136 MW of renewable energy capacity currently deployed. There are additional opportunities to promote the usage of biomass, wind, and solar projects. The Pakistani economy is well situated to sustain its development trend despite environmental difficulties, thanks to this progress and good policy design to diversify the energy portfolio.

5 | CONCLUSION AND POLICY DIRECTION

The current research re-assesses the ongoing studies on the connection between economic growth and CO_2 emissions as well as the role of agriculture, energy utilization, and urbanization by applying recent novel econometric techniques. To accomplish the aforementioned objectives, the present study applied a time-frequency approach such as wavelet coherence, wavelet cohesion, and wavelet causality to capture the interconnection between GDP and the variables of interest at different frequencies and time periods. The outcomes of the wavelet coherence test disclosed that urbanization, agriculture, energy consumption, and CO_2 emissions impact economic growth positively. Lastly, the wavelet-based causality disclosed feedback causality between economic growth and the regressors (CO_2 emissions, urbanization, energy consumption, and agriculture); however, the frequency and time of causality varies.

5.1 | Policy direction

Based on the findings, the present research proposes the following policy suggestions. Pakistan's economic development path is unsustainable due to its reliance on fossil fuel-based energy. BP (2021) states Pakistan's energy mix comprises 64% fossil fuels. Pakistan mostly produces energy from fossil fuels (gas, coal, and oil), which is expensive due to huge financial strain and oil imports. As a result, maintaining the current economic development trend necessitates substituting renewable energy solutions for fossil fuel-based energy solutions. However, a sudden shift in energy sources can have a major negative influence on economic growth. As a result, a phase-by-phase policy development plan must be devised, allowing the policy framework to not only internalize the negative environmental externalities of growth in the economy but also keep the economic expansion trend unchanged. Therefore, policymakers should set the conditions for rapid dissemination and acceptance of renewable energy consumption. Furthermore, renewable energy alternatives must be made available and cheap to businesses and families in order to accomplish this. Increased affordability and accessibility may lead to a demand for renewable energy sources among the general public.

Updating policies, including tax changes, minimum mark-up business loans, a market-friendly environment, order and stability, and simple import–export capacity, will entice foreign and local investors. Industry expansion is important for economic growth and for creating more jobs for the general public. Policy to slow down the increasing rate of urbanization in the country, especially if it hampers agricultural activities or seen to induce environmental degradation. Additionally, urbanization should be considered while evaluating refugee policy regarding appropriate registration, job opportunities capability, and job registration capacity. Importantly, a more pragmatic approach to decrease CO_2 emissions should be further adapted in order to protect the environment, avoid global warming by mass planting, and stimulate the use of renewable energy. Finally, since agriculture makes up a significant share of the country's economic growth measure, policymakers should promote agricultural crop production by using appropriate technology, inputs, resource management alternatives, and market facilities.

The advantages for the surrounding nations and the time span covered by this study are among the research's implications and limitations. The outcomes of this research will benefit surrounding nations, which can use the recommendations to improve their sustainable growth. The research only covers the years 1965 to 2021, which limits the capacity to evaluate Pakistan's present performance in terms of economic growth and environmental protection. This will allow future study on a comparable issue, incorporating data from recent years. Other determinants of economic growth, such as trade openness and globalization, can also be incorporated into future research.

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ENDNOTE

[1] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC185076/.

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