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The externalities of solid fuel CO2 emissions on rice production: A time series analysis for Pakistan

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Abstract

Purpose — This study examines the externalities of CO2 emissions from solid fuel consumption on rice production in Pakistan using time series data from 1984 to 2021.

Methods — The independent variables include CO2 emissions from solid fuel consumption, cultivated area, agricultural equipment, tube wells, and improved seed, whereas the dependent variable is rice production. A robust analysis was done by altering the solid fuel CO2 emissions proxy. The empirical study used the vector error correction model and Johansen's cointegration test.

Findings — Solid fuel CO2 emissions negatively and significantly impact rice production, implying that solid fuel CO2 emissions decrease rice production. Tube wells have a negative and significant influence on rice production. Conversely, cropped land, agricultural machinery, and improved seeds boosted rice production. The results remained robust even when the proxy for solid fuel CO2 emissions was changed.

Implications — The study recommends developing regulations to limit solid fuel CO2 emissions to prevent environmental degradation and increase rice production. To boost rice production, more land should be farmed, agricultural machinery should be employed, and improved seeds should be used.

Originality — This study is the first to examine the impact of CO2 emissions from solid fuel consumption on rice production in Pakistan.

Keywords — Externalities, CO2, Pakistan, rice production

Introduction

Food security has been challenged by various interconnected factors, including population growth, environmental problems, and land degradation (Chandio, Magsi, et al., 2020). To fulfill global food demand, primary crop production must be significantly expanded (Godfray et al., 2010). However, there may be several barriers to boosting the production of agriculture to fulfill this need, one of which is environmental deterioration (Adzawla et al., 2020; Arunrat & Pumijumnong, 2015; Tripathi et al., 2016).

To encounter the harmful effects of environmental degradation and lower the agriculture sector's sensitivity, adaptation approaches, and feasible cures must be created (J. Wang et al., 2018). Natural disasters are predicted to occur more frequently and with greater severity because of global warming. Other effects include erratic climate extremes, intense heat waves, decreased soil moisture, rising sea levels, surface water runoff, droughts, excursions of glaciers, and erosion of soil (Pickson

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et al., 2020; Praveen & Sharma, 2019; Tesfahunegn & Gebru, 2021). These changes will have a disastrous effect on global economies and may lead to socio-economic chaos (Chandio et al., 2021).

Although climate change affects all significant sectors, agriculture is the most vulnerable (Guntukula, 2020) because many crops are temperature-sensitive. Global warming will lower agricultural output (Appiah et al., 2018). Higher mean temperatures can potentially affect the agricultural production of both crops by modifying the time necessary for a plant to develop (Hatfield & Prueger, 2015). Climate has a wide-ranging impact on agricultural output. Many plant species are temperature sensitive, and rising global temperatures severely impact agriculture and crops (Appiah et al., 2018; Ben Zaied & Ben Cheikh, 2015; Vaghefi et al., 2016).

Rice output is predicted to be altered by unforeseeable future changes in temperature, CO2, and rainfall caused by global warming. Climate change's quick consequences may be seen as harmful consequences of harsh weather conditions on rice production systems and food security (Chandio, Jiang, et al., 2020).Previous studies have indicated that the changing climate is increasing temperatures while reducing rice crop output and quality. This detrimental impact might be attributed to land degradation (Magsi & Sheikh, 2017) and weather variations (Joyo et al., 2018).

Climate change has both positive and negative effects on grain crop output. Nonetheless, the negatives outweigh the benefits generally, and various climatic factors affect different crops and regions in different ways (Akhtar & Masud, 2022; Pickson et al., 2020). In recent years, greater heat from climate change has aided in extending grain-planted areas and generating more grain (Yang et al., 2015). Increasing CO2 concentrations and rainfall favor agricultural productivity to a certain level, although higher temperatures may negate this benefit in specific locations (Dai et al., 2018; Malhi et al., 2021). Similarly, climate change exerts a negative impact on the yield of grain by expanding disease and pest occurrence areas, decreasing crop growing seasons, and increasing the frequency of extreme events of weather (Wang et al., 2021).

Carbon emissions play a vital role in agricultural production to prevent climate change. Various studies suggest that CO2 emissions impact farmland, which evaluates the input function to agricultural productivity (e.g., Ayyildiz & Erdal, 2021; Rehman et al., 2020). Furthermore, the carbon footprint of crops in significant agricultural areas differs from the norm, and the highest crop yields are carbon emitters (She et al., 2017). The environmental impact of harmful gas emissions has become a primary concern. CO2 emissions are a significant contributor to global warming and continue to gain scholarly interest (Appiah et al., 2017; İpek Tunç et al., 2009; Sarkar et al., 2015). Carbon dioxide emissions are the most significant proportion of greenhouse gas emissions in rising economies (Khan et al., 2011). The emissions of carbon dioxide have risen with time because of rising population, rising consumption of energy, rising economic growth, and rising agricultural productivity to ensure food security (Asumadu-Sarkodie & Owusu, 2016; Kofi Adom et al., 2012; McAusland, 2010).

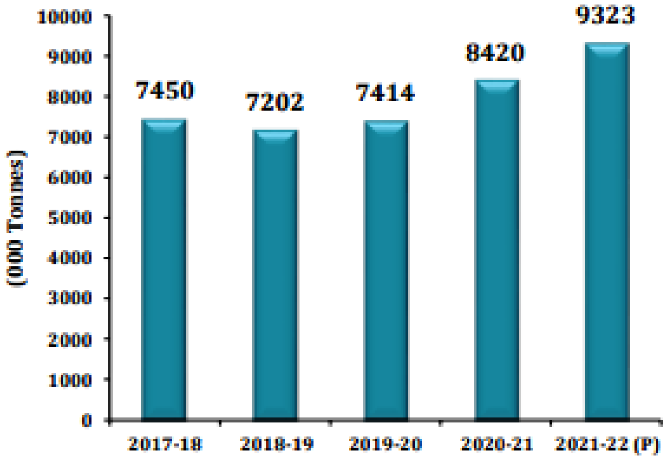
Rice is a vital cash crop and, after wheat, the country's second-most-eaten staple food. Its output comprises 34% basmati (fine) and 66% coarse varieties. The output of coarse kinds has increased recently as farmers have brought additional land under hybrid coarse types. It contributes 0.5% to GDP and 2.4% to the value-added of agriculture. In 2021-22, 3,537 thousand hectares of crop were planted, a 6.1 percent increase from the previous year's yield of 3,335 thousand hectares. In 2021-22, rice output hit a record high of 9.323 million tonnes, a 10.7 percent increase over the output for last year, which was 8.420 million tonnes. The area under rice farming has been increasing during the previous several years. Domestic rice output typically surpasses domestic yearly requirements, producing an exportable surplus (Source: Pakistan Bureau of Statistics). Table 1 displays the rice production, area, and yield during the previous five years.

Many research studies investigated this link after Auffhammer et al. (2006) published a seminal article assessing climate change's impact on agriculture productivity. Climate change may influence agricultural productivity in both direct and indirect ways. The direct way is through changes in rainfall patterns and increases in temperature. The indirect channel is through the spread of diseases, which raises costs and complicates the management of crops (Ben Zaied & Ben Cheikh, 2015; Qureshi et al., 2016).

Table 1. Production, Area, and Yield of Rice

Year	Production		Area		Yield	
	(000 Tonnes)	% Change	(000 Hectare)	% Change	(Kgs/Hec.)	% Change
2017-18	7,450	-	2,901	-	2,568	-
2018-19	7,202	-3.3	2,810	-3.1	2,563	-0.2
2019-20	7,414	2.9	3,034	8.0	2,444	-4.6
2020-21	8,420	13.6	3,335	9.9	2,52	3.3
2021-22	9,323	10.7	3,537	6.1	2,635	4.4

Source: Pakistan Bureau of Statistics



Source: Pakistan Bureau of Statistics (2022)

Figure 1: Production of rice

Even though there is research that looks at the link between environmental degradation and rice yield (Chandio, Magsi, et al., 2020; Gul et al., 2022), they fail to take into account the role of CO2 emissions from solid fuel consumption, which is a significant contributor to environmental degradation in rural areas, as suggested by increased production, the improper use of plant hormones, chemical fertilizers, pesticides and, processing of soil, irrigation and the dumping the animal waste unsuitable for soil (Önder et al., 2011; Waheed et al., 2018). The present study covers this gap. Second, to test the robustness of the estimated results, this study employs two measures of CO2 emissions from solid fuel consumption. The consumption of solid fuel in rural areas makes the country's agricultural sector sensitive to environmental degradation (Önder et al., 2011), and a significant contributor to climate change is the carbon dioxide emissions from agriculture besides the industrial sector (Ayyildiz & Erdal, 2021). This also applies to Pakistan being an agricultural economy. We analyze the influence of CO2 emissions from solid fuel use on rice production using time series data from 1984 to 2021 to offer a foundation for policy making. We use Johansen's cointegration test as suggested by the results of two tests of unit root, i.e., the Phillips-Perron (PP) test and the Augmented Dickey-Fuller (ADF) test. Considering the findings, the present study would enable the country to develop policies to achieve agricultural sustainability regarding rice production, one of the most cultivated in Pakistan, and to use strategies to reduce the harmful effects of environmental degradation on rice production.

The remaining portions of the study are structured as follows: the second section addresses the literature review; the third section includes data, methodology, empirical findings, and interpretations; and the fourth section concludes.

Although the impact of CO2 emissions on rice production has received significant attention due to its importance, empirical findings have been inconsistent and sometimes ambiguous. CO2 emissions, according to several studies, are harmful to rice production. Rice is susceptible to weather and environmental challenges. CO2 emissions, according to studies, enhance the rate of photosynthesis, loss of water, and, eventually, yield (Mahato, 2014). However, rising temperatures would reduce rice output since temperatures above 35 °C damage the viability of pollen and spikelet sterility (Tesfahunegn & Gebru, 2021). The rising temperatures and a decrease in precipitation induce a decrease in the quality and output of crops (Boonwichai et al., 2019; Shrestha et al., 2017). Özdoğan (2011), based on simulations, projected that increased CO2 emissions might affect agricultural yields by 5 to 35% in northern Turkey.

From 1986 to 2018, Javed et al. (2017) investigated the influence of CO2 emissions on cereal crop yield in Pakistan. The empirical findings indicated that CO2 emissions reduce cereal crop production. From 1968 to 2015, Hussain et al. (2018) evaluated the link between emissions of CO2 and the productivity of rice crops in Pakistan. The study established a short-run and long-run linkage between variables and indicated that an increase in CO2 by 1% results in a 1.3% drop in rice crop yield. Similarly, Vanli et al. (2019) verified, utilizing the data on the farmer field level, that environmental issues harmed agriculture.

Chandio, Magsi, et al. (2020) investigated the effect of emissions of CO2 on the yield of rice in the case of Pakistan. The significant findings revealed that a rise in emissions of CO2 by 1% affects rice crop yield by 0.21%. Pickson et al. (2020) examined how climate change would affect China's rice farming. The data suggest that rice production is negatively impacted by climate change. Ozdemir (2022) investigated the role of CO2 in the agricultural sector's productivity in Asia and discovered that CO2 has a detrimental impact on agricultural output.

Gul et al. (2022) discovered that the productivity of food-producing vital crops was negatively impacted by temperature in Pakistan from 1985 to 2016, although the impact of rainfall is positive. Similarly, Chandio et al. (2021) discovered that CO2 negatively affected grain productivity in Pakistan from 1977 to 2014, lowering cereal production. In the instance of India, Bhardwaj et al. (2022) found that climatic factors had a detrimental effect on rice production. CO2 emissions, according to Akhtar and Masud (2022), have a detrimental impact on Malaysian agricultural output.

Some studies contend that, in the medium and short term, some locations, such as the northern region of Europe, may benefit from climate change and improve food yields (Isoard, 2011). Janjua et al. (2014) discovered that CO2 emissions, yearly temperature, and annual rainfall had a beneficial short-term and long-term effect on the output of the main crops in Pakistan. Ntiamoah et al. (2022) studied the influence of CO2 emissions on agricultural output in Ghana from 1990 to 2020. According to the data, CO2 emissions favorably influence crop productivity. Similarly, Kumar et al. (2021) examined the climate change-cereal crop output relationship in selected countries with lower middle income between 1971 and 2016. The data demonstrated that CO2 emissions increased and that there was a bidirectional relationship between CO2 emissions and agricultural yields.

However, Zhai et al. (2017) found that from 1970 to 2014 in China, temperature did not affect wheat productivity per acre in both the long and short term. Pickson et al. (2020) examined how climate change affected rice growing in China from 1998 to 2017. The data revealed that the impact of climatic variables on rice output is insignificant.

A study of the existing literature reveals that the link between CO2 emissions and rice production needs to be clarified. Secondly, the lack of literature on the relationship between solid fuel consumption CO2 emissions and rice production makes the empirical inquiry necessary.

Methods

For an empirical investigation of the effects of CO2 emissions on rice production, the following models will be specified:

$$lnRICEP = a + \beta_1\, CO21 + \beta_2\, AREA + \beta_3\, lnAGM + \beta_4\, lnTUBEWELL + \beta_5\, SEED + \mu \tag{1}$$

For robustness analysis, the following model has been specified:

$$lnRICEP = a + \beta_1\, CO22 + \beta_2\, AREA + \beta_3\, lnAGM + \beta_4\, lnTUBEWELL + \beta_5\, SEED + \mu \tag{2}$$

It may be derived from the generic equation (1) as follows to establish the long-run equation:

$$lnRicep_{t} = a + \beta_1\, Co21_{t\text{-}1} + \beta_2\, Area_{t\text{-}1} + \beta_3\, lnAgm_{t\text{-}1} + \beta_4\, lnTubewell_{t\text{-}1} + \beta_5\, Seed_{t\text{-}1} + \mu_t \tag{3}$$

For robustness analysis, the following model will be specified:

$$lnRicep_{t} = a + \beta_1\, Co22_{t\text{-}1} + \beta_2\, Area_{t\text{-}1} + \beta_3\, lnAgm_{t\text{-}1} + \beta_4\, lnTubewell_{t\text{-}1} + \beta_5\, Seed_{t\text{-}1} + \mu_t \quad (4)$$

If, at minimum, one cointegration association exists, this analysis will utilize the Vector Error Correction Method (VECM) to examine the association in the short run. The VECM equation for rice production and other variables is as follows:

$$\Delta lnRicep_t = a + \beta_1 \Delta Co21_{t\text{-}1} + \beta_2 \Delta Area_{t\text{-}1} + \beta_3 \Delta lnAgm_{t\text{-}1} + \beta_4 \Delta lnTubewell_{t\text{-}1} + \beta_5 \Delta Seed_{t\text{-}1} + \pi\, (lnRicep_t - a - Co21_{t\text{-}1} - Area_{t\text{-}1} - lnAgm_{t\text{-}1} - lnTubewell_{t\text{-}1} - Seed_{t\text{-}1}) + \mu_t \quad (5)$$

For robustness analysis, the following model is specified:

$$\Delta lnRicep_t = a + \beta_1 \Delta Co22_{t\text{-}1} + \beta_2 \Delta Area_{t\text{-}1} + \beta_3 \Delta lnAgm_{t\text{-}1} + \beta_4 \Delta lnTubewell_{t\text{-}1} + \beta 5 \Delta Seed_{t\text{-}1} + \pi\, (lnRicep_t - a - Co22_{t\text{-}1} - Area_{t\text{-}1} - lnAgm_{t\text{-}1} - lnTubewell_{t\text{-}1} - Seed_{t\text{-}1}) + \mu_t \quad (6)$$

where RICEP is rice production measured in thousands of tons (Chandio et al., 2021; Chandio, Magsi, et al., 2020), which is the dependent variable, CO21 is emissions of carbon dioxide from the use of solid fuels as a percentage of the total, CO22 is emissions of carbon dioxide from the use of solid fuels in kilotons previously used by Ahmad et al. (2020), Ahsan et al. (2020), and Pickson et al. (2020) which is the primary independent variable; however, these studies used overall CO2 emissions but not CO2 emissions from solid fuel consumption. AREA is cropped area measured in million hectares (Chandio et al., 2018; A. Hussain, 2012; Janjua et al., 2014), AGM is agricultural machinery proxied by number of tractors being used (Ozdemir, 2022), TUBEWELL is the number of tube wells public and private measured in thousands (Asumadu-Sarkodie & Owusu, 2016) and SEED is improved seed distribution measured in thousands of tonnes (Abbas, 2022; Zhai et al., 2017; Zhang et al., 2022). The data has been taken from 1984 to 2021. The data has been gathered from the Economic Survey of Pakistan and WDI. To calculate the elasticity of coefficients, we use the logarithmic values of the variables.

Table 2. Results of Augmented Dickey-Fuller (ADF) test for unit root

Variable	Intercept	Intercept and Trend
lnRicep	-0.286	2.175
	(0.917)	(0.992)
ΔlnRicep	-9.179*	-8.474*
	(0.000)	(0.000)
CO21	-0.327	-0.940
	(0.911)	(0.940)
ΔCO21	-5.649*	-5.950*
	(0.000)	(0.0001)
CO22	1.211	-0.690
	(0.998)	(0.967)
ΔCO22	-5.518*	-5.946*
	(0.0001)	(0.0001)
Area	-2.508	0.940
	(0.122)	(0.904)
ΔArea	-9.765*	-9.417*
	(0.000)	(0.000)
lnAgm	-1.607	-2.688
	(0.469)	(0.247)
ΔlnAgm	-6.426*	-6.335*
	(0.000)	(0.000)
lnTubewell	-1.888	-0.556
	(0.334)	(0.976)
ΔlnTubewell	-5.917*	-6.491*
	(0.000)	(0.000)
Seed	1.881	-0.851
	(0.999)	(0.951)
ΔSeed	-5.461	-5.445
	(0.000)	(0.000)

Before starting the empirical study, the variables must be verified for stationarity. The Augmented Dickey-Fulller and Phillips-Perron tests for the unit root were applied at the level and the first difference. These are statistical tests for checking the stationarity of variables. The null hypothesis is that a unit root exists within a given time series sample. The results are in Tables 2 and 3.

Table 3. Results of Phillips-Perron (PP) test for unit root

Variable	Intercept	Intercept and Trend
lnRicep	0.139	3.365
	(0.965)	(0.999)
ΔlnRicep	-15.933*	-8.474*
	(0.000)	(0.000)
CO21	-0.702	-1.2131
	(0.834)	(0.893)
ΔCO21	-5.692*	-5.950*
	(0.000)	(0.000)
CO22	1.034	-1.033
	(0.996)	(0.927)
ΔCO22	-5.617*	-5.976*
	(0.000)	(0.000)
Area	-2.366	2.010
	(0.158)	(0.988)
ΔArea	-9.831*	-9.417*
	(0.000)	(0.000)
lnAgm	-1.439	-2.654
	(0.553)	(0.260)
ΔlnAgm	-7.052*	-6.761*
	(0.000)	(0.000)
lnTubewell	-1.945	-0.532
	(0.309)	(0.977)
ΔlnTubewell	-5.955*	-6.492*
	(0.000)	(0.000)
Seed	8.266	0.0411
	(1.000)	(0.995)
ΔSeed	-5.335*	-8.998*
	(0.000)	(0.000)

The results of the unit root analysis's ADF test and PP test show the stationarity of all the variables at first difference. However, non-stationarity at their levels suggests the order of integration for all of these is one, namely *I*(1). As a result, Johansen's cointegration test is an appropriate option for empirical analysis.

The optimal lag to include in the model has been chosen using the Vector Auto Regression (VAR) lag order selection criterion. One lag was chosen because it fulfilled three criteria that recommended including one lag in the model.

Table 4. Lag length criteria (VAR) for model 1

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-310.683	NA	2.912	18.096	18.363	18.188
1	-155.311	248.595*	0.003	11.275	13.141*	11.919*
2	-120.176	44.170	0.004	11.324	14.791	12.521
3	-65.482	50.006	0.003*	10.256*	15.322	12.005

Following is Johansen's test of cointegration for model 3.

Table 5. Unrestricted cointegration trace test for model 3

Hypothesized CE(s)	Trace Statistic	Eigenvalue	Critical Value (0.05)	Prob.
None *	119.420	0.763	95.753	0.001*
Maximum 1	67.531	0.568	69.818	0.075
Maximum 2	37.277	0.370	47.856	0.335
Maximum 3	20.655	0.275	29.797	0.380
Maximum 4	9.061	0.219	15.494	0.360
Maximum 5	0.157	0.004	3.841	0.692

*Indicates that the hypothesis was rejected at 0.05 level.

Table 6. Unrestricted cointegration maximum eigenvalue test for model 3

Hypothesized CE(s)	Max-Eigen Statistic	Eigenvalue	Critical Value (0.05)	Prob.
None *	51.889	0.763	40.077	0.002*
Maximum 1	30.254	0.568	33.876	0.128
Maximum 2	16.622	0.370	27.584	0.613
Maximum 3	11.594	0.275	21.131	0.588
Maximum 4	8.904	0.219	14.264	0.294
Maximum 5	0.157	0.004	3.841	0.692

* indicates that the hypothesis was rejected at 0.05 level.

The null hypothesis in Johansen's cointegration test is the absence of cointegration among the variables. The Maximum EigenValue and Trace cointegration tests both show the existence of cointegration or a long-run association and reject the null hypothesis.

Table 7. Estimation result for equation (normalized), model 3

Dependent variable: lnRiceP			
Variable	Coefficient	Standard Error	t-Statistic
CO21	-0.020	0.004	-5.314
Area	0.139	0.015	9.096
lnAgm	0.201	0.021	9.413
lnTubewell	-0.137	0.046	-2.980
Seed	0.001	0.000	12.707

Normalized cointegration coefficients have been used to demonstrate the impact of independent factors on rice production. The findings indicate that emissions of CO2 have a significantly negative impact on rice production. However, cropped areas, agricultural machinery, and improved seeds significantly impact rice production. However, tube wells have a negative and significant impact on rice production. When other parameters are held constant, the elasticity of rice production with CO2 emissions is -0.0203, which means that a 1% rise in CO2 emissions would result in a 0.02% reduction in rice output. A 1% rise in the cropped area, agricultural machinery, and improved seed leads to a rise in rice production by approximately 0.13%, 0.20%, and 0.001%, respectively. As tube wells harm rice production, a 1% rise in tube wells will reduce rice production by approximately 0.13%.

Table 8. VECM estimation results for model 3

Error Correction:	D(lnRiceP)	D(CO21)	D(Area)	D(lnAgM)	D(lnTubewell)	D(Seed)
CointEq1	-0.343	-3.233	-2.508	0.360	0.101	-19.002
Std. Error	0.141	1.893	0.633	0.374	0.058	71.630
t-Ratio	-2.434	-1.707	-3.960	0.962	1.727	-0.265

The next stage is to examine the short-run connection among variables carried out by using VECM, given that there is cointegration among variables. The value of the error correction term is -0.343 with the *t*-statistic of -2.434. This demonstrates convergence in the model since the error correction term is significant and has a negative sign, which suggests that if there is any disruption in equilibrium, there will be a 34% adjustment in the model throughout each phase from dis-equilibrium to equilibrium.

The results of the empirical study were checked for robustness in the second stage. For this, the variable CO2 emissions from the usage of solid fuel in kilotons (CO22) were used instead of the variable CO2 emissions from the usage of solid fuel as a percentage of the total (CO21). The following is the lag length criteria (VAR) for model 4.

Table 9. Lag Length Criteria (VAR) for Model 4

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-566.193	NA	6385864	32.697	32.963	32.789
1	-407.805	253.421*	6055.316	25.703	27.570*	26.348*
2	-371.928	45.103	7381.249	25.710	29.176	26.907
3	-321.841	45.793	5779.242*	24.905*	29.971	26.654

The following is Johansen's test of Cointegration for Model 2

Table 10. Unrestricted cointegration trace test for model 4

Hypothesized CE(s)	Trace Statistic	Eigenvalue	Critical Value 0.05	Prob.
None *	121.967	0.719	95.753	0.000*
Maximum 1*	76.284	0.629	69.818	0.014*
Maximum 2	40.574	0.394	47.856	0.203
Maximum 3	22.529	0.317	29.797	0.270
Maximum 4	8.814	0.213	15.494	0.383
Maximum 5	0.183	0.005	3.841	0.669

* indicates that the hypothesis was rejected at 0.05.

Table 11. Unrestricted cointegration maximum eigenvalue test for model 4

Hypothesized No. of CE(s)	Max-Eigen Statistic	Eigenvalue	Critical Value 0.05	Prob.**
None *	45.683	0.719	40.077	0.011*
Maximum 1*	35.710	0.629	33.876	0.030*
Maximum 2	18.046	0.394	27.584	0.491
Maximum 3	13.715	0.317	21.131	0.389
Maximum 4	8.630	0.213	14.264	0.318
Maximum 5	0.183	0.005	3.841	0.669

* indicates that the hypothesis was rejected at 0.05.

Table 12. Estimation result for equation (normalized), model 4

Dependent variable: lnRiceP			
Variable	Coefficient	Standard Error	t-Statistic
CO22	0.000	0.000	-4.243
Area	0.202	0.023	8.874
lnAgM	0.262	0.030	8.604
lnTubewell	-0.219	0.061	-3.588
Seed	0.002	0.000	9.239

Table 13. VECM results for Model 4

Error Correction:	D(lnRiceP)	D(CO22)	D(Area)	D(lnAgM)	D(lnTubewell)	D(Seed)
CointEq1	-0.401	-6345.800	-3.199	0.571	0.095	23.029
Std. Error	0.16633	3619.250	0.722	0.439	0.076	88.8743
t-Ratio	-2.408	-1.753	-4.432	1.299	1.254	0.259

The findings demonstrate that the optimal lag length, as recommended by three VAR lag order selection criteria, was 1. At a 5% level of significance, the trace test and the maximum eigenvalue test both rejected the null hypothesis that there was "no cointegration" between rice production and the model's independent variables, indicating the occurrence of a long-run association. According to the normalized equation's results, every variable's coefficient had the same sign as that of model 1 and was statistically significant. This suggests that the empirical findings from the model were robust. CO2 emissions continue to have a significant and adverse impact on rice output. The VECM findings demonstrated that with a value of -0.400, the error correction term's value is still statistically significant and negative, indicating a model convergence rate of about 40% each period.

The findings of this analysis are supported by earlier studies. Climate change and environmental issues can affect rice yield. Research reveals that CO2 emissions result in a reduction in rice production (Boansi, 2017; Boonwichai et al., 2019; Ozdemir, 2022; Özdoğan, 2011; Pickson et al., 2020; Shrestha et al., 2017). The cropped area positively affected rice production, as found by Ahsan et al. (2020), Chandio et al. (2018), Hussain (2012), and Janjua et al. (2014). Agricultural machinery significantly enhanced rice output as found by Ozdemir (2022). Similarly, improved seed positively impacts rice production, as previously found by Abbas (2022), Zhai et al. (2017), and Zhang et al. (2022).

Conclusion

Climate change is caused by a sharp rise in carbon dioxide emissions, threatening food security. The ongoing threat of climate change brought on by carbon dioxide emissions has prompted various countries to make a concerted effort to address it seriously. Researchers' interest has increased in determining the causes and effects of different variables on global emissions. The relationships between factors are crucial for establishing policy. Pakistan's fast development makes it highly vulnerable to climate change due to conventional technical production methods. The current study collects time series data from 1984 to 2021 to empirically investigate the impact of CO2 emissions on rice production in Pakistan. Rice production is the regressed, and the regressors are CO2 emissions, cropped area, agricultural machinery, tubewells, and improved seeds. The CO2 emissions have been calculated in two ways: as a percentage of all CO2 emissions and kilotons of CO2 emissions from burning solid fuel. The ADF and PP tests have been employed to determine the integration order of the variables, and the results showed that all the variables are stationary at their first difference. The long-run connection between variables was investigated using the Johansen cointegration test, whereas VECM was used to examine the short-term relationship. There were two models designated for empirical analysis. The findings suggested that both models had long-term relationships between the variables, and short-run analysis demonstrated that both models were convergent toward equilibrium in the long run. The negative and significant effects of CO2 emissions on rice production imply a reduction in rice output with increased CO2 emissions from solid fuel. Like this, tube wells significantly and adversely affect rice production. However, cropped areas, agricultural machinery, and improved seeds increase rice production. Even with a different proxy for CO2 emissions from the solid fuel, the findings remained robust with the same signs. The negative role of CO2 emissions in reducing crop production may be due to the cause of environmental degradation, as suggested by Boonwichai et al. (2019), Ozdemir (2022), and Pickson et al. (2020).

As the results show that CO2 emissions from solid fuel consumption reduce rice production, the government should devise a policy to reduce solid fuel combustion, especially in rural areas, to reduce environmental degradation. This may help in increasing rice production. Secondly, more area should be cropped, more agricultural machinery should be used, and more improved seeds should be used to increase rice production.

The limitation of the current study is that it only considers the impact of CO2 emissions on rice production. The future direction of the study may be to check this impact on other major crops, such as wheat. The open-access datasets employed in the analyses can be accessed from the following links: https://databank.worldbank.org/source/world-development-indicators; www.finance.gov.pk/survey_2022.html

Conflict of Interest

The authors declare no conflict of interest.

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