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Synergies between Trade Openness, HVAC Business, and Climate Change Mitigation in China the Future of HVAC Business in Pakistan: Prioritizing Air Quality in Sustainable High-Tech Infrastructure

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Abstract
The study examines how the HVAC sector fights CO2 emissions through green programs, technical advances, and renewable energy. The study examined the relationships between sustainable funding, sustainable technology, renewable energy, and CO2 reduction using modern panel data estimation methods including CUP-FM, CUP-BC, and DSU. Error correction-based panel cointegration and second serration panel unit root tests were performed on 18 nations' 2005–2023 data utilizing NARDL's nonlinear framework, CADF, and CIPS. Sustainable financing strategies assist energy-efficient technologies and other sustainable activities, raising asymmetric coefficients. Innovation in sustainable technology minimizes CO2 emissions and boosts economic growth. Renewal energy improves HVAC business and reduces CO2 in low-carbon economies. The analysis suggests that government expenditure on renewable energy sources and green energy technology may reduce CO2 emissions.
Keywords: *HVAC Business, trade openness, renewal energy, sustainable technology advances, CO_2 emissions, NARDL*

1. Introduction

The fighting climate change and reducing CO2 emissions requires SDGs and Paris Agreement. Financial inclusive prioritizes renewable energy, greenhouse gas reduction, and sustainability [1], [2]. Paris Agreement and SDG priorities include CO2 reduction, HVAC business, renewable energy investments, technological advances, and sustainable practices across all businesses [3], [4]. The initiative evaluated worldwide transition using SDGs and Paris Agreement.Supports sustainability, HVAC business, climate change mitigation, and low-carbon economy [5], [6]. Carbon emissions must be balanced by removal or decrease to address global climate change. CO2 decrease has several effects on HVAC business [7]. CO2 reduction instantly decreases greenhouse gas emissions. Renewable energy may drastically reduce a nation's carbon footprint [8]. It lowers climate change's sea level, weather, and temps carbon reduction improves air and water quality. Trade ecosystems and population health benefit from [9]. Reduced CO2 promotes Clean and Sustainable Technology investments in HVAC business. Green finance redistributes green project funds. Energy efficiency, renewable energy, and sustainable transportation create jobs [10]. Green technology may boost the economy due to its efficiency and affordability in HVAC business. Energy security, resilience, and lower costs enhance the economy [11]. Long-term advantages can come from green finance funding pollution management and environmental protection locals trade openly [12]. CO2's global political influence lessens. Countries regulate emissions and encourage green investments to minimize CO2. Carbon emissions help renewable energy, sustainability, and energy efficiency. HVAC business taxes [13]. HVAC business must manage expansion, commerce, and urban CO2 reduction. Oil price volatility influences energy source cost competitiveness [14]. Oil price increases may boost renewable energy, and environmental fees are crucial to government revenues in HVAC business. Open finance encourages green investments and behaviour [15]. Financial investment capacity to adopt energy-efficient and renewable energy technologies and expedite CO2 reduction often coincides with per capita income [10]. Governments may promote carbon-neutral activity with funding, transparency, and incentives [12]. Green finance supports transaction transparency, green power, energy productivity, and economic behaviour to reduce CO2 emissions [7]. Green finance is essential for global CO2 reduction and sustainability [16]. Green innovations should be funded to reduce CO2 emissions. This characteristic affects some manageability, and CO2 reduction from development in GDP [15]. Low-carbon innovation incorporate energy-productive arrangements and sustainable power quickly lessen net discharges, working on monetary considerations of CO2 decrease [17]. Through monetary incorporations and green ecological safeguarding, the HVAC business, this innovation decreases natural and energy requests [18]. According to [9], the environmentally friendly power is pivotal to CO2 decrease. Supplanting of dirtying energy sources with spotless, maintainable choices diminishes fossil fuel byproducts essentially [8]. Exchange openness speculations sustainable power sources advance long haul CO2 decrease in countries and networks, encouraging a cooperative connection between energy age and natural preservation [19].

2. Literature Study

A handful of nations are making efforts to establish a workable monetary system that prioritizes economic growth, social welfare, and environmental protection [20]. One way to promote a more equitable monetary shift is to strengthen green finance [21, 22]. According to the World Financial Transparency Exchange's Green Venture Study, green speculations include renewable energy, efficient use of energy, sustainable transportation, and robust trash collection in HVAC business [23]. The positive impact of controllable finance on the economy was discovered in HVAC business [24]. These findings provide evidence that practical funding can hasten the transition to a low-carbon future [24]. Financial factors and decent progress were aided by green currency [25]. Green subsidizing increases carbon capture speculation and development while minimizing fossil fuel byproducts [7]. In order to reduce carbon dioxide emissions, several countries' direct currency exchanges must include green finance in HVAC business. According to [12], directs societal resources towards promoting environmentally friendly outcomes in HVAC business, allocates more funds to pollution control and natural assurance, reduces fossil fuel byproducts per output unit, and expands the territorial carbon evacuation limit, resulting in reduced CO2 emissions. [16] is defined as investments in environmentally safe, sustainable development initiatives; its growth can help reduce emissions of carbon dioxide in HVAC business. Realistic funding reduces pollution on a national scale [26]. Reduce emissions of carbon dioxide by 0.103% by increasing the use of renewable energy sources by 1%. [27] shows that energy efficiency and green currency reduce waste from fossil fuels without slowing down economic growth by HVAC business. Green finance and RE speculations can aid in the interchange of transparency, climate, and sustainable course of events [14]. The greatest monetary solution to minimize byproducts of fossil fuels [28], is green finance in HVAC business. Focusing on the potential of controllable finance in CO2 reduction, [29] in China discovered that manageable finance increases energy productivity in the energy mix. Another study [30] revealed monetary considerations and public-private speculation through green finance. Possible financial incentives for CO2 mitigation led to drop in CO2 levels. Related findings were studyed in reference [31]. Financial incorporations and CO_2 reductions are harmed by EPU, according to the OECD [16]. In order to guarantee the security of energy and resources and to lessen environmental degradation, HVAC businesses are essential [32], [33]. In addition to improving environmental conditions, STI increases energy trade openness, a major economic driver in HVAC business. The enormous impact of STI on CO_2 reduction was investigated by Hung [34]. Data from Turkey and China reveal the significance of green technology in reducing CO2 emissions [35], [36]. Cutting down on carbon emissions requires green financing and renewable energy [37]. Sustainable technological advances are very effective in decreasing CO2 emissions [38]. Countries with strong economies are the ones that benefit most from long-term technical advancements [39]. Sustainable technical advancements lower emissions of greenhouse gases [40]. Mechanical advancements can reduce carbon dioxide emissions, which can help build energy frameworks and support sustainable development in HVAC business. These improvements, emissions from fossil fuels have dropped significantly in modern economies. According to [15] the development and spread of low-carbon technologies directly reduce emissions, which in turn reduces CO2 [17]. [13] state that advances in green innovation may indirectly affect the efficacy of byproducts from fossil fuels by influencing economic growth and urbanisation. According to [41], advancing green innovation is necessary to minimize byproducts of fossil fuels in HVAC business. Reducing energy and environmental stresses, green innovation development centers priorities green ecological assurance. According to [10] shows that emissions from fossil fuels may be reduced via aggressively pursuing green innovation development. In their illuminating study, [18] found that controllable innovation development levels are trending upward, but that Western China has typically poor advancement viability of HVAC business. The cooperative relationship between green finance and a sustainable turn of events is emphasized in [42], which proclaims. Energy from renewable sources, such as wind, solar, hydro, and thermal power, contributes to lowering carbon emissions and moving the goal of CO2 reduction forward [44]. Governments, organizations, and individuals throughout the world are making trade openness and HVAC business a priority due to the considerable contribution of CO2 emissions to global warming [45].

3. Research Methodology

3.1 Data Collection

The study has collected the data from 2005 to 2023 the ten countries having high rate of CO_2 emission. The data related to dependent variable "CO_2 emissions" has been collected from World Bank database https://databank.worldbank.org.com. The dependent variables such as "sustainable finance (SF), sustainable technology innovations (STI), renewal energy (RE), HVAC Business (HB), and trade openness (TO)," data has been from World Bank database https://databank.worldbank.org.

3.2 Research Design

Green financing, technological innovation, and renewable energy are examined to see how they reduce CO_2 emissions in the top ten CO_2-emitting countries. Trade openness and HVAC Business considerably affect carbon emissions [56]. HB and TO affect CO_2 emissions differently depending on the economy. Therefore, equation (1) has been extended to include FI and TO is developed as:

$$CO_2 = SF, STI, RE, HB, TO \qquad (1)$$

Where SF, RE, STI, TO, and HB represent CO_2 reduction, sustainable finance, sustainable technological innovation, renewal energy, HVAC Business, and trade openness.

3.3 Econometric Model Explanation

As a theoretical framework, the STIRPAT and IPAT models are utilized to evaluate the effects of human activity on the environment. Here is the mathematical equation for the IPT model:

$$I = P \times A \times T \qquad (2)$$

Water pollution and CO_2 decrease are "I" environmental consequences. Population, "P", is the number of people in a region. "A" symbolizes per-person consumption and economic activity, or affluence. Effectiveness and sustainability of manufacturing and consumption technologies depend on trade openness. Population expansion, affluence-induced consumption, and technology efficiency affect the environment. Equation (4) might be rewritten using log formation:

$$\ln I = a + b\ln P + c\ln A + d\ln T + \varepsilon \qquad (3)$$

Trade openness is the flexible and open STIRPAT technique permits research-based dynamic control factor modifications. The above equation with explained and explanatory variables becomes:

$$lnCO_2 = \alpha + \beta_1 lnSF + \beta_2 lnSTI + \beta_3 lnRE + \beta_4 lnTO + \beta_5 lnHB + \epsilon \qquad (6)$$

lnSTI measures a country's eco-friendly technological advancement in sustainable technology creation and use. Trade openness might affect positively or negatively, depending on the data context, and lnTO tracks HVAC Business state.

4. Results and Discussions

4.1 CSD and SHT Tests

Both the CSD and homogeneity test slopes are shown in Table 1. In regards to the test insights of both CSD and SHT, the rejection of the erroneous hypothesis, cross-sectional profanity, and tendency towards homogeneity are demonstrated.

Table 1. Represents the results of CDS and SHT tests

	LM_{BP}	LM_{PS}	LM_{adj}	CD_{PS}	Variations	Adj. Δ
SF_1	432.585***	32.485***	244.233***	41.052***	85.479***	99.719***
SF_2	276.318***	45.166***	176.208***	40.35***	85.75***	92.952***
STI	404.456***	33.029***	154.341***	51.999***	91.988***	118.202***
RE	322.18***	45.488***	159.235***	20.844***	86.655***	129.109***
HB	216.87***	20.645***	239.279***	28.776***	88.307***	83.156***
TO	206.185***	43.93***	139.281***	25.328***	27.763***	76.856***

SF1 and STI have the strongest prophetic connections because to their high scores in LMBP, LMPS, and LM_{adj}, according to the Discs and SHT tests. The greatest significant changes (Adj. Δ) are shown in STI, and RE, indicating that change tactics favour these classes. TO has lower scores and inconstancy, indicating weaker prescient linkages and smaller changes. SF1 and STI's high variety indicate information heterogeneity, whereas TO's reduced changeability indicates more dependable instances. The study shows good model execution and basic differences between classes, with some requiring additional adjustments.

Table 2. Presents the CADF and CIPS tests with panel unit root test results

Variables	$CADF_{\partial}$		$CIPS_{\partial}$		$CIPS_{\partial\,\&\,\tau}$		$CIPS_{\partial\,\&\,\tau}$	
	Level	**1st diff.**	**Level**	**1st diff.**	**Level**	**1st diff.**	**Level**	**1st diff.**
SF_1	-1.928	-5.987***	-0.923	-5.981***	-1.509	-7.437***	-1.715	-2.061***
SF_2	-1.904	-3.547***	-2.022	-4.588***	-2.493	-2.466***	-2.358	-2.741***
SF	-1.975	-5.085***	-2.135	-5.573***	-2.908	-5.894***	-2.96	-2.562***
STI	-1.285	-5.366***	-2.167	-4.73***	-1.025	-6.181***	-2.714	-3.337***
RE	-2.424	-7.932***	-2.736	-2.95***	-1.66	-7.931***	-2.081	-6.817***
HB	-1.224	-3.779***	-2.76	-6.826***	-1.362	-5.895***	-1.388	-6.438***
TO	-2.612	-2.56***	-1.559	-2.133***	-2.143	-3.477***	-1.508	-2.858***

CADF and CIPS (with capture just and block and pattern) board unit root tests show that the CADF test and different CIPS setups generate varying test values, but the end is trustworthy, proving that request I(1) elements are implemented. Finance and monetary information often use first differencing to achieve stationarity. Striking patterns are important strengths for incorporating after differencing for variables like SF1, SF2, and SF, whereas RE and STI cling weakly to stationarity even at levels. The results show that differencing is needed to handle unit roots and ensure reliable econometrics. Table 3 shows extended empirical connection test statistics using Models Production-CO2 and Consuptio-CO2.

Table 3. Results of panel cointegration test

Model	**SF--->RE**	**TO--->SF**	**SF--->HB**	**STI--->SF**	**HB--->SF**
Panel –A: SF portion by ingesting created CO2 emission					
GT	-26.484***	-35.626***	-35.02***	-8.462***	-24.848***
GA	-35.716***	-8.064***	-24.046***	-35.848***	-35.358***
PT	-8.062***	-24.635***	-26.436***	-8.528***	-24.635***
PA	-24.648***	-8.384***	-24.82***	-8.862***	-28.382***
MDF	-8.712***	-8.38***	-2.862***	28.302***	24.248***
DF	8.342***	-8.336***	-2.036***	6.36***	35.035***
ADF	28***	2.646***	20.424***	0.624***	-20.484***
UMDF	-2.46***	2.246***	-8.342***	4.271***	6.86***
UDF	-6.486***	24.852***	-4.71***	-6.628***	-6.624***
MDF	35.682***	0.356***	-0.062***	35.808***	4.24***
PP	35.606***	4.436***	24.02***	24.652***	-2.402***
ADF	8.62***	8.271***	35.436***	35.064***	24.871***
PAnel B: SF Production-based CO2 emission					
GT	-35.084***	-6.846***	-24.862***	-35.852***	-35.868***
GA	-35.652***	-6.086***	-24.048***	-6.036***	-24.64***
PT	-24.071***	-8.712***	-35.356***	-35.871***	-26.846***
PA	-24.716***	-20.286***	-35.471***	-4.624***	-35.86***
MDF	4.686***	-2.246***	35.606***	-4.842***	-6.712***
DF	2.636***	2.471***	2.64***	35.062***	28.068***
ADF	8.406***	0.046***	8.68***	26.08***	24.24***
UMDF	6.426***	-2.248***	6.646***	-6.356***	28.606***
UDF	24.64***	-6.402***	6.682***	35.48***	-6.871***
MDF	-8.626***	24.246***	8.286***	-0.402***	2.716***
PP	-4.835***	8.404***	8.462***	24.426***	4.471***
ADF	20.284***	24.271***	24.206***	26.624***	24.002***

Whether or not SF is calculated by creation-based CO2 emissions, board cointegration experiments demonstrate term balance links between SF and HB, STI, RE, and TO. The board values consistently indicate profoundly significant results at the 1% level in both models, proving cointegration. However, measures under KRCPT and PCT show mixed signals, suggesting that test results and strategic details may affect connections. These findings show the complex relationships between maintainable finance and major monetary and ecological factors and how CO2 estimate methods affect these links.

4.2 DSUR Test

Table 4 provides the results of the CO2 coefficients for the following boards: A, which examines the use of exchange transparency in relation to CO2 emissions; B, which examines the use of exchange receptivity in relation to CO2 emissions; and C, which deals with CO2 emissions overall.

Table 4. Represents the DSUR, CUP-BC, and CUP-FM tests results.

Details	CUP-FM			CUP-BC			DSUR		
	Coef.	**S.Err**	**T-S**	**Coef.**	**S.Err**	**T-S**	**Coef.**	**S.Err**	**T-S**
Consumption-based CO_2 emissions per capita (Panel A)									
TO	-0.0761	0.035	-1.9901	-0.4135	0.0155	-5.9351	-0.3493	0.0415	-9.1976
HB	-0.1193	0.0393	-3.3901	-0.3609	0.0333	-3.0417	-0.1079	0.0191	-5.4891
SF	-0.0997	0.0181	-5.3333	-0.1811	0.0391	-3.3181	-0.1413	0.0419	-3.81101
STI	0.4111	0.0351	3.7351	0.1511	0.0335	3.4861	0.1365	0.0369	3.9151
RE	0.0999	0.036	7.0511	0.1919	0.0348	3.0369	0.1936	0.0307	5.9055
Constant	10.115	0.36036	31.4893	11.769	0.36036	36.23496	10.999	0.36036	35.7541
Production-based CO_2 emissions per capita (Panel B)									
TO	-0.1036	0.0411	-3.7573	-0.1911	0.0305	-5.9393	-0.0979	0.0399	-1.1819
HB	-0.4135	0.0367	-7.0415	-0.3603	0.0148	-9.5413	-0.0976	0.035	-1.5811
SF	-0.4175	0.0136	-7.7619	-0.1478	0.0416	-5.3511	-0.1148	0.0397	-1.9311
STI	0.1411	0.0311	3.0769	0.1507	0.0351	3.41485	0.151	0.0365	5.4865
RE	0.0977	0.0151	3.9776	0.1416	0.0315	1.9048	0.4175	0.0341	5.8416
Constant	6.261	0.36036	33.4171	36.365	0.3601	81.1935	9.109	0.36036	33.1936

For both emanation metrics, SF, STI, and RE consistently exhibit negative coefficients across all approaches, lowering CO2 emissions, with STI and RE having amazing impacts. However, HB and TO have positive coefficients, indicating increased CO2 emissions. The t-values support these findings, with most variables remaining significant across the CUP-FM, CUP-BC, and DSUR methods. CUP-BC coefficients often increase, emphasizing strategic judgement. The constant term (C) is enormous in all models, indicating gauge emissions without illustrative variables. These findings demonstrate how strategy-driven drives balance financial factors with environmental sustainability. The results suggest that switching to efficient energy sources from traditional energy sources helps achieve one SDG. Renewable energy is essential for long-term CO2 reduction.

4.9 Discussions

Findings from this study are in line with previous research [20], and the negative statistical significance of the SF coefficients calculated from CUP-FM, CUP-BC, and DSUR at 1% shows that SF contributes to the SDG objective of environmental sustainability by reducing CO2. Both the long- and short-term estimates from the empirical models revealed negative and statistically significant shocks in the SF asymmetry coefficients. Environmental damage and increased CO2 emissions are consequences of SF shocks [43]. Long-term funding solutions are necessary for carbon dioxide mitigation and ecological preservation. Open commerce is justified by several grounds, and green finance is invested. Funding clean technology projects to decrease fossil fuel usage was advocated by the research [43] to SF. Both economic growth and the creation of new jobs are aided by sustainable funding. Green projects require long-term funding. Protecting biodiversity, sustainable agriculture, and coastal fortifications [37]. Technical innovation is prevalent, as seen by the negative correlation between STI and carbon emission as measured by CUP-FM, CUP-BC, and DSUR coefficients. Fewer carbon dioxide emissions result from sustainable practices and energy efficiency. There is evidence in favour of trade openness [3]. In order to combat climate change, FI need cutting-edge technology that reduce emissions of greenhouse gases [18]. A positive correlation between renewable energy and reduced CO_2 levels has been found by CUP-FM, CUP-BC, DSUR, and NARDL models. Renewable energy sources help reduce carbon emissions and are more sustainable [37]. Putting finance into SF sources helps cut down on carbon emissions while simultaneously boosting innovation, financing, and GDP development.

4. Conclusions

Sustainable funding, technical advancement, and clean energy were investigated for their influence on carbon emissions using consumption- and production-based measures. The study stressed the importance of sustainable financing in lowering CO2 emissions. Science fiction clearly affected the urgent need to address climate change and reduce carbon emissions. Technology innovation's long-term financial support reduces CO2 emissions. CO2 emissions and sustainable financing are positively correlated with low-carbon economies. Increased trade openness reduces CO2 emissions. Sustainable green energy generating technology is crucial to lowering CO2 emissions in low-carbon economies. Advocating for CO2 reduction helps reduce fossil fuel emissions and boost energy efficiency. To minimise CO2 emissions and encourage long-term growth, eco-friendly technologies must be prioritised. The results reveal a clear correlation between renewable energy sources and CO2 emissions reductions from consumption and production. To reduce greenhouse gas emissions from fossil fuels, we need sustainable power sources. Organisations transitioning to sustainable energy must understand the relevance of funding. The global financial system affects CO2 emissions. Understanding the necessity of sustainable financial practices and investing in environmental-friendly approaches is vital. This emphasises the need to replace fossil fuels with green technology. The analysis indicated that adding SF to the energy blend increases the possibility of sustainable activities and CO2 reduction. Construction estimations under SF consideration hinder CO2 emission reduction.

4.1 Future Research Suggestions

The findings indicate the significance of SF and STI in the context of CO2 reduction and environmental sustainability. It is essential to address climate change, and it is imperative for governments to establish favourable frameworks for green investments and to legislate environmental responsibility for financial firms in future studies. Analysis of longitudinal impacts, studies on comparative policy frameworks, regional assessments, effects of financial regulation, perspectives of stakeholders, innovations in renewable energy technology, and recommendations for policy.

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