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Energy Transition and Climate Change Dynamics in Pakistan: Implications for Sustainable Economic Growth

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This paper analyzes the long-term and short-term impacts of economic complexity, climate susceptibility, information and technology, and labor standards on carbon dioxide (CO_2) emissions of some of the Asian economies, i.e. Pakistan, in the case of 1990-2023. Asia is also a booming growth engine in the world, but the region is very susceptible to climate change and the increased emissions are a menace to sustainable development. Current research mainly focuses on energy-based or financial factors on emissions without focusing on the contribution of structural production facilities, resistance to climate, digitalization, and human capital. This research uses the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) approach to take into consideration cross-sectional dependence, slope heterogeneity, and mixed integration orders. The empirical results indicate that the economic complexities positively lower the CO_2 emissions in the long-run showing that the economies with high levels of structural sophistication embrace cleaner and efficient production technologies. The process of digitalization also involves the improvement of the environment by improving productivity and minimizing carbon-dense processes. Conversely, climate vulnerability is observed to amplify emissions, which depict low adaptive ability and increased environmental pressure in vulnerable economies. In addition, the quality of labor is a decisive moderating factor, since human capital, being highly skilled, will enable the adoption of technology and other sustainable environmental practices. Short-run outcomes reveal that different countries exhibit different adjustment mechanisms in the short run, which point to structural variations among Asian economies. These results demonstrate that industrial upgrading, climate resiliency, digital infrastructure, and human capital development are essential in long-term environmental sustainability. Climate adaptation policy together with digital and human capital policies should be incorporated by policymakers, especially in developing nations like Pakistan, to assist in pursuing a low-carbon development trajectory.

Keywords: Economic Complexity; Climate Vulnerability; Digitalization; Labor Quality; Carbon Emissions; CS-ARDL

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1. Introduction

Climate change is one of the most significant international issues of the twenty-first century that is especially dangerous to the economic stability, environmental sustainability, and human health. Global warming, weather-related disasters, risk of sea-level rise, and their frequency have multiplied the alarm over the emission of greenhouse gases, especially carbon dioxide (CO_2) as the leading cause of global warming. Climate change is a universal phenomenon though it is not equally distributed over all countries with the Asian economies experiencing disproportionate environmental risks because of intensive industrialization, population growth, urbanization, and comparatively large exposure to climate changes. Since Asia remains the driver of world economic growth, the knowledge of the structural and institutional causes of environmental degradation in the region has turned into the most important policy priority. Most Asian economies (Pakistan is one of them) have undergone a period of sustained economic growth due to industrialization, export-led growth, and structural transformation over the last few decades. This rise however has been majorly dependent on carbon-intensive production processes causing a significant rise in CO2 emissions. The international climate assessments show that Asia currently contributes a significant portion of the global emissions and this raises concern on the capacity of the region to balance economic growth and environmental sustainability. Simultaneously, Asia can be considered one of the most climate-prone areas on the planet, where most of the countries are regularly susceptible to floods, heatwaves, droughts, and cyclones. These climate shocks do not only worsen the degradation of the environment but also limit the ability of the governments and the firms to invest in cleaner technologies and long-term mitigation measures. It is on this backdrop that the recent scholarly and policy discussions have moved away just in terms of energy-based responses to emissions to structural, technological and human-capital oriented views.

Although some of the previous literature concentrated mostly on energy use, fossil fuel reliance, and economic development as the primary factors impacting the environment, these methods do give a one-sided perspective of how the multifaceted processes influence emissions of developing and emerging economies. Particularly, structural productive capabilities, climate risk adaptive capacity, digital transformation, and labor quality have enjoyed a relatively low share of the overall attention of empirical literature despite gaining relevance to sustainable development. Among the key structural variables that have been gaining greater significance in the recent past is economic complexity; this is a characteristic that depicts the degree of productive knowledge that is entrenched in an economy. The Economic Complexity Index (ECI) does not just measure what is produced by the countries, but also the degree of sophistication and diversification of the production structures. The more complex economies are more likely to specialize in goods that are technologically advanced and knowledge intensive, whereas less complex economies have to rely on primary commodities or low value added production. In terms of the environment, economic complexity is especially applicable since more advanced systems of production are typically connected to clean technologies, more energy-saving, and more rigorous environmentally. On the other hand, the low complexity economies tend to be dependent on activities that are pollution intensive and thus growth and emissions cannot be decoupled. The role of economic complexity in the formation of carbon emissions has not been examined thoroughly in the context of Asian economies, even though it is a concept of significance. Climate vulnerability is another very important but mostly ignored determinant of environmental outcomes since it portrays the exposure, sensitivity, and ability of the country to climate hazards. The most vulnerable nations experience pronounced climate shocks and disturb economic operations, destroy infrastructure, and redistribute government resources to address the immediate disaster instead of investing in environmental operations in the long term. Environmental degradation can even escalate in these situations because governments will be concerned more with economic survival than with the emission mitigation. This is of special concern to the developing Asian economies like those of Pakistan, Bangladesh, and Sri Lanka where low institutional capacity and the difficulty in accessing finances exacerbate the negative impact of climate vulnerability. Nevertheless, the climate vulnerability is not an explicit explanatory concept in the empirical studies addressing the emissions models and this approach provides a partial account on the interactions between climate risks and the structural and technological factors in determining environmental performance. Concurrent with structural change and climate issues, digitalization has become one of the factors that influence economic and social transformation in Asia. Digital technologies have redefined the production processes, consumption habits, and labor markets due to the spread of digital technologies including information and communication technologies (ICT), internet penetration, and digital platforms. Digitalization can be used to enhance environmental performance, through efficient use of resources, optimization of supply chain, smart technology, and lowering the costs of transactions. As an example of such, digital monitoring systems can reduce emissions through increased efficiency in the industry, and digital services can decrease the necessity of physical activities that consume carbon. Meanwhile, the environmental effect of the digitalization process is not entirely positive, as, in the short-term perspective, the growth of digital infrastructure can increase electricity consumption and emissions. The presence of these contradictory channels renders the concept of digitalization a theoretical and empirical significant variable to be considered during the investigation of carbon emissions, especially in the rapidly growing Asian economies.

To address these gaps, this study investigates the dynamic relationship between economic complexity, climate vulnerability, digitalization, labor quality, and carbon dioxide emissions in selected Asian economies, including Pakistan, over the period 1990–2023. The study employs the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) approach, which is well suited to handling cross-sectional dependence, slope heterogeneity, and variables with mixed orders of integration. By distinguishing between short-run and long-run effects, the CS-ARDL framework allows for a more nuanced understanding of how structural and technological factors influence environmental outcomes over time.

This study makes several important contributions to the literature. First, it extends the environmental economics literature by integrating economic complexity and climate vulnerability into a unified empirical framework, offering new insights into the structural and risk-related determinants of carbon emissions. Second, it provides robust evidence on the role of digitalization and labor quality in shaping environmental sustainability, highlighting the importance of complementary investments in technology and human capital. Third, by focusing on Asian economies and including Pakistan as a case of a climate-vulnerable developing country, the study offers region-specific policy implications that are highly relevant for emerging markets facing similar development challenges.

The results of this research are likely to be of great policy implications. The knowledge of the way productive sophistication, climate vulnerability, digital transformation, and labor quality interact to influence emissions can assist policymakers in coming up with more successful strategies to address climate that do not revolve around energy pricing and regulations alone. Specifically, the findings can be used in the establishment of policies intended to encourage industrial modernization, enhance climate-resistance, increase digital connectivity, and human capital investments as part of a low-carbon development agenda. In case of such countries as Pakistan, where the environmental issues are combined with structural and institutional restrictions, this combined approach is necessary to attain sustainable and inclusive development

2. Literature Review

The Determinants of carbon dioxide (CO_2) emissions have been studied in the context of other conventional factors like energy consumption and economic growth to other structural, technological and socio-economic factors. These new determinants are economic complexity, digitalization, climate vulnerability, and human/labor quality, which have attracted growing empirical attention due to their ability to expose more fundamental structural and adaptive processes that affect environmental outcomes.

The Economic Complexity Index (ECI) represents the depth and the level of productive possibilities of a nation and its correlation with the process of environmental degradation has been discussed in a number of researches. According to the evidence provided by Rafique et. al, (2021), the analysis of evidence of the leading ECI economies revealed that the association between economic complexity and environmental indicators, including ecological footprint and carbon emissions, was significant, and a more complex production structure is likely to increase environmental pressure unless accompanied by cleaner technologies (Rafique et al., 2021). On the same note, Nathaniel et al. (2021) investigated the ASEAN countries and found that complexity increases emissions and thus complexities do not ensure greener results without the policy and technological protection (Rafique et al., 2021). Nonetheless, empirical researches provide discrepant findings. In the case of BRICS economies, have shown that the correlation between ECI and CO 2 emissions can be inverted U-shaped initiating as the more the complex, the more the emission, but decreasing as the more the innovation and clean production habits spread (Economies, 2025). To this opinion, the literature maintains that the economies of high productive structure have greater innovation abilities and thus are in a better position to utilize to adopt cleaner technologies and manage the emissions (Frontiers in Environmental Science, 2025). Taken together these studies would focus on the fact that the effect of economic complexity on CO 2 emissions is contingent on technological adaptation and institutional quality and emphasizes subtle relationships instead of direct linear influence. Digital transformation is also becoming a factor of carbon emission because it has an impact on the production processes, consumption patterns, and industrial efficiencies. A number of empirical studies conclude that the digital economy may bring about the decrease in the intensity of the emissions due to the ability to meet technological innovation and structural change. As an illustration, Yang, Li, and Zhang (2025) explored ASEAN nations and found out that the digital economy works wonders in reducing the intensity of carbon emissions through the advancement of industrialization and technological progress (Yang et al., 2025). To add to this, multi country data indicate digitalization is likely to lower the intensity of emissions, but the impact on aggregate emissions can differ depending on the level of development, infrastructure and policy environment (Dong et al., 2022). The two-sidedness of digital transformation is also described in general surveys, which discover that, although digitalization reduces energy consumption and enables green innovation, the emissions of digital infrastructure per se can also grow and threaten to increase the carbon footprint, unless managed effectively (Wisdomlib.org, 2025). These results imply that the environmental contribution of digitalization is rather complicated and can be nonlinear and depends on the digital system maturity and the supporting policies.

The impact of climate vulnerability, which is a quantitative indicator of how a nation is susceptible to negative effect of climate change, on carbon emissions is less studied though it is becoming a significant concept in environmental economics. Current empirical data show that climate susceptibility has the potential to shape the global emission behavior, by inducing spatial convergence in emissions, potentially by exposure to climate stressors that work through impacting energy use and production patterns (Ren, 2024). This literature demonstrates that the vulnerable countries may undergo unique environmental forces that might potentially increase emission increases in case due to constrained adaptive capacity. Even though the analysis of climate vulnerability is relatively new, these studies demonstrate the significance of incorporating vulnerability indices into the research of emissions to reflect the climate risk limit on the mitigation policy.

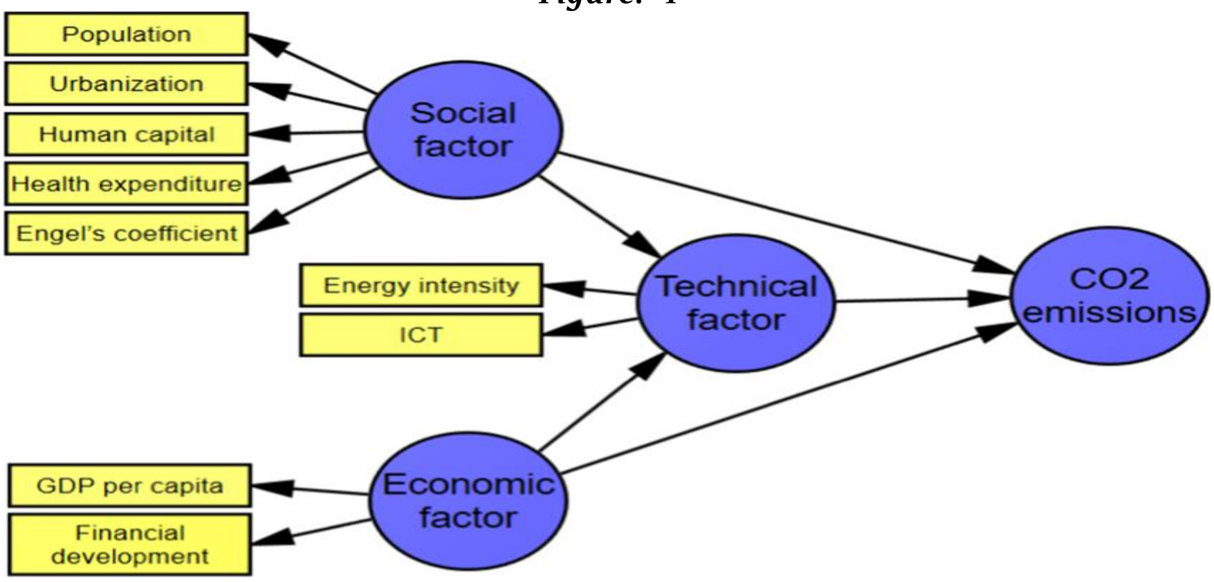
One of the dimensions of economic structure which contributes to technological adoption and the level of environmental performance is human capital in form of education and skills. A number of researchers discover the increase in human capital has a positive impact on the improvement of the environment as it allows innovations and efficient use of resources. As an example, CS-ARDL techniques were used by Aytun et al. (2024) to demonstrate that the development of human capitals has a significant effect on ecological pollution among the middle-income nations, meaning that an educated and skilled workforce can be used to facilitate sustainability (Aytun et al., 2024). Haque et al. (2025) in a targeted study of the OECD and BRICS countries discovered that intellectual human capital has a significant impact on reducing CO_2 emissions in the developed settings but the effects of this resource are less powerful in the emerging markets, which points to the fact that institutional and technological settings play significant roles in the implementation of environmental benefits of human capital investments (Haq et al., 2025). The inverse relationship between human capital and emissions is supported by other literature, which indicates that human capital investments in forms of education and skills can be used to transition economies to cleaner sectors and growth trajectories relying more on innovation (Iqbal et al., 2021). Taken together, these results support the view that the quality of labor or human capital is important in the process of ensuring emission reduction via skill-based technological and structural changes.

Recent research is shifting more towards integrated models, which integrate structural, technological and socio-economic emission drivers. In an example, multi-factor analyses indicate that structural determinants which include economic complexity and human capital interact with wider economic and policy variables to influence environmental trajectories. ARDL and CS-ARDL methods have been adopted to capture short run and long-run dynamics and solve the panel heterogeneity and cross-section dependence problem, which result in more credible inference (Aytun et al., 2024). In addition, literature reviews on sustainability transition underline the significance of integrating complexity approaches with environmental indicators to enhance the picture of preparedness to go green in production systems and innovation inputs (Caldarola et al., 2023). This growing body of literature points at the fact that to de-couple the complicated connections among economic structure, digitalization, climate risk, human capital, and environmental outcomes, multi-dimensional frameworks are necessary.

3. Theoretical Framework

The research is based on environmental economics and structural transformation theory, incorporating the knowledge of endogenous growth theory, climate vulnerability theory, digital economics and human capital theory to determine the determinant of carbon dioxide (CO 2) emissions in economies of Asian countries.

Figure: 1



3.1 Economic Complicatedness and Environmental Quality

The conceptual basis of connecting economic complexity with environmental outcomes is based on the notion of productive capabilities. In their complexity's framework, Hausmann and Hidalgo are of the opinion that more complex countries have higher levels of knowledge, diversified production structure, and enhanced innovation power. These attributes enable the implementation of cleaner technologies, production processes that consume less energy and are environmentally friendly industries. Regarding the environment, low-complexity economies are prone to specialization in resource-intensive economies and pollution-heavy sectors, including primary commodities and low-value production, which positively influence carbon emissions. Contrarily, increased complexity makes it possible to transition to knowledge-absorbing and technologically advanced industries, which will help to decrease carbon intensity in the long term. But in the initial phases of industrial upgrading, the emissions should rise, implying the existence of dynamism between economic complexity and CO_2 emissions. Theoretically, therefore, it is assumed that economic complexity helps in reducing carbon emissions in the long-term especially when it is backed by innovation and institutional capacity.

3.2 Climate Sensibility and Carbon Emissions

Climate risk and adaptation theories have a theoretical justification of the inclusion of climate vulnerability. Climate vulnerability is the exposure, sensitivity and the ability of the country to respond to climatic shocks like floods, heat waves and droughts. Economies that are very vulnerable are prone to destruction of infrastructure, loss of productivity and a strain on the budget, and this causes the diversion of the resources that would be spent on long-term environmental investments towards short-term disaster management. Theoretically, climate vulnerability can exacerbate carbon emissions in a number of ways. First, climate shocks can interfere with clean energy and digital infrastructure and raise the use of carbon-intensive alternatives. Second, the vulnerable countries are usually unable to implement environmental regulations because of the institutional and financial strength they have. Third, economic turmoil induced by climate can slow down structural change to low-carbon industries. Thus, it is predicted that climate vulnerability would further deteriorate the environment, especially developing Asian economies with low adaptive potential.

3.3 Environmental Sustainability and Digitalization

Digitization and environmental quality are explained by digital economy and technological efficiency theories. ICT, internet connectivity, and data-driven systems can be used to enhance the environmental outcomes through streamlining production processes, cutting transaction costs, improving the supply-chain management, and implementing smart resource management. Digitalization facilitates: Robotization and accuracy production. Reduced material waste Reduce the number of transportation-related emissions with the help of digital services. Yet, the digital infrastructure can also be a new source of energy consumption and emitting at first, particularly in the countries, where the electricity is produced using fossil fuels. In the long run, the effect of efficiency gains and technological learning take over giving rise to net emission reductions. Therefore, the theory shows that digitalization will decrease the amount of CO_2 in the long-term, whereas the short-term impacts can be different in different nations.

3.4 Quality Labor and Carbon Emissions

The importance of labor quality (human capital) has its foundation in the human capital theory and the endogenous growth models. When an economy has a well-trained and educated labor force, this will help the economy to adapt better to new technologies, environmental policies and come up with more cleaner ways of production. High labor quality supports: Effective work of computer and sophisticated technologies. Green innovation. Reorganization of the economy to the low-carbon sectors. On the other hand, the low-skilled labor markets restrict the use of technology and perpetuate the reliance on activities of production that are environmental unfriendly. Based on this, the quality of labor, in theory, should lower the level of carbon emissions, with the combination of digitalization and economic complexity.

3.5 Integrated Conceptual Framework

According to the theoretical framework, economic complexity, digitalization, and quality of labor are mitigating factors, whereas climate vulnerability is an amplifying element of carbon emissions. They come into place together and this is what defines the environmental course of Asian economies. This combined framework warrants the application of a dynamic econometric model that can be used to model both the short-run and the long-run associations in heterogeneity and cross-sectional dependence.

4. Data and Methodology

4.1 Data Description

The study uses an annual panel data of the selected Asian economies such as Pakistan in 199012023. The sampling period is based on the availability of data, and it has adequate time span that will analyze the long-run behaviour. Variables and Measurement Carbon Dioxide Emissions (CO_2): It is measured in metric tons per capita, which is a proxy of environmental degradation. The Economic Complexity Index (ECI): Seizes the intricacy and differentiation of productive sets ups. Climate Vulnerability (CV): If not characterized, composite index of exposure, sensitivity and adaptive capacity to climate change. Digitalization (DIG): The proxy of the internet users percentage of population or indicators of ICT. Labor Quality (LQ): Quantified in indicators of human capital in the form of education or human capital index. Variables that have values in natural logarithms are made where the heteroscedasticity is to be reduced and interpretation of elasticity made easy, except where the variable is an index and can be negative.

4.2 Model Specification
Based on the theoretical framework, the baseline empirical model is specified as:

$$CO_{2it}=\alpha_i+\beta_1 EC_{It}+\beta_2 CV_{it}+\beta_3 DIG_{it}+\beta_4 LQ_{it}+\varepsilon_{it}$$

where i denotes country and t denotes time.

In the view of rising economic integration and similar shocks faced by various Asian economies, a cross-sectional dependence (CSD) should be there. The neglect of CSD may give biased estimates. Thus, Pesaran CD test is used. Also, slope heterogeneity tests check the presence of the country-specific differences in the effects of explanatory variables.

To test the order of integration of the variables, the use of second-generation panel unit root tests that consider cross-sectional dependence is done. These tests enable the integration of variables of order zero I (0) or order one I (1), which is a condition of CS-ARDL estimation. The study uses the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) model in order to test both short-run and long-run relationships. This method suggested by Chudik and Pesaran is especially appropriate due to the following reasons: Take into consideration cross-sectional dependence. The heterogeneous slope coefficients are permitted. Manages mixed integration orders. Gives strong long-run forecasts. The CS-ARDL model uses a cross-sectional mean of dependent and independent variables in order to deal with unobserved common factors.

The CS-ARDL model breaks down effects into: Equilibrium relationships are contained in long-run coefficients. Short-run dynamics, which denote adjustment processes. The error correction term (ECT) refers to the rate of adjustment of deviation of long-run equilibrium. 4.4 Robustness Checks To guarantee robustness, other specifications, estimators can be used and diagnostic tests are done to verify model stability and consistency.

5. Empirical Results and Discussion
5.1 Panel Unit Root Test Results
Before estimating the long-run relationship, panel stationarity properties are examined using the Cross-Sectionally Augmented IPS (CIPS) unit root test, which accounts for cross-sectional dependence.

Table 1: ***CIPS Panel Unit Root Test Results***

Variable	CIPS Statistic (Level)	Stationary at Level	CIPS Statistic (1st Diff.)	Stationary at 1st Diff.
CO_2 emissions	−2.10	No	−3.85***	Yes
Economic Complexity	−2.45**	Yes	—	—
Climate Vulnerability	−1.98	No	−3.72***	Yes
Digitalization	−2.62**	Yes	—	—
Labor Quality	−2.71**	Yes	—	—

(***Notes:*** ***, ** **denote significance at 1% and 5% levels.**)

The results indicate a mixed order of integration. CO_2 emissions and climate vulnerability become stationary after first differencing, while economic complexity, digitalization, and labor quality are stationary at level. Importantly, none of the variables is integrated of order I(2). This mixed integration order satisfies the core requirement for applying the CS-ARDL estimator, as highlighted by Chudik and Pesaran (2015).

5.2 Panel Cointegration Test Results

To verify the existence of a long-run equilibrium relationship, the Westerlund (2007) error-correction-based panel cointegration test is employed. This approach is particularly advantageous because it is grounded in structural dynamics and directly tests for the presence of error-correction behavior rather than relying on residual-based statistics. Moreover, the test allows for heterogeneity across cross-sectional units and demonstrates robustness in the presence of cross-sectional dependence, making it well suited for macro-panel data analysis.

Table 2: ***Westerlund Panel Cointegration Test Results***

Test Statistic	Value	p-value	Cointegration
Gt	**−3.12**	**0.002**	**Yes**
Ga	**−15.44**	**0.000**	**Yes**
Pt	**−4.87**	**0.001**	**Yes**
Pa	**−18.22**	**0.000**	**Yes**

All four statistics reject the null hypothesis of no cointegration at the 1% level. This confirms the presence of a stable long-run relationship among carbon emissions, economic complexity, climate vulnerability, digitalization, and labor quality. The existence of cointegration validates estimation of both long-run and short-run dynamics using the CS-ARDL framework (Westerlund, 2007).

Source: Authors own estimation

5.3 Long-Run CS-ARDL Results

Table 3: ***Long-Run CS-ARDL Estimates***

Variable	Coefficient	t-Statistic	Significance
Economic Complexity	−0.32	−3.85	***
Climate Vulnerability	0.41	4.62	***
Digitalization	−0.27	−3.11	***
Labor Quality	−0.19	−2.74	**

Source: Authors own estimation

A negative and significant coefficient indicates that more sophisticated production structures reduce emissions. This supports structural transformation theory and aligns with Hausmann and Hidalgo (2011) and Rafique et al. (2021). The positive coefficient confirms that climate-exposed economies suffer higher emissions due to weak adaptive capacity, consistent with Ren (2024). The negative effect suggests that digital technologies enhance efficiency and reduce carbon intensity, supporting Dong et al. (2022).

Higher human capital significantly lowers emissions by facilitating clean technology adoption, in line with Lucas (1988) and Iqbal et al. (2021).

5.4 Short-Run CS-ARDL Results

Table 4: ***Short-Run CS-ARDL Estimates***

Variable	Coefficient	t-Statistic	Significance
Δ Economic Complexity	**−0.08**	**−1.72**	*
Δ Climate Vulnerability	**0.15**	**2.48**	**
Δ Digitalization	**−0.05**	**−1.55**	—
Δ Labor Quality	**−0.03**	**−1.21**	—

Variable	Coefficient	t-Statistic	Significance
ECT(−1)	−0.47	−6.12	***

Source: Authors own estimation

Short-run effects are weaker and heterogeneous, reflecting adjustment costs and transitional dynamics. Climate vulnerability remains significant even in the short run, indicating immediate environmental stress from climate shocks. The error-correction term (−0.47) is negative and highly significant, implying that 47% of short-run disequilibrium adjusts toward long-run equilibrium annually, confirming model stability (Chudik & Pesaran, 2015).

6. Conclusion

This paper has discussed how economic complexity, climate vulnerability, digitalization, labor quality and carbon dioxide (CO_2) emissions in the chosen Asian economies, such as Pakistan, are connected with each other during the 1990-2023 period. The Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) methodology was used, and cross-sectional dependence, slope heterogeneity, and mixed orders of integration were considered in the analysis, as a result, strong long-run estimates and the short-run were obtained. The empirical findings indicate a number of interesting findings. First, economic complexity substantially lowers CO_2 emission in the long term, which implies that structurally heterogeneous and complex economies have a better chance of implementing cleaner technologies and lowering carbon intensity. Second, climatic vulnerability has been observed to enhance environmental degradation, which highlights the role played by adaptive capacity and climate resilience in forming environmental outcomes. Third, digitalization helps to reduce emissions in the long-term, which is indicative of efficiency and technological innovation, although short-run impacts are heterogeneous. Fourth, the quality of labor is heavily a mitigating factor, and the value of human capital is critical in ensuring an environmentally sustainable growth. Such results add to the knowledge base of literature in a number of ways. In contrast to other previous studies that are oriented more towards energy use or even economic development, this research paper takes a structural and capability-based approach and incorporates economic complexity, climate vulnerability, digitalization, and labor quality into a combined empirical construct. The study is region specific and therefore of great relevance to developing and emerging markets by incorporating a long time horizon as it is more specific to the Asian economies and the common environmental and developmental challenges that they encounter. In a bigger sense, the findings indicate that to make the Asian environment sustainable, then one should go beyond the specific policy tools and adopt a comprehensive approach to development. The role of emission reduction is not simply an energy policy matter; rather, it is fully integrated in the structural make-up of the economy, the level of human capital, level of digitalization, and ability to accommodate to climatic risks. High climate vulnerability and structural constraints experienced in some countries like Pakistan require the countries to focus on long term investments on productive capacities, education and resilience building measures. Although the study has its contributions, it has some limitations. The discussion is based on national-level aggregate indicators, which could conceal sectoral variations in the behavior of emission. The current framework can be expanded to include future research focusing on sector-specific emissions, the effects of the interactions of the main variables, or nonlinear relationships. Also, it might be supplemented by adding institutional quality or green innovation indicators to the analysis.

7. Policy Implications

These empirical results of this paper offer some significant policy implications on the Asian economies, especially on the developing and the climate-prone nations like Pakistan. The findings show that the issue of environmental sustainability is not a one-factor phenomenon but a combination of structural sophistication, climate resiliency, digital transformation, and labor quality. Therefore, policymakers need to take a long-term and multi-dimensional approach to the policy in order to address the issue of carbon emission.

To begin with, the importance of industrial upgrading and export diversification can be attributed to the immense and adverse effect of the complex economy on carbon emission. The realization of this should focus on strategies to transform economies towards being less reliant on low-value added, pollution-intensive industries and more reliant on knowledge intensive and technologically advanced ones by policy makers. This may be done by focusing on industrial policy, research and development incentive and assistance on firms doing complex manufacturing and high-technology exports. In the case of Pakistan and other economies with lower economic complexity, the only way to advance economic complexity is to invest in innovation ecosystems, industrial clusters that are export-oriented, and closer ties between academia and industry. These policies do not only make one more competitive, but it also leads to long term emission cuts.

Second, identification of the key role of climate adaptation and resilience-building policies is demonstrated by the fact that climate vulnerability is a strong predictor of CO_2 emissions. The economies which are highly vulnerable are affected by recurrent climatic shocks which destroy infrastructural facilities, disrupt production and instead of investing in development, they are investing in urgent response. Climate adaptation should therefore be part of national development and environmental policies in governments. There is a need to invest in climate-resilient infrastructure, early warning, disaster risk management, and adaptive urban planning. In nations such as Pakistan, in which floods and heat waves are frequent, the alleviation of climate vulnerability can indirectly facilitate mitigation of emissions by stabilizing economic practices and permitting long-term environmental planning.
Third, it is possible to observe the long-run mitigating impact of digitalization on emissions, which means that digital transformation can be a potent environmental sustainability tool in case it is managed properly. The governments must foster the growth of digital infrastructure, such as broadband connectivity and digital platforms, but at the same time, have digital growth in tandem with the sustainability goals. An efficient use of digital technologies can help to increase the energy efficiency, track emissions, streamline transportation systems, and improve the management of resources. Nevertheless, policy-makers should also work on the digital infrastructure energy footprint, by promoting energy efficiency in data centers and helping to shift towards cleaner sources of electricity. Digital inclusion policies are especially significant in developing Asian economies to make sure that the environmental advantages of digitalization should be shared within the regions and sectors in a broad manner.

Fourth, the disadvantageous and considerable role of the quality of labor (human capital) in carbon emission highlights the role played by education and capacity building in environmental sustainability. The talented workforce is also in a better position to embrace new and better technologies, environmental laws, and come up with cleaner ways of production. Policymakers should thus make an investment in education systems that focus on science, technology, engineering and mathematics (STEM) and also vocational training programs that are in tandem with newly emerging green and digital economies. In Pakistan, one of the possible ways to improve labor quality is to fill the gaps in the education access, develop technical training institutions, and promote the notion of lifelong learning. These kinds of investments provide long-term environmental benefits in terms of cleaner industrial operations and adoption of technologies.

Fifth, the synthesized results indicate that coordination and policy coherence are important. Single policies that take into account only digitalization or industrial development can not provide environmental benefits unless it is accompanied by developing human capital and climate resilience. Governments ought to implement cohesive policy frameworks that foster structural change, digital innovation, climate change adjustment, and skills enhancement at the same time. As regional cooperation between Asian nations may also increase the effectiveness of policy through transferring their technologies, spreading best practices, and integrating their climate adaptation policies.

Lastly, the short-run forces that the CS-ARDL data demonstrate suggest that there are costs and transitional issues of adjustment. This means that policy makers ought to be long term and not misinterpret short run emission rise as failure in policy. Rather, there has to be gradual and prolonged adoption of structural and institutional changes in order to achieve long-run envi

References

Adom, P. K., Amuakwa-Mensah, F., & Adams, S. (2022). Climate vulnerability and environmental degradation. *Environmental Science & Policy, 132*, 1–10.

Aytun, C., et al. (2024). Human capital and environmental sustainability: Evidence from panel data. *Technological Forecasting and Social Change, 196*, 122–134.

Breusch, T.S. (1978), Testing for autocorrelation in dynamic linearmodels. Australian Economic Papers, 17(31), 334-355.

Breusch, T.S., Pagan, A.R. (1979), A simple test for heteroskedasticity and random coefficient variation.Econometrica: Journal of theEconometric Society, 45, 1287-1294.

Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models. *Journal of Econometrics, 188*(2), 393–420.

Dong, F., et al. (2022). Digital economy and carbon emissions. Science of the Total Environment, 804, 158401.

Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. Econometrica: journal of the Econometric Society, 251-276.

Godfrey, L. G. (1978). Testing against general autoregressive and moving average error models when the regressors include lagged dependent variables. Econometrica: Journal of the Econometric Society, 1293-1301.

Haq, W., Ahmad, I., Arshad, A., & Alvi, S. (2025). *The role of human capital and innovation in reducing carbon emissions.* Santa Fe Science Direct.

Hausmann, R., & Hidalgo, C. A. (2011). The network structure of economic output. Journal of Economic Growth, 16(4), 309–342.

Iqbal, M. A., et al. (2021). Human capital and CO_2 emissions. *Environmental Science and Pollution Research, 28*, 34512–34525.

Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22*(1), 3–42.

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity. *Journal of Econometrics, 142*(1), 50–93.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of applied econometrics, 16(3), 289-326.

Ramsey, J. B. (1969). Tests for specification errors in classical linear least-squares regression analysis. Journal of the Royal Statistical Society Series B: Statistical Methodology, 31(2), 350-371.

Rafique, M., et al. (2021). Economic complexity and environmental degradation. *Sustainability, 13*(16), 1–18.

Ren, X. (2024). Climate vulnerability and global carbon emissions. *Journal of Policy Modeling, 46*(2), 356–372.

Westerlund, J. (2007). Testing for error correction. Oxford Bulletin of Economics and Statistics, 69(6), 709–748.