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Impact of Globalization on Environmental Sustainability: ARDL Based Evidence from Pakistan

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Abstract: *This study investigates the impact of globalization on sustainable development in Pakistan from 1990 to 2022 using the Autoregressive Distributed Lag (ARDL) bounds testing framework. The analysis confirms a stable long-run cointegrating relationship among the variables. Globalization exerts a significant positive effect on the ecological footprint, indicating that deeper global integration has so far intensified environmental pressures. Rising energy use, rapid urbanization, and expanding industrial activity further aggravate unsustainable development pathways, reflecting Pakistan's reliance on fossil fuels, unplanned city growth, and resource-intensive production. Short-run estimates mirror the long-run findings, and the negative, highly significant error-correction term shows a strong speed of adjustment toward equilibrium after short-term shocks. Diagnostic and stability tests validate the robustness of the model. Overall, the evidence suggests that Pakistan's current pattern of globalization and structural transformation undermines environmental sustainability. Policy efforts must prioritize renewable energy adoption, sustainable urban planning, and cleaner industrialization to align economic integration with long-term ecological resilience and the Sustainable Development Goals (SDGs).*

Introduction

In the 21st century, globalization has emerged as one of the most unavoidable and transformative processes affecting economies, societies and cultures at an unprecedented scale. Globalization is characterized by intensification in cross-border flows of trade, capital, investment, information, technology, and people which creates a more interconnected and interdependent world (Friedman, 2005; Dicken, 2015). For many nations, globalization has further expanded the potential for growth and inclusive development, making it easier to integrate into global value chains, access global services, and tap into technological transfer. Yet while globalization is often seen as providing economic and social benefits, it raises difficult questions about environmental costs, and whether the growth and development it enables is ultimately sustainable (Leichenko & O'Brien, 2008; Rasheed et al., 2025).

Environmental sustainability, generally understood as the capability of human systems to sustain natural resources, ecosystems, and the health of the planet for current and future generations, has emerged as a priority in the global policy arena (United Nations, 2015). The need for environmental sustainability is further highlighted by the accelerating pace of climate change, biodiversity loss, resource depletion, and rising pollution rates. In its sixth assessment report, the Intergovernmental Panel on Climate Change

(IPCC, 2023) forecasted that the globe has already warmed by 1.1°C above pre-industrial levels, suggesting severe threats to ecosystems, and vulnerable populations, if efforts are not made to support mitigation and adaptation. Globalization is situated paradoxically within the current state of the world. On one hand, globalization provides countries with access to green technologies, encourages foreign direct investment into pollution-free sectors, and enables them to enter into international environmental agreements. Globalization creates several domains where it impacts sustainability and progress toward sustainability: spread of ethical technology through the exchange of technologies that respect the environment; multinational corporations interested in ethical supply chains; and the movement toward collective regulation of environmental groups (Kolk & Pinkse, 2007; Gereffi et al., 2001). Conversely, globalization creates demand for energy-intensive production, transports pollution intensive industries to developing areas of the world and encourages consumption patterns that are not sustainable through the interactions of global markets (Martinez-Alier, 2002; Rafique et al., 2024). The contradictory nature of globalization leads to a larger question of whether it promotes development toward sustainability or degrades the environment.

The international community has attempted to deal with this tension through a universal framework for sustainability. The United Nations Sustainable Development Goals (SDGs), adopted in 2015, clearly connect environmental sustainability with economic and social development. Several goals specifically resonate with the nexus between globalization and environment. SDG 7 calls for a global transition to renewable energy, SDG 12 calls for sustainable, global value chains and cleaner industrial practices, SDG 13 calls for urgent action on climate change further exacerbated through global trade and growth reliant on fossil fuels, and SDG 15 highlights environmental consequences of deforestation, habitat destruction, and threats to biodiversity - often driven by global demand. The Paris Agreements of 2015 go further by specifically referring to international cooperation being a tool to combat climate change and encourage countries to develop their economic policy in recognition of low carbon pathways. The United Nations Environment Program has even reported that global environmental goals will remain remote without significant changes to systemic trade, investment and production patterns (UNEP, 2022). Therefore, globalization must be managed in a way that it bolsters, rather than hampers the stated global sustainability agendas.

The relationship established in academic literature is inherently complex. The literature documents three overall pathways for how globalization influences the environment. The first is the scale effect, suggesting globalization enhances economic activity, increases resource extraction rates, and raises emissions rates, which then leads to declines in the environment. Second, the composition effect indicates that globalization can alter the composition of economies, which could pull countries towards cleaner sectors. The third emphasis comes from the technique effect, which appreciates the differences that globalization makes cleaner technologies and environmental standards attainable (Grossman & Krueger, 1995). Overall, empirical evidence remains mixed. Some studies analyzing cross countries used to examine whether globalization leads to a reduction in ecological footprints, found that diffusions of green technologies through globalization had a positive influence (Tang et al., 2020). At the same time, these findings are countered by studies that identify evidence of globalization driving environmental degradation, especially in low and middle-income countries (Ahmed et al., 2020). A blending of both advantages and counter-finding evidence reflects the lack of taken-for-granted, since experiences of that lack of agreement depend to a large measure on institutional capacity, the regulatory environment, and ultimately patterns of integrating into the global political economy.

The globalization–sustainability dilemma is especially acute for developing countries. Industrialization, urbanization, and economic growth may be considered development imperatives that foster social change, but all of the processes of developing entail a demand for resources and energy. The rapid engagement into the global market presents opportunities (i.e., access to cleaner technologies) for developing nations, but also exposes them to risks (i.e., ecological devastation, and/or vulnerability to shocks in the global economy). Compounding that is the developing nations' generally weak environmental governance, capacity of institutions, and ability to get off fossil fuels, all of which add complexity to the challenge of integrating globalization and sustainability (Usman et al., 2020).

Pakistan is an especially important case in this global discussion. As a developing country with a focus on rapid development, Pakistan's engagement in the world system has deepened by trade liberalization, foreign direct investment, and infrastructure mega projects such as China-Pakistan Economic Corridor (CPEC). These may yield economic advantages but also have the potential to create detrimental environmental considerations. The country remains highly vulnerable to climate change, floods, droughts, heat waves and glacial melting are serious considerations. (World Bank, 2022). Meanwhile, increasing energy consumption, rapid urbanization, deforestation, and industrial expansion are increasing Pakistan’s ecological footprint (Global Footprint Network, 2023). Pakistan's sustainability dilemma represents the broader dilemma of the developing world: balancing globalization-driven growth with environmental protection and long-term resilience. Globalization could afford cleaner production practices, renewable energy adoption, and sustainable urban environments, but it could also result in locking in unsustainable development pathways, should environmental risks be trumped by the short-term economic benefits.

The effects of globalization on environmental sustainability have generated considerable debate, and it is still unclear exactly what the ultimate implications will be, especially in developing contexts such as Pakistan. On the one hand, some evidence suggests that globalization strengthens the effectiveness of governance and efficiency to improve environmental performance (Antweiler, Copeland, & Taylor, 2001; Frankel & Rose, 2005). On the other hand, there is evidence that globalization has adverse effects such as resource extraction and growth based on existing pollution (Cole, 2004; Jorgenson & Clark, 2012) and ultimately worsens environmental degradation. In addition to these conflicting views on globalization and environmental sustainability, most studies on the topic have been at the aggregate global or regional levels without exploring the country specific interactions between globalization and sustainability (Shahbaz, Lean, & Shabbir, 2013; Ahmed, Wang, Mahmood, Hafeez & Ali, 2019). There is a strong need for country-level evidence-based understandings, specifically in Pakistan, where globalization pressures are at odds with grave environmental vulnerabilities that should inform and ultimately shape global and national discourse in both environmental and economic policy (Usman, Ozturk, Hassan and Zafar, 2020). Deciding if globalization is a catalyst for sustainability or a danger to ecological integrity is not only an academic endeavor, but it remains necessary to address the SDGs, achieve climate obligations in the Paris Agreement and create cleaner production policies (United Nations, 2015; World Bank, 2022).

This research contributes to the globalization-sustainability debate from three perspectives. First, it relates Pakistan's experiences, to larger narratives and conversations about globalization and environmental sustainability, providing relevant context-based evidence from a climate high risk country. Second, it employs the ecological footprint as a multidimensional metric of environmental sustainability that incorporates the collective effect of energy consumption, land use and resource consumption, which provides a more useful evaluation of sustainability than select indicators (e.g. carbon emissions). At last, it can aid the problem justification, in terms of thinking about globalization alongside the critical need for sustainability, in terms of the alignment of national strategies with the internationally endorsed commitments associated in the SDGs and the Paris Agreement.

Literature Review

The relationship between globalization and environmental sustainability has been the focus of attention from scholars for quite some time and continues to be a source of interest, not least because of the multi-dimensional concerns with both globalization and sustainability as concepts. The literature on globalization and the environment can be described in broad terms, as it relates to sustainability, as divided into two major areas. First, theoretical literature attempts to show how globalization and other economic drivers like energy consumption, urbanization, and industrialization are linked to environmental outcomes, especially the emerging notion of ecological sustainability based on some economic theory or causal channel. Second, there has also been empirical literature produced in several different countries using a variety of methodologies that shows some degree of evidence which may imply or show these variables are connected or related in practice. This literature review will provide a summary of the theoretical and empirical literature on the globalization-sustainability relationship.

Theoretical Literature

The ecological footprint index is a representation of the environmental sustainability, indicating how much pressure human activity puts on natural resources and ecosystems. The ecological footprint measures not just carbon emissions, but also land use, energy demand, water use and waste, and thus is multidimensional in measuring ecological stress (Wackernagel et al., 2002). Understanding how globalization, energy consumption, urbanization and industrialization affect sustainability requires placing these studies into larger economic theories, which inform channels through which independent variable will affect environmental outcomes, even in contradicting ways, depending on institutions, the country’s stage of development, and the level of technological capabilities.

Ultimately, globalization has been referred to as a “double-edged sword” regarding its environmental effects. Theoretically globalization will enhance environmental degradation, as countries become more industrialized and expand production, and/or lessen environmental degradation. For example, the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995) is one such framework. As countries grow, which will most likely be linked to globalization, the EKC proposes environmental degradation increases as a country’s income levels increase, as income is reinvested into cleaner technologies and better environment regulations (Shafik, 1994; Stern, 2004).

Globalization also affects ecological footprints through three established effects: scale effects, composition effects, and technique effects. The scale effect states that trade liberalization and global integration lead to higher economic activity, thereby increasing resource use and emissions and two times expanding ecological footprints (Copeland & Taylor, 2003). The composition effect states that globalization affects the composition of economies. If developing economies specialize in pollution-intensive industries grounded in comparative advantage, their ecological footprint worsens (Cole, 2004). If, on the other hand, globalization lubricates the switch of economies into service and technological economies, ecological impacts may diminish. The technique effect describes how globalization facilitates the diffusion of technologies that are cleaner, environmentally higher standards, and environmentally preferred items through multinational firms and global value chains (Antweiler et al., 2001; Kolk & Pinkse, 2007). Ultimately, the extent or balance of these three different effects will determine whether globalization reduces or increases ecological footprints. In the context of a country like Pakistan, the predominance of scale effects and pollution haven tendencies, globalization most likely increase ecological stress (Shahbaz et al., 2013).

Energy-use is linked to ecological sustainability via environmental externalities. Contemporary externality theory (Pigou, 1920) describes how energy-use based on fossil fuels provides negative externalities (carbon emissions, air pollution and resource depletion), which are not fully internalized into market prices, resulting in overconsumption of fossil fuels, and increased ecological concern (Sadorsky, 2010).

In contrast the theory of induced innovation offers a more positive channel. Increased energy demand, especially under globalization and competitive conditions, may induce technological change toward renewable and or energy efficient sources (Popp, 2002). For example, as fossil fuels become more expensive, or more constrained in terms of the environment, firms and countries will opt for cleaner energy sources, and over time this would reduce the ecological footprint. However, the energy - sustainability relationship is highly path dependent. For example, in countries like Pakistan, where the energy mix is non-renewable, the negative externality channel predominates, and energy-use or energy consumption produced negative externalities (Usman et al., 2020).

Urbanization plays a crucial role in impacting environmental sustainability vis-a-vis urban economic theory. Cities are centres for production, consumption, and density for populations, all of which create opportunities for efficiency and the possibility for ecological degradation. One theory - the compact city hypothesis - posits that well organized urbanization results in lower per capita energy consumption and emissions due to efficient public transportation, sharing of hard and soft infrastructure, and economies of scale for services (Newman & Kenworthy, 1999). In this view, urbanization could mitigate ecological footprints if properly organized. Some would argue this is not the lived experience for many countries currently experiencing urban growth in the developing world. Poorly organized, rapid urbanization leads to congestion, increase demand for transportation systems, poor waste management, deforestation, and urban sprawl, all of which increase ecological footprints (Henderson, 2003; Seto, Güneralp, & Hutyra, 2012). The impacts of urbanization on ecological sustainability will rely on the quality of governance, investment in infrastructure, and population pressures to inform and deliver local government decisions. For a country like Pakistan with rapidly growing cities, investment in infrastructure is not meeting the demand, and poor governance at municipal levels creates the potential for urbanization to increase ecological stress (Ali et al., 2019).

Industrialization has long been considered a central driver of environmental degradation. The structural change theory posits that as economies develop, they transition from agriculture to industry and eventually to services. During the industrial phase, resource-intensive production and high energy demand increase ecological footprints (Fisher-Vanden et al., 2004).

The pollution hypothesis (Copeland & Taylor, 2004) also suggests globalization intensifies the environmental costs associated with industrialization present in the countries most affected. Pollution-intensive industries relocate to countries with laxer environmental regulations, which adds to the ecological footprint on the countries that host those factories (Cole, 2004; Eskeland & Harrison, 2003). At the same time, throughput globalization can lead to industrial upgrading and industrial modernization, which may create avenues for cleaner production by acting as a channel for technology transfer and increased standards (Zhang et al., 2011). What happens depends on whether those countries also take steps to effectively enforce existing environmental regulations and invest in technological innovation. In Pakistan, the country lacks institutional capacity, and its dependence on energy-intensive, low-value-added industries means industrialization continues to exacerbate ecological pressures (Nasir & Rehman, 2011).

Overall, the theoretical literature indicates several interconnected pathways that connect globalization, energy use, urbanization and industrialization, and ecological sustainability. Globalization (or the effects of globalization) has connections to sustainability through scale, composition, and technique effects, while the EKC framework suggests that at some point there may be an eventual change associated with increased income levels. Energy use is known to contribute to ecological degradation through negative externalities; however, it can also provide a channel to mitigate in the long run through induced innovation. Urbanization has a mixed impact on sustainability; planned urbanization tends to reduce per capita footprints, whereas unplanned urbanization would increase per capita footprints. Lastly, industrialization, through globalization, indicates increases in ecological stress related to structural transformation unless the effects are countered through technological upgrading and effective regulatory regime.

In developing nations, such as Pakistan, where there is reliance upon fossil fuel resources, unregulated urban growth and industrial maturation are at their infancy, these mechanisms are currently advancing towards compromising ecological footprints. The associated theories, therefore, suggest sustainability outcomes are not given, but instead depend on the characteristics of institutions, governance, and sustainability-oriented policy coherence with global sustainability.

Empirical Literature

Various empirical studies have attempted to explore the theoretical links among globalization, energy consumption, urbanization, industrialization, and environmental sustainability with different methodological approaches and data. The outcomes appear to be somewhat mixed, resembling the complex relationships among these concepts across different countries, and among different levels of development and institutional contexts.

Many studies have sought to explore the implications of globalization for ecological sustainability, with some studies affirming the Environmental Kuznets Curve (EKC) hypothesis that links globalization with ecological degradation in the first stages, and ecological sustainability in later stages (Shahbaz et al., 2013). The logic follows the theoretical compositional and technique effects narratives: in the earlier stages of globalization, globalization leads to an increase in industrial capacity and extraction of resources formerly untapped, while later globalization leads to diffusion of technology and efficiencies gained. That said, the evidence is by no means uniform. Other empirical studies argue that globalization increases ecological pressures on some developing countries in which exploitation of the environment is compounded by weak governance and limited technology adoption (Ahmed et al., 2019). Cross-country studies variable ecological indicator footprints have frequently found a positive relationship between globalization and ecological footprint, although the magnitude varies across regions influenced by institutional and structural circumstances (Jorgenson & Clark, 2012).

Energy consumption has always been a significant factor in environmental outcomes. Empirical studies in both developing and developed economies show that greater energy consumption, particularly through fossil fuels, increases the environmental burden and carbon footprints (Ang, 2007). The puerile theoretical explanation for these finding stems from externality theory (Pigou, 1920) which explains the environmental exploitation from fossil fuel combustion due to negative externalities that are unpriced. For South Asian economies, the empirical evidence also suggests that energy consumption is the foremost driver of unsustainable environmental trends, given that coal, oil, and gas occupy a large proportion of their energy mixes (Zhang et al., 2017). However, sustainability in relation to energy consumption is little more than a singular concept. Studies that distinguish between renewable and non-renewable energy available as literatures show that renewable energy consumption lessens ecological footprints and could possibly present a pathway for sustainability in a globalising world

(Nathaniel & Iheonu, 2019). This has been theorized long ago within the induced innovation hypothesis, which posits that continuous demand of energy consumption could induce technological change that favour cleaner energy production (Popp, 2002; Rasheed et al., 2022).

The topic of urbanization has been extensively considered in literature related to ecological sustainability. The existing evidence confirms the two theoretical pathways that were discussed previously within urban economic theory: compact city versus unplanned sprawl. Poumanyvong and Kaneko (2010) note that in developing countries, rapid urbanization invariably produces significantly larger ecological footprints due to greater energy consumption, housing demand, and transportation emissions. In contrast, in developed countries, controllable urbanization could improve environmental impacts per capita as increased efficiencies are realized in infrastructure and transportation systems (Newman & Kenworthy, 1999). Seto et al., (2012) have more recently offered evidence, suggesting that global urban expansion contributes to biodiversity loss and carbon emissions, which reinforces the scale effect. In South Asia, literature indicates that weak municipal governance and inadequate investment in infrastructure worsens the negative environmental impacts of urbanization (Ali et al., 2019; Sajid et al., 2024). In summary, the empirical evidence on urbanization aligns with theoretical claims that the effects on ecological sustainability depend highly on the quality of governance and planning.

The second key determinant of environmental outcomes is industrialization, and the empirical context generally backs up both the structural change theory and pollution have hypothesis. Sadorsky (2010) provided evidence that the growth of industry leads to increases in emissions in growth countries. This was reflective of the scale and composition effects. Cole (2004) and Eskeland and Harrison (2003) also showed that multinationals reallocate pollution-intensive businesses to countries with lax regulations, increasing environmental costs to society in the receiving countries. For Pakistan, Nasir and Rehman (2011) reported that industrialization is responsible for the substantial increases in carbon emissions and ecological stress, and some evidence suggests the potential for upward industrial mobility toward cleaner production has been low. However, other researchers find that industrial modernization and innovation decrease the environmental intensity (or improving the ecological efficiency) of industrial output over time (Zhang & Zhang, 2011), and therefore, the long-run technique effect can balance out the short-run costs of industrialization.

Numerous studies have examined Pakistan and South Asia as a region affected by the globalization–environment nexus. For instance, Shahbaz et al., (2013) found that globalization was harmful to the environment in Pakistan, but through renewable energy investment and institutional or governance reforms, changing transmission mechanisms could improve environmental outcomes over time. In a similar manner, Ali et al. (2019) focused on the ecological footprints of Pakistan demonstrated that energy consumption and industrialization were significant contributors to ecological footprints in Pakistan, while globalization was conditional (positive or negative) upon whether it was the economic, social, or political dimension that were being considered. Similarly, Usman et al., (2020) demonstrated that although globalization and energy consumption are detrimental to environmental sustainability in the short run, ARDL compatibility implies long-run sustainable opportunities through policy interventions, technology transfer, and structural reforms.

The neighbouring countries provide empirical evidence to reinforce the previously discussed insights. For example, in Malaysia, Saboori, et al., (2012) identified evidence of the EKC and concluded that economic growth and globalization would eventually lead toward an improved ecology. Balsalobre-Lorente et al. (2018) highlighted the experience of India to demonstrate that renewable energy and technological innovation can help reduce globalization and industrialization-related ecological pressures, illustrating the importance of energy transitions for implementing sustainability goals. Overall, these findings suggest that, for South Asian economies, short-run effects tend to be scale-driven, while long-run effects may reveal composition and technique impacts with adequate policy measures.

Overall, the empirical findings suggest complex and context-specific associations between globalization, energy consumption, urbanization, industrialization and ecological sustainability. On the one hand, globalization enables the diffusion of clean technologies and other practices that can support better ecological outcomes, while it may also amplify ecological pressures linked to economic growth focused on resource extraction and pollution. Urbanization, energy consumption, and industrialization also have both positive and negative implications for sustainability outcomes, which depend on structural conditions, governance and level of development. In Pakistan, the empirical findings indicate that globalization and modernization continue to increase ecological pressures, while at the same time, undermining opportunities to achieve sustainable development goals (SDGs).

Overall, the literature on globalization and environmental sustainability combines theoretical richness and empirical heterogeneity. Theoretical models explain multi-dimensional impacts from globalization on ecological impacts - scale effects, composition effects, and technique effects; however, the empirical evidence on globalization is vague and context specific. In the case of Pakistan, globalization complements increasing energy demand, urbanization and industrialization in the context of growing energy intensity; the literature suggests there is increasing ecological footprints from regional production systems, but there is ample opportunity to push globalization towards regional cleaner production and sustainability. Therefore, this implies the need to conduct studies specific to resource-rich countries to disentangle short-term vs. long-term effects and provide evidence-based policy guidance when looking at regional case studies.

Methodology

This chapter elaborates on the methodology of investigating the effect of globalization for environmental sustainability in Pakistan, with a primary focus on ensuring the empirical analysis is conducted based on sound econometric techniques, and measurement and diagnostics of relevant variables. To that end, the chapter begins by detailing how the data and relevant variables are operationalized, before describing the functional form of the model. It then describes the econometric process, outlining the econometric tests beginning with introductory tests for multicollinearity and stationarity, followed by the rationale and approach to bounding testing procedures based on an Autoregressive Distributed Lag (ARDL) framework. The chapter then concludes with a description of the model diagnostics criteria conducted to provide assurance of the reliability of the model.

The study uses annual time series data for Pakistan from the period 1990 to 2020, with the balanced sample providing a lens on key events surrounding globalization, energy consumption, urbanization, industrialization, and environmental stress. The dependent variable is environmental sustainability as measured by the ecological footprint index provided by the Global Footprint Network. Globalization is measured using the KOF Globalization Index which provides a measure of globalization that includes economic, social, and political indicators. Energy consumption is described as total energy consumption measured in quadrillion British thermal units (btus) sourced from the U.S. Energy Information Administration. Urbanization is described as the share of urban population to total population and industrialization is measured by referring to a share of industrial value added in to GDP; urbanization and industrialization are both also referred from the World Bank's indicators in the World Development Indicators database. To facilitate, the following table presents a summary of variables, measures, and data sources.

Table 1. Description of variables

Variables	Abbr.	Measure	Source
Environmental Sustainability	EFP	Ecological footprint index	World Footprint (2025)
Globalization	GI	Index	KOF(2025)
Energy consumption	EC	QBTU	USEIA (2025)
Urbanization	Urb	Ratio of urban population to total population	World Bank (2025)
Industrialization	Ind	Ratio of industrial value added to GDP	World Bank (2025)

The use of natural logarithms in all variables serves to stabilize the variance and allows the estimated coefficients to be interpreted as elasticities. The functional specification of the model in long-run log-linear form is expressed as follows:

$$lnEFP_t = \alpha + \beta_1 lnEC_t + \beta_2 lnGI_t + \beta_3 lnUrb_t + \beta_4 lnInd + U_t$$

Where $lnLEFP_t$ the ecological footprint at time t is, $lnGI_t$ represents globalization, $lnEC_t$ is energy consumption, $lnUrb_t$ is urbanization, $lnInd$ is industrialization, and U_t is the error term.

Prior to proceeding to estimation, it is necessary to examine the extent of correlation among explanatory variables as a precaution against multicollinearity, which inflates standard errors and obscures the true relationship between variables. While pairwise correlation coefficients are an initial examination, a more reliable diagnostic is the Variance Inflation Factor (VIF). The VIF, for each explanatory variable Xi, is calculated by estimating an auxiliary regression on all other independent variables, and using the coefficient of determination for the auxiliary regression, Rj2, to calculate the VIF as:

$$VIF_j = \frac{1}{1 - R_j^2}$$

If VIF_j values exceed the value of 10, we notice an issue of multicollinearity. In this project, all VIF values were well below conventional standards, validating that multicollinearity is not an issue.

The next important step is to test stationarity. For example, it is well established that time-series data commonly display stochastic trends, which can make non-stationary variables useless, because that can lead to regression analysis that had no theoretical link to causal inferences. To test the order of integration of each variable, we conducted the ADF and PP tests. The ADF test estimates the following regression for each variable y_t:

$$\Delta Y_t = \alpha + \beta_t + \gamma y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \varepsilon_t$$

Where Δ represents the first difference operator, t is a time trend, and p refers to the number of lagged differences added to accommodate any potential serial correlation. The null hypothesis is H0: γ = 0, meaning there is a unit root and non-stationarity. If the null is rejected, then the series is stationary. The PP test employs the same regression form and non-parametrically adjusts the test statistic to account for heteroskedasticity and autocorrelation in the error term. The results from both the ADF and PP tests indicated that some of the series were stationary in levels I(0), whereas other series were stationary after the first difference I(1), and none were integrated of order two. The presence of both I (0) and I(1) series allows for the application of the ARDL bounds testing framework developed by Pesaran, Shin, and Smith (2001).

This ARDL model is particularly suited to this study because of three key features: it allows for regressors that have different orders of integration (as long as none are I(2), it has good performance in finding legitimate estimates of relationship even with small samples size, and it produces both short-run estimates and long-run estimates of the quartet to be included within one broad modeling framework. The general ARDL (p,q1,q2,q3,q4) model in this case is specified as follows:

$$lnEFP_t = \alpha_0 + \sum_{i=1}^{p} \phi_i \Delta lnEFP_{t-j} + \sum_{j=0}^{q1} \beta_1 lnGI_{t-j} + \sum_{j=0}^{q2} \beta_2 lnEC_{t-j} + \sum_{j=0}^{q3} \beta_3 lnInd_{t-j} + \sum_{j=0}^{q4} \beta_3 lnUrb_{t-j} + \varepsilon_t$$

If cointegration exists among the variables, the ARDL can be re-parameterized into an error-correction representation:

$$\Delta lnEFP_t = \alpha + \sum_{i=1}^{p} \phi_i \Delta lnEFP_{t-j} + \sum_{j=0}^{q_1-1} \beta_1 \Delta lnGI_{t-j} + \sum_{j=0}^{q2-1} \beta_2 \Delta lnEC_{t-j} + \sum_{j=0}^{q3-1} \beta_3 \Delta lnInd_{t-j} + \sum_{j=0}^{q4-1} \beta_3 \Delta lnUrb_{t-j} + \phi ECT_{t-1} + \varepsilon_t$$

Where ECT_{t-1} is the error-correction term, derived from the lagged residuals of the long-run relationship. A negative and statistically significant coefficient φ confirms both cointegration and adjustment toward long-run equilibrium.

The presence of a long-run relationship is formally tested using the bounds procedure. The null hypothesis of no cointegration is H_0: $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 0$. Computed F-statistic is compared against the lower and upper critical bounds provided by Pesaran et al. (2001). If the statistic exceeds the upper bound, the null is rejected, confirming cointegration. If it falls below the lower bound, the null cannot be rejected, while values between the two bounds render the result inconclusive.

Once the ARDL model is estimated, it is essential to confirm that the assumptions of classical regression are satisfied. First, the normality of residuals is tested using the Jarque–Bera statistic, calculated as

$$JB = \frac{n}{6}\left(S^2 + \frac{(K-3)^2}{4}\right)$$

Where n is the sample size, S is skewness, and K is kurtosis. Under the null hypothesis of normality, this statistic is approximately a chi-squared distribution with two degrees of freedom.

Serial correlation in the residuals is tested with the Breusch–Godfrey Lagrange Multiplier (LM) test, which regresses the residuals on their lagged values and the original regressors. The test statistic is:

$$LM = nR^2 \sim \chi^2(p)$$

where p is the count of lagged residuals. Not rejecting the null means the residuals are serially uncorrelated.

Heteroskedasticity is tested using the Breusch–Pagan test by regressing the squared residuals on the set of regressors, with test statistic as follows:

$$LM = nR^2 \sim \chi^2(k)$$

where "k" is the number of explanatory variables. A non-rejection of the null hypothesis provides evidence of homoskedasticity.

The model specification is evaluated using Ramsey's RESET (Regression Equation Specification Error Test) test. This entails examining the regression model with increasingly higher powers of the fitted values and testing the joint significance of the variables. If the variables are found to be significant, this is an indication of potential misspecification or omitted variable bias.

The last evaluation is of coefficient stability within the sample period utilizing the CUSUM and CUSUMSQ tests developed by Brown, Durbin, and Evans (1975). These tests take the recursive tails of the errors and plot the cumulative sums against the time dimension. The null hypothesis is that the cumulative sums of the residuals fall within the 5 percent critical p-value bounds (or within them). If the plot stays between the 5 percent bounds, the hypothesis that the estimation of the parameters was stable is generated.

In short, this chapter is a description of the methodological design used to analyze the relationship between globalization and environmental sustainability in Pakistan. With a log-linear ARDL framework and supported with rigorous preliminary and diagnostic testing, the study provides a basis for the results - both valid statistically and in terms of economics. The preliminary investigation of correlations, unit root testing and cointegration analysis, and diagnostic validation added value and credibility to the investigation.

Results and Discussion

This chapter outlines the research findings from the study on globalization and environmental sustainability in Pakistan. With the ecological footprint as the measure of sustainability, the ARDL approach is used to estimate the long- and short-run relationship between globalization, energy consumption, urbanization, and industrialization. The results are presented using descriptive statistics, stationarity tests, diagnostic checks, and the ARDL estimations followed by stability and normality tests. The findings are subsequently attuned to the relevant empirical literature and economic theories.

The descriptive statistics presented in Table 4.1 outline correlations between the key variables examined in the study. The mean for the ecological footprint (EFP) is 1.24E+08 and the standard deviation is 2.76E+07, both showing significant variation over the time horizon of the study. The variation represented in EFP reflects the variability in Pakistan's environmental sustainability, especially periods of significant energy consumption and industrial growth, which, not surprisingly, put increased ecological pressure on the environment. The mean for globalization (GI) was 48.81, and the GI ranged between 38.28 and 54.75, suggesting a trend for Pakistan toward increased globalization and integration into the global economy. Urbanization (Urb) and industrialization (Ind) show low variability, consistent with their evolutionary and gradual development, with mean values of 0.338 and 0.185, respectively. The mean for energy consumption (EC) was 453.49, with a tight range meaning that energy consumption has continued to show a consistent increase over the decades of measurement. The descriptive statistics suggest that while globalization and ecological footprints show variability correlation, structural variables like urbanization and industrialization capture more gradual processes consistent with demographic and economic changes in the long run (Shahbaz et al., 2013).

Table 4.1: Descriptive Statistics

Variable	Obs.	Mean	Median	Std. Deviation	Min	Max

EFP	33	1.24E+08	1.26E+08	2.76E+07	7.87E+07	1.72E+08
GI	33	48.8183	50.2197	5.5142	38.2811	54.7585
Urb	33	0.3384	0.3388	0.0187	0.3058	0.3691
Ind	33	0.1852	0.1902	0.0108	0.1699	0.2086
EC	33	453.4953	461.4597	25.2291	397.0965	500.4320

The next step is to investigate the stationarity properties of the data. The results of unit root tests using the ADF and PP methods are presented in Table 4.2. The results indicate that the ecological footprint, globalization, energy consumption, and industrialization are all stationary after first differencing, thus, they are confirmed to be I(1). Urbanization is stationary at level I(0). These results establish that none of the variables are I(2), confirming the appropriateness of ARDL, which allows for a mixture of I(0) and I(1) variables (Pesaran et al., 2001).

Table 4.2: Summary of Unit Root Tests (ADF and PP)

Variable	ADF Statistic	Result	PP Statistic	Result	Order of Integration
Ecological Footprint	−6.31***	I(1)	−6.29***	I(1)	I(1)
Globalization Index	−5.76***	I(1)	−5.18**	I(1)	I(1)
Energy Consumption	−4.21***	I(1)	−4.21***	I(1)	I(1)
Urbanization	−1.67	I(0)	−0.96	I(0)	I(0)
Industrialization	−5.86***	I(1)	−6.14***	I(1)	I(1)

According to the multicollinearity test results shown in Table 4.3, all VIF values are comfortably below the cutoff of 10, with the overall mean VIF value being 0.25. This will not create concern about multicollinearity. This means the independent factors of globalization, energy consumption, urbanization, and industrialization, are independent explanatory variables of environmental sustainability that will produce reliable coefficient estimates (Gujarati & Porter, 2009).

Table 4.3 Variance Inflation Factor

Variable	VIF Coefficient
LGI	0.2767
LEC	0.2216
LUZ	0.3604
LID	0.1419
Mean	**0.2515**

The diagnostic tests verify the strength of the ARDL specification. Table 4.4 provides the Breusch–Godfrey test which did not show any evidence of serial correlation. Table 4.5 shows the Breusch–Pagan–Godfrey heteroscedasticity test, confirming that residuals are homoscedastic. Table 4.6 provides the Ramsey RESET test confirming that the model is correctly specified and that there are no incorrect functional forms. Overall, these diagnostics confirm that the estimated ARDL model is valid.

Table 4.4: Breusch–Godfrey Serial Correlation Test

Statistic	Value	Probability
F-statistic	0.0512	0.9503

Obs*R-squared	0.2488	0.8830

Table 4.5: Breusch–Pagan–Godfrey Heteroscedasticity Test

Statistic	Value	Probability
F-statistic	0.2061	0.9962
Obs*R-squared	4.6135	0.9827
Scaled SSR	3.2510	0.9969

Table 4.6: Ramsey RESET Test

Statistic	Value	Probability
t-statistic	0.3805	0.7066
F-statistic	0.1448	0.7066
Likelihood ratio	0.1722	0.6782

Now, focusing on the key findings, Table 4.7 provides the long-run and short-run coefficients of the ARDL model. The long-run coefficient for globalization (lnGI) is positive and statistically significant, measuring 2.804, which implies that an increase in globalization will increase Pakistan's ecological footprint. This finding supports the "pollution haven hypothesis" and the "scale effect" hypothesis, where globalization enhances trade, production, and industrial activities in developing economies, resulting in more significant degradation to the environment (Shahbaz et al., 2015). This evidence is contrary to findings in developed economies that find globalization leads to cleaner production and technology transfer (Antweiler, Copeland, & Taylor, 2001). In the case of Pakistan, the implementation of weak environmental regulations, coupled with the higher level of reliance on resource-intensive industry indicates higher levels of the ecological footprint as a result of globalization.

The positive and significant value of energy consumption (lnEC) (1.121) indicates that higher energy consumption exacerbates environmental sustainability. This finding corresponds with past literature indicating the dependence on fossil fuels increase for ecological stress (Usman et al., 2020). The reason for this robust positive effect is likely due to the continued dependence of Pakistan's energy mix on non-renewables. Urbanization (lnUrb) also demonstrates a positive and significant value (1.687). This suggests that as urban areas spread out, ecological footprint, driven by energy demand, transportation, and waste, rises (Seto et al., 2012). Industrialization (lnInd) also has a significant positive coefficient (1.178) which correlates to studies indicating early-stage industrialization exacerbates pollution and resource consumption (Zhang & Zhang, 2011). The constant term (19.537) was also statistically significant, indicating baseline pressure on environment.

The short-run dynamics further confirm these results. Globalization (ΔlnGI) has a positive significant coefficient (0.856), meaning shocks to globalization immediately exacerbate sustainability. Likewise, energy consumption (ΔlnEC), urbanization (ΔlnUrb) and industrialization (ΔlnInd) all have significant positive impacts in the short run. This suggests that, in the short run and the long run, globalization and development dynamics in Pakistan are harmful to the environment. The error correction term (ECT = -0.684) is negative and statistically significant, suggesting that deviations from the long-run equilibrium are corrected at a speed of 68% per year.

Table 4.7: ARDL Long-Run Coefficients

Long Run

Variable	Coefficient	Std. Error	T. stat	P value
ECT	-0.684 ***	0.145	-4.71	<0.01
lnGI	2.804 ***	0.648	-4.32	<0.01
lnUrb	1.687 ***	0.319	5.28	<0.01
lnInd	1.178 ***	0.199	5.92	<0.01
lnEC	1.121 ***	0.241	4.65	<0.01
C	19.537 ***	3.469	5.63	<0.01
Short Run				
Δ lnGI	0.856 ***	0.216	3.96	<0.01
Δ lnUrb	0.854 ***	0.146	5.84	<0.01
Δ lnInd	0.417 ***	0.138	3.02	<0.01
Δ lnEC	1.124 ***	0.362	2.20	<0.01

The ARDL bounds test further validates the existence of cointegration. The F-statistic (4.039) exceeds the upper critical value at the 5% significance level, confirming a long-run relationship among the variables. This means that globalization, energy consumption, urbanization, and industrialization are jointly linked with Pakistan's ecological footprint over time.

Table.5. ARDL Bound Test result

Test Statistic	**Value**	**Significance**	**I(0) Bound**	**I(1) Bound**
F-statistic	4.0392	10%	2.20	3.09
		5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

We confirmed the stability of the estimated model using the CUSUM and CUSUM of Squares tests, illustrated in Figures 1 and 2. The CUSUM and CUSUM of Squares tests showed that the blue line was within the two red lines if the 5% significance bound. The stability tests are shown in figure 1 and 2. The model is deemed stable as the blue line is between the two red lines in both figures.

Figure 1. CUSUM stability test

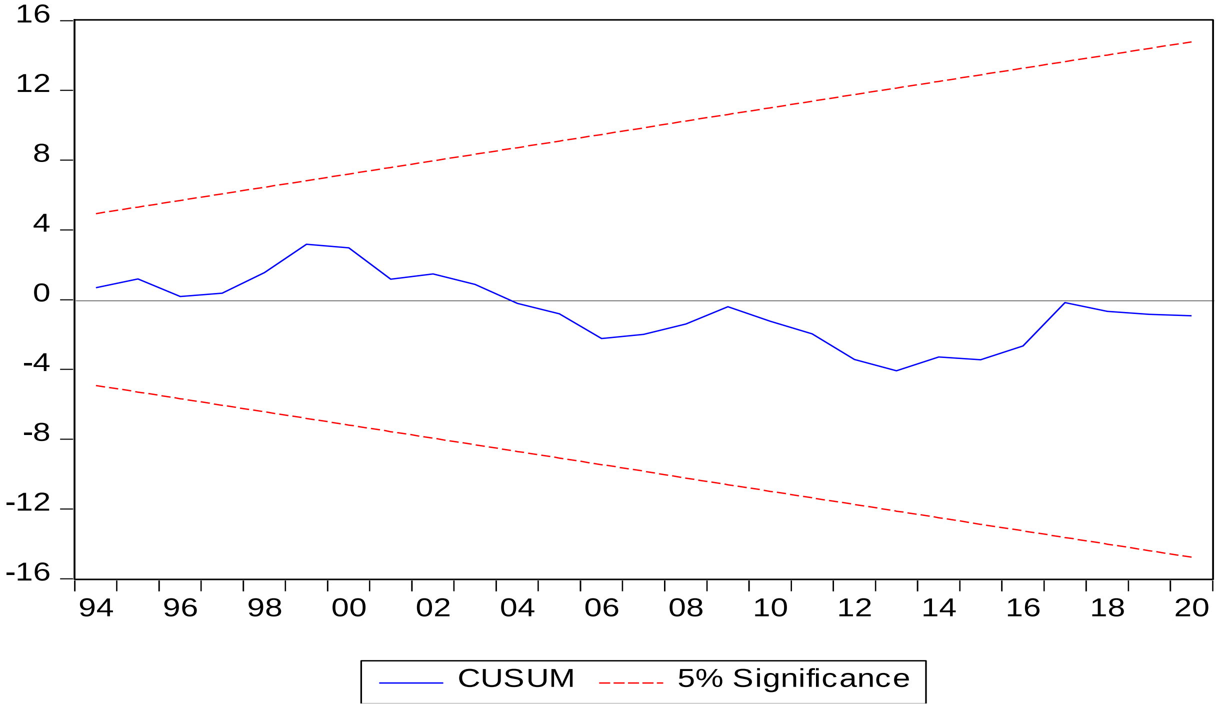
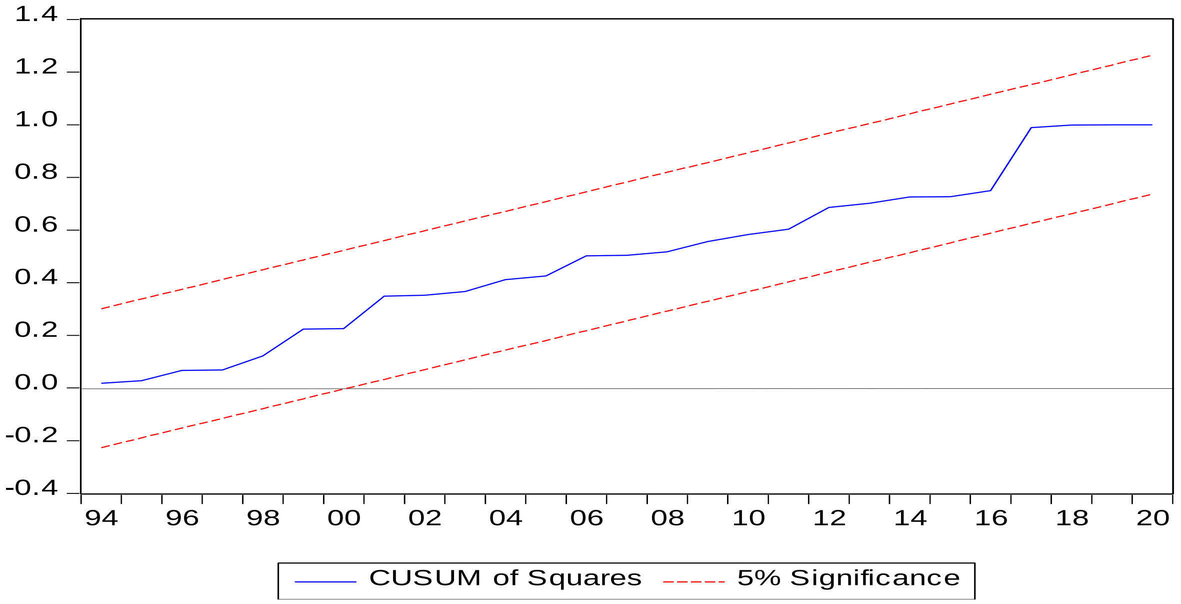


Figure 2. CUSUM of Square



Normality Test

Table 9 reveals the results of the Jarque-Bera (JB) error term normality test. The result indicates a probability value greater than 0.05 which indicates normal distribution of error term.

JB Statistic	Degree of Freedom	P-value	Decision
7.18	4	0.255	Errors are Normally Distributed

In Table 5, the JB statistic is equal to 5.78 with 5 degrees of freedom. The associated p-value is equal to

0.255. Since the p-value exceeds the conventional levels of statistical significance of 1%, 5% even and 10%, we cannot reject the null hypothesis (the residuals or error term are normally distributed). In conclusion, the residuals from the FGLS estimator are normally distributed, meeting one of the assumptions required for valid econometric inference.

Discussion

The findings of this research demonstrate the intricacy of the interaction between globalization and sustainable development in Pakistan. The positive and significant footprint globalization particularly underscores the pollution heaven hypothesis, in which developing economies with weak or no regulations attract highly pollutive industries into their economies once they begin the process of globalization (Cole 2004). In Pakistan, globalization has contributed to energy intensive exports (for example, textiles, cement) and has consequently intensified ecological stress. Certainly, this is different from the technique effect hypothesis which posits that globalization, through the introduction of cleaner technologies can increase sustainability (Antweiler et al. 2001). The findings suggest that Pakistan has yet to benefit from such technique effects, perhaps due to weak institutional capacity and/or investment in green innovation.

The positive effect of energy consumption supports the energy environment nexus literature, which has consistently shown that fossil fuel dependence, leads to environmental degradation (Shahbaz et al., 2013; Usman et al., 2020). The continued strong association still exists because of the limited degree of diversification to renewables in Pakistan. In the similar vein, urbanization's positive impact indicates unplanned urban growth, poor infrastructure, and rising emissions from transportation, consistent with Seto et al.'s (2012) findings in other developing economies. The positive influence of industrialization reflects the earlier stages of the Environmental Kuznets Curve, with industrial expansion contributing to declines in environmental well-being until countries adopt cleaner production methods (Shafik, 1994).

Overall, the implications of the results indicate that the economic globalization and development processes intensify environmental stress rather than alleviate it in Pakistan. The results could also be understood through an economic context: the scale effect dominates over the technique effect in the equation of globalization; urban transition theory shows the ecological burden of badly managed cities; and utilizing the EKC framework suggests that Pakistan is still in the upward-sloping side of the curve. The results also suggest an urgent need for policies that encourage renewable energy usage, sustainable urban planning and stronger environmental governance to move towards sustainable pathways from globalization and industrialization rather than pathways of degradation.

Conclusions and Policy Recommendations

This study investigated globalization and its impact on environmental sustainability in Pakistan using the Autoregressive Distributed Lag (ARDL) approach. Studying ecological sustainability through the lens of the ecological footprint, globalization, energy consumption, urbanization, and industrialization were all included in a model of the short- and long-run dynamics. The results lead to important understandings of how globalization and the structural evolution of the economy shape the ecology of the country.

Conclusions

The study results revealed a consistent and sizable positive association between globalization and ecological footprint in both the short-run and long-run cases. That is, globalization and together having positive economic integration contribute to increased environmental pressures in Pakistan. This suggestion is consistent with the pollution haven hypothesis and scale effect literature that suggests developing countries with weak environmental governance will incur increased ecological pressures when integrated with the globe (Cole, 2004; Shahbaz et al., 2015).

Energy consumption also emerged as another factor was another strong contributor to increased ecological footprint pressures. Pakistan's main energy source continues to be fossil fuel, and that reasoning is indicative of a strong positive relationship with energy consumption and environmental degradation in South Asian economies (Usman et al., 2020; Ang, 2007; Rasheed et al., 2023). Urbanization was also another factor that presented a significant increase in ecological pressures from ecological footprint with rapid unplanned urban development, energy consumption, and waste disposal; Seto et al. (2012) found similar results on rapid urbanization. Industrialization increased regulation of sustainability outcomes similar to the earlier examples of the Environmental Kuznets Curve (Shafik, 1994) and pollution intensive growth in emerging economies (Nasir & Rehman, 2011).

The collective results reveal that Pakistan still occupies a position where economic gains from globalization, urbanization, and industrialization have both negative consequences to the environment. This research suggests that if policies and interventions are submitted to political decisions instead of taking a proactive approach, globalization and modernization will continue to work against the long-term sustainability objectives of Pakistan.

Policy Recommendations

This study presents important considerations for policy making in Pakistan. The following are several policy suggestions:

Facilitating globalization with sustainable trade policies: As Pakistan moves forward with trade liberalization, it must be careful not to establish a pollution haven through weak environmental regulations. The environmental costs of globalization can be lessened by developing policies that regulate the export of green products, constructing green supply chain systems, and securing clean foreign direct investment (Kolk & Pinkse, 2007).

Moving towards renewable energy: Because there is a strong association between energy consumption and ecological degradation, Pakistan must move away from its dependency on fossil fuels by diversifying its energy mix while ramping up solar, wind, and hydropower projects. Making the transition to renewable energy would support SDG 7 (Affordable and Clean Energy), and Pakistan's obligations under the Paris Agreement by decreasing green-house gas emissions (World Bank, 2022).

Sustainable Urbanization: Urbanization policies should focus on providing a public transport system for urban residents, energy efficient residential and commercial buildings, and practices for waste disposal that minimize the ecological cost of future urbanization (Henderson, 2003). Urbanization plans that link to SDG 11 (Sustainable Cities and Communities) would reduce urbanization's ecological footprint (Henderson, 2003).

Promotion of Clean Industrialization: Pakistan's industrial sector needs to develop in a more modern way, with approaches such as energy-efficient technologies, more rigorous environmental standards, and industrial symbiosis. Establishing a connection to SDG 9 (Industry, Innovation and Infrastructure), and SDG 12 (Responsible Consumption and Production), would help guide the transition to more green production systems (Zhang and Zhang 2011).

Strengthening of Institutional Capacity: To reconcile globalization and sustainability requires establishing good governance, and effective implementation of regulatory regimes; enactment and enforcement of environmental law; monitoring government accountability; and engagement in global environmental governance. Building up Pakistan's environmental institutions, increasing transparency, and facilitating Pakistan's engagement in global environmental governance has potential for achieving SDG 13 (Climate Action), and reduce ecological stress (Leichenko and O'Brien 2008).

Limitations of the Study

Although the research makes a valuable contribution, it does come with a series of limitations. First, using aggregate national level data may hide the potential differentials across regions in the impacts of globalization or in the environmental impacts. Second, although the ecological footprint measure of the environment is useful and comprehensive, it cannot capture biodiversity loss, ecosystem resilience, or qualitative facets of sustainability (Wackernagel et al., 2002). Third, while it focuses on Pakistan, it does not consider the inherent spillovers across regions and countries that accompany globalization. Fourth, our time series is limited to 1990-2020, and the limited temporal range does not allow us to assess long-term structural changes.

Future Research Directions

There are various directions that future research can take in expanding on this research. First, it can disaggregate globalization into its social, economic, and political dimensions, which may produce more nuanced findings regarding sustainability. Second, looking at renewable vis-a-vis non-renewable energy utilization would produce clearer interpretations of the energy–environment nexus. Third, looking at the econometric relationships at the regional and city levels would allow for the potentially uneven impacts of urbanization and industrialization on sustainability to be appropriately captured across the spatial dimension, especially in the context of Pakistan. Fourth, comparative research across South Asian nations may be able to reveal whether Pakistan's experience is unique to a particular context – or perhaps there is a regional pattern. Lastly, future studies may incorporate indices of institutional quality and environmental policy as either mediators or moderators to investigate how governance conditions might shape relationships within the globalization–sustainability nexus.

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