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RESEARCH ARTICLE

Examining the carbon emissions and climate impacts on main agricultural crops production and land use: updated evidence from Pakistan

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Abstract
One of the major challenges to the survival of life on earth is the increasingly evolving climate change. The key source of environmental pollution is global warming. With the combustion of fossil fuels, greenhouse gas (GHG), which is generated in the external environment, is increased and air pollutant as well. The present analysis key intention was to examine the CO_2 emission and climatic effects on major agricultural crop production and land use in Pakistan. The study used time span annual data varies from 1970 to 2019, and data stationarity was rectify by utilizing the unit root tests. A generalized method of moments with two-stage least squares technique was applied to expose the variables' association with CO_2 emission. The study consequences uncover that the wheat, maize, sugarcane, cotton, bajra, gram, sesamum crops, and land use have constructive association with CO_2 emission having positive coefficients with probability values (0.3762), (0.0435), (0.2287), (0.2303), (0.2272), (0.0192), (0.4535), and (0.0017) correspondingly, while rainfall, temperature, rice, jowar, and barley uncovered an adversative linkage to CO_2 emission in Pakistan. As Pakistan is an emerging country, potential constructive measures must be introduced in directive to reduce CO_2 emissions to improve the agricultural productivity.

Keywords Carbon emission · Agricultural crops · Climate change · Environment · Temperature · Generalized method of moments

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Abbreviations

CO_2e	Carbon dioxide emission
GHG	Greenhouse gas
PP	Phillips-Perron
ADF	Augmented Dickey-Fuller
GOP	Government of Pakistan
WDI	World Development Indicators
RAFL	Rainfall
TMPE	Temperature
WHEC	Wheat crop
RICC	Rice crop
MAIC	Maize crop
SUGC	Sugarcane crop
COTC	Cotton crop
JOWC	Jowar crop
BAJC	Bajra crop
BARC	Barley crop
GRAC	Gram crop
SESC	Sesamum crop
LANC	Land use

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Introduction

Agriculture has always been the most labor-intensive sector in the Pakistani economy; it is however a direct or indirect source of income for the majority of people (Rehman et al. 2015). However, the contribution to economic progress in the last few decades has slowly declined to 19.3% but the economy is still able to expand its domestic use by raising the productivity rates of modern farming technology to upsurge the economic growth. The sector with the highest manpower and the supply of raw materials for many manufacturers not only contributes to reducing poverty but also improves the socio-economic structure of most people. The agricultural sector's production increased last year and has also improved over other sectors. But agricultural output is also far from achieving its promise due to the threats posed by climate change, pests, water shortages, etc. A key problem in agriculture is the reduced direct market access for farmers, which makes the position of mediators crucial. Farmers often do not get competitive market prices for their products. In terms of capability, the agricultural sector is competent not only of providing for its own people, but also of providing excess demand for exports, which may ensure food security and increase foreign exchange profits (GOP 2020).

Agricultural exports have been one of Pakistan's most important economic growth areas in recent decades. However, the country's agricultural export commerce is severely hampered by carbon dioxide and other environmental indicators' pollution caused by increasing climate change and unexpected weather shifts (Rehman et al. 2019). Global warming is caused by carbon pollution, changes in land use, and other human activities that emit large amounts of greenhouse gases into the atmosphere. Many industrialized nations are exhibiting major demographic growth drivers for the end of the twenty-first century, such as declining fertility, increasing life expectancy, and an aging population structure. As a result, the agricultural sector continues to dominate all areas and play a significant role in the economy, particularly in emerging nations. Soil deterioration, habitat loss, resource shortages, and forest destruction are all worldwide environmental issues (IPCC 2014; Aydoğan and Vardar 2020; Qiao et al. 2019). Rising temperature has now become a problem for mankind, with human greenhouse gases being the primary cause of the disaster. The major negative effects of greenhouse gases may be summed up by continuing to expose the planet to infrared radiation, which raises the average earth's temperature (Yousefi et al. 2016; Arora et al. 2018).

Agricultural activities have multiple environmental impacts; first, the farming industry is a significant source of CO_2 emission due to trash talking plants, microbial degradation, and organic soil. Second, the usage of traditional agriculture in the farming sector would deteriorate the environmental condition of emerging countries, as farming in the various regions intensifies and regional practices such as animal husbandry concentrate. Third, the major source of CO_2 pollution is indeed the usage of non-renewable fuels in agricultural practice. It would cause over nutrition, raise ammonia and greenhouse gas pollution, and increase the number of toxins caused by water and air. Unlike the above debate, the usage of sustainable energies, advanced farming practices, and organic seeds in cultivation would decrease atmospheric carbon dioxide emissions (Oenema et al. 2005; Green et al. 2005; Jalil and Mahmud 2009; Rehman et al. 2020a, b). Multiple studies have highlighted the link between CO_2 emission and rainfed agriculture production, energy usage, population growth, foreign investment, natural resources, energy investment, air pollution, health expenditures, and ecological footprint (Soni et al. 2013; Khan et al. 2014; Islam et al. 2017; Behera and Dash 2017; Kwakwa et al. 2020; Ahmad et al. 2021; Hussain and Rehman 2021; Alvarado et al. 2021), but the recent study expresses the CO_2 emission and climatic impacts on major agricultural crop productivity and land usage in Pakistan by taking annual time series data. Stationarity of the major variables was rectified by utilizing the unit root tests. Further, generalized method of moments with two-stage least squares technique was employed to expose the variables' association with CO_2 emission.

The rest of the study is consequently organized. The "Existing literature" section presents the prior related literature, while "Study methods and data" section describes the research methodology and the data collection utilized for the analysis. The findings of the research and their interpretation are noted under the "Results and discussion" section. Finally, suggestions and the associated policy consequences are advocated in the "Conclusion and policy implications" section.

Existing literature

Climate change has given human life and development unparalleled obstacles, including severe weather, species extinction, and food scarcity. To target the major emitters using appropriate techniques is necessarily a good knowledge of the determinants and trends of regional carbon emissions. Moreover, in the sense of globalization, international convergence is one of the most debated and contentious topics in recent times. Commerce, investment, and finance are critical considerations in speeding up the liberalization of the economy. Because of the globalization mechanism, the exchange of products, resources, and intelligence from countries across the world improved rapidly (Dong et al. 2019; Wu et al. 2019). Recycling industrial and agricultural wastes on agricultural land was an important method to resolve environmental and resources issues. With growing use of industrial and agricultural waste on farming soil, the effect of waste on soil inputs, plant growth, and emissions of greenhouse gases was analyzed, and biomass and steel slag were thoroughly researched to maximize crop returns (Zhang et al. 2012; Prendergast-Miller et al. 2014; Arel and Aydin 2018).

Taking into account the environmental implications, and increasing worries regarding the greenhouse gas emissions capacity in the agriculture industry, sustainable energy usage has become an important factor in the global resource use. Local fiscal, environmental, and social concerns should drive interest in the agricultural sustainability. Decision-making on sustainability can include national policy on energy production and local goals. In order to provide energy resources to developed countries' agriculture, emphasis should be put on alternatives to non-fossil fuels. In several areas of the world, renewable energy solutions for different agriculture uses are encouraged to minimize CO_2 pollution and to reduce the economic effect of energy pricing volatility (Ahiduzzaman and Islam 2011; Shafiei and Salim 2014; Heidari and Pearce 2016; Zheng et al. 2019). Modern economic growth, though, relies primarily on industrialization and the application of modern technologies. It continues to play a very significant role for the conventional agricultural sector since it is the base of basic agricultural industries' production and the key food supply. Moreover, the farming industry can help preserve the atmosphere from contamination. Industrialization is claimed to be responsible for eliminating the conventional market when it redistributes capital from agriculture to manufacturing between different sections. In view of these systemic reforms in various nations, many economies are still concerned about the agriculture sector since they can have a positive or negative environmental effect (Sayer and Cassman 2013; Ullah et al. 2018; Xiao et al. 2021).

The most susceptible to the impact of global climate change is perceived to be agriculture. Food safety is another matter which all human beings ought to be acquainted about. There has been much debate about the effect of climate change on agriculture. For most rural areas, agriculture is the primary source of revenue. It uses climate change's detrimental repercussions to shield rural poor families and plays a crucial part in maintaining food protection. Adoptions can improve climate change and unpredictability for rural populations, minimize future harm, or help them deal with adverse effects and thereby significantly reduce their climate change risk. Agriculture is a major concern to the economic sustainability of climate change because of its dependency on agricultural and non-agricultural practices, since the majority of the population of the world resides in rural zones. Farmers are increasingly attempting to respond to climate and weather improvements. But the scope that farmers need to build and execute recovery plans has increased in environmental and global change (Wang et al. 2009; Collier 2013; Dumrul and Kilicaslan 2017; Chandio et al. 2020). If the economy moves from the farm to the macro-industrial market, environmental damage is growing and the share of farm incomes will preserve the climate. Agricultural production will also promote a green ecosystem and potentially contribute to emissions reduction. Furthermore, agricultural engineering will also contribute to the resolution of environmental problems (Sayer et al. 2013; Hongdou et al. 2018).

Carbon dioxide emission and climate change are hot problems in different areas of society and countries are working hard to reduce industrialization's detrimental impact on the climate. The global economy has experienced major industrialization and urbanization in the last couple of decades, on the one hand. On the other side, inhabitants have called for effective food development in order to satisfy global demand for food under frequent droughts and adverse weather conditions. The market is rising and need of agriculture and industrialization to eliminate carbon emissions is rival. It is crucial to estimate the association between agricultural and carbon emissions and the link between industrial and carbon releases in order to decide how these two sectors contribute to climate change (Bai et al. 2019; Gollin et al. 2016; Ma et al. 2019). Global warming jeopardizes the earth because it deteriorates the atmosphere and disturbs the normal temperature, water, and food cycle. The levels of the sea increase, and every day the glaciers decrease. Many environmental explanations clarify the main source of the global warming induced by human activity by the rise of the carbon dioxide level in the atmosphere. Today, CO_2 emission has been reached in recent decades (Clark et al. 2016; Anderson et al. 2016; Kweku et al. 2017; Rehman et al. 2021a). Therefore, the international community is beginning to address environmental problems linked to rising emissions of carbon dioxide. In this context, several nations across the globe are progressively realizing green energy possibilities and impacts (Dong et al. 2020; Dong et al. 2021).

Emissions of greenhouse gases are considered a critical element in farm sustainability. The growth in pollution affects the valuation of natural resources negatively. The reason for deciding how to minimize harmful environmental impacts lies in the cumulative data on greenhouse farm gas issues. At the same time, farming must satisfy the increasing demand for food within current resource constraints. A recent priority for agriculture is to identify solutions to how more food is generated while the importance of natural resources is not reduced. The environmental effects of agricultural properties must be assessed and explained as a remedy (Franks and Hadingham 2012; Tubiello et al. 2013; Wollenberg et al. 2016; Lenerts et al. 2017). Most if not all societies on the planet have been hampered in the process of mitigating global temperature and reducing greenhouse gases. Politicians and government officials have therefore called for the development of a safe and environmentally friendly climate. For government officials, environmentalists, and energy analysts, the question of environmental protection is a major concern. However, with the human activities, degrading the ozone and degrading the whole climate and habitats, it seems almost difficult to achieve the goal milestone (FAO 2016; Balsalobre-Lorente et al. 2019).

Study methods and data

We have used annual time series data in this analysis which is ranging from 1970 to 2019. The key sources of this data are Economy Survey of Pakistan (http://www.finance.gov.pk/survey_1920.html) and WDI (World Development Indicators) (https://data.worldbank.org/country/pakistan). Major study variables include CO_2 emission, rainfall, temperature, wheat, rice, maize, sugarcane, cotton, jowar, bajra, barley, gram, sesamum crops, and land use. Table 1 presents the chief study variables' explanations. Furthermore, Fig. 1 uncovered the trends of the study variables.

Econometric specification of model

In directive to verify the variables association, we will follow the Ozturk (2016) study and the following model was stated as:

$$Y_t = f(\mathrm{RAFL_t, TMPE_t, AGCP_t, LANC_t}) \quad (1)$$

By expending the AGCP (agricultural crops production), we can write Eq. (1) further as:

$$Y_t = f(\mathrm{RAFL_t, TMPE_t, WHEC_t, RICC_t, MAIC_t, SUGC_t, COTC_t, JOWC_t, BAJC_t, BARC_t, GRAC_t, SESC_t, LANC_t}) \quad (2)$$

Furthermore, Eq. (2) can also be expressed as:

$$\mathrm{CO_2e_t} = f(\mathrm{RAFL_t, TMPE_t, WHEC_t, RICC_t, MAIC_t, SUGC_t, COTC_t, JOWC_t, BAJC_t, BARC_t, GRAC_t, SESC_t, LANC_t}) \quad (3)$$

In the above equation, CO_2e_t indicates the carbon dioxide emission, $RAFL_t$ denotes the rainfall, $TMPE_t$ indicates the temperature, $WHEC_t$ shows the wheat crop, $RICC_t$ indicates rice crop, $MAIC_t$ shows the maize crop, $SUGC_t$ indicates sugarcane crop, $COTC_t$ shows the cotton crop, $JOWC_t$ indicates the jowar crop, $BAJC_t$ demonstrates the bajra crop, $BARC_t$ indicates the barley crop, $GRAC_t$ shows the gram crop, $SESC_t$ indicates the sesamum crop, and $LANC_t$ shows the land use in Pakistan. Equation (3) can further be stated as:

$$\begin{aligned}\mathrm{CO_2e_t} = {} & \tau_0 + \tau_1\mathrm{RAFL_t} + \tau_2\mathrm{TMPE_t} + \tau_3\mathrm{WHEC_t} \\ & + \tau_4\mathrm{RICC_t} + \tau_5\mathrm{MAIC_t} + \tau_6\mathrm{SUGC_t} \\ & + \tau_7\mathrm{COTC_t} + \tau_8\mathrm{JOWC_t} + \tau_9\mathrm{BAJC_t} \\ & + \tau_{10}\mathrm{BAJC_t} + \tau_{11}\mathrm{GRAC_t} + \tau_{12}\mathrm{SESC_t} \\ & + \tau_{13}\mathrm{LANC_t} + \varepsilon_t \end{aligned} \quad (4)$$

The variables' logarithmic form can be specified in the model as:

$$\begin{aligned}\mathrm{LnCO_2e_t} = {} & \tau_0 + \tau_1\mathrm{Ln(RAFL_t)} + \tau_2\mathrm{Ln(TMPE_t)} \\ & + \tau_3\mathrm{Ln(WHEC_t)} + \tau_4\mathrm{Ln(RICC_t)} \\ & + \tau_5\mathrm{Ln(MAIC_t)} + \tau_6\mathrm{Ln(SUGC_t)} \\ & + \tau_7\mathrm{Ln(COTC_t)} + \tau_8\mathrm{Ln(JOWC_t)} \\ & + \tau_9\mathrm{Ln(BAJC_t)} + \tau_{10}\mathrm{Ln(BAJC_t)} \\ & + \tau_{11}\mathrm{Ln(GRAC_t)} + \tau_{12}\mathrm{Ln(SESC_t)} \\ & + \tau_{13}\mathrm{Ln(LANC_t)} + \varepsilon_t \end{aligned} \quad (5)$$

Equation (5) is viewing the form of logarithmic for all research variables. t is showing the time measurement, where ε_t denotes the error term, τ_0 intercept is constant, and the τ_1 to τ_{13} are model's coefficient for long-range conductivity.

Unit root test description

This analysis also utilized the unit root test to validate the variables' consistency and the representation can be shown as:

Table 1 Demonstration of study variables

Study variables	Logarithmic forms	D-sources	Online web links
Carbon dioxide Emission	$LnCO_2e$	WDI	https://data.worldbank.org/country/pakistan
Rainfall	LnRAFL	WDI	
Temperature	LnTMPE	WDI	
Wheat	LnWHEC	GOP	http://www.finance.gov.pk/survey_1920.html
Rice	LnRICC	GOP	
Maize	LnMAIC	GOP	
Sugarcane	LnSUGC	GOP	
Cotton	LnCOTC	GOP	
Jowar	LnJOWC	GOP	
Bajra	LnBAJC	GOP	
Barley	LnBARC	GOP	
Gram	LnGRAC	GOP	
Sesamum	LnSESC	GOP	
Land use	LnLANC	GOP	

Note: GOP designates the Government of Pakistan

$$\Delta G_t = \alpha_\circ + \gamma_\circ T + \gamma_1 U_{t-1} + \sum_{i=1}^{m} \alpha_1 \Delta G_{t-1} + \mu_t \quad (6)$$

where G defines the unit root variables to be assessed, T shows the linear trends, Δ exposes the initial difference between the operators, t is the time subscription, and μ_t is generally a stochastic error.

Results and discussion

Summary statistics and variables' correlation

Table 2 is expressing the outcomes of the summary statistics of all variables with having probability values. Similarly, Table 3 is uncovering the correlation among the variables

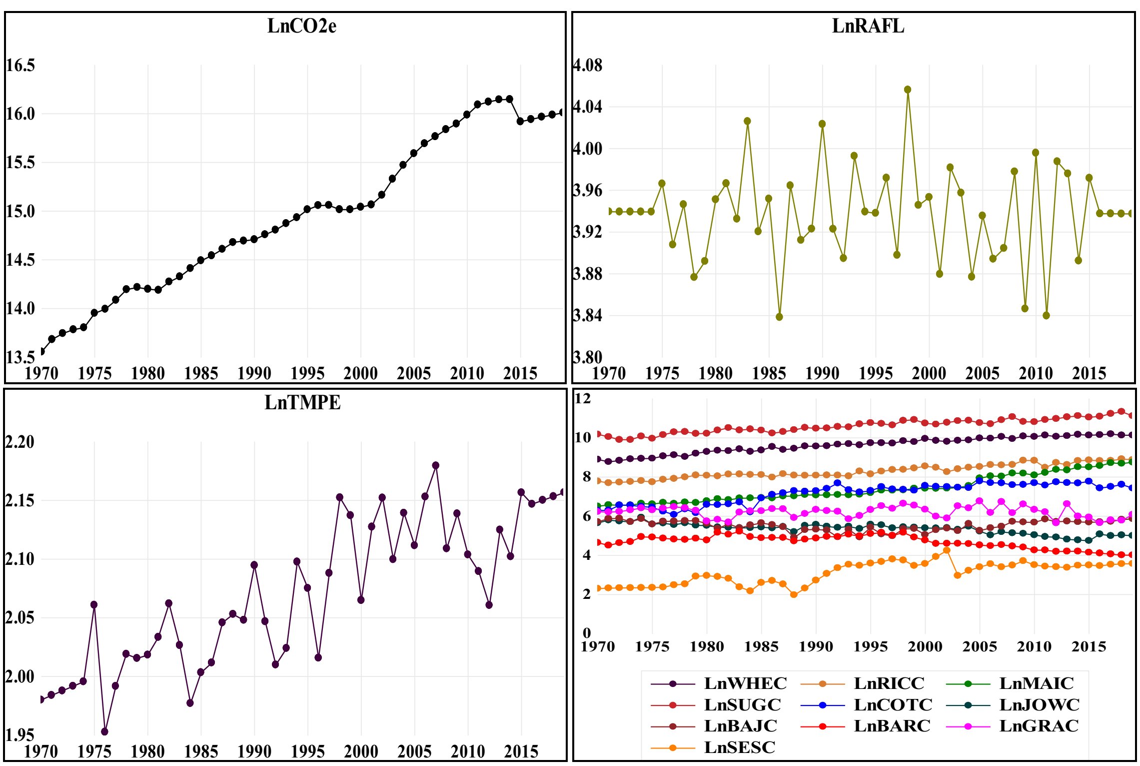

Fig. 1 Plot of variables trend

Table 2 Summary statistics

	$LnCO_2e$	LnRAFL	LnTMPE	LnWHEC	LnRICC	LnMAIC	LnSUGC	LnCOTC	LnIOWC	LnBAJC	LnBARC	LnGRAC	LnSESC	LnLANC
Mean	14.95668	3.937393	2.070341	9.627387	8.293981	7.396979	10.60928	7.153533	5.353083	5.512022	4.684955	6.216144	3.087879	3.049047
Median	14.97412	3.939243	2.063467	9.705168	8.210308	7.142362	10.66417	7.346630	5.409389	5.594649	4.770685	6.259580	3.365533	3.088988
Maximum	16.14687	4.056004	2.179428	10.19144	8.915969	8.749732	11.33060	7.793999	5.934894	5.886104	5.220356	6.766192	4.242765	3.183041
Minimum	13.55624	3.838300	1.952613	8.775858	7.696213	6.504288	9.900834	6.075346	4.744932	4.905275	4.007333	5.648974	1.974081	2.809403
Std. Dev.	0.783159	0.045241	0.061947	0.420884	0.357257	0.691082	0.364620	0.530512	0.272406	0.272232	0.337366	0.285301	0.566923	0.104946
Skewness	0.020110	0.012031	−0.005836	−0.446120	0.176031	0.593978	−0.126788	−0.683643	−0.432995	−0.657414	−0.480165	−0.294028	−0.245362	−0.844393
Kurtosis	1.815005	3.323999	1.750695	2.024028	1.930286	2.023305	2.155250	1.999080	2.634754	2.500817	2.208817	2.392387	1.829672	2.575679
Jarque-Bera	2.928817	0.219905	3.251872	3.642944	2.642158	4.927440	1.620632	5.981899	1.840296	4.120737	3.225424	1.489593	3.355160	6.316766
Probability	0.231215	0.895877	0.196727	0.161787	0.266847	0.085118	0.444717	0.050240	0.398460	0.127407	0.199346	0.474831	0.186826	0.042494

Table 3 Correlation analysis amid variables

	$LnCO_2e$	LnRAFL	LnTMPE	LnWHEC	LnRICC	LnMAIC	LnSUGC	LnCOTC	LnJOWC	LnBAJC	LnBARC	LnGRAC	LnSESC	LnLANC
$LnCO_2e$	1.000000	−0.049540	0.813402	0.968754	0.948341	0.961548	0.933595	0.874928	−0.894925	0.007143	−0.687735	−0.089731	0.747186	0.896509
LnRAFL	−0.049540	1.000000	0.046878	−0.016491	−0.024456	−0.034247	0.049845	0.018987	0.057830	−0.099491	0.171388	−0.086060	0.023525	0.011763
LnTMPE	0.813402	0.046878	1.000000	0.829004	0.825539	0.795267	0.826057	0.761064	−0.679510	−0.076285	−0.534348	−0.041247	0.738316	0.788911
LnWHEC	0.968754	−0.016491	0.829004	1.000000	0.935176	0.912347	0.944522	0.907098	−0.845430	−0.149910	−0.561099	−0.095421	0.806296	0.948737
LnRICC	0.948341	−0.024456	0.825539	0.935176	1.000000	0.953017	0.927456	0.786073	−0.876508	0.047342	−0.694457	−0.142688	0.736247	0.858545
LnMAIC	0.961548	−0.034247	0.795267	0.912347	0.953017	1.000000	0.913583	0.786406	−0.902781	0.171093	−0.803282	−0.180587	0.675243	0.792317
LnSUGC	0.933595	0.049845	0.826057	0.944522	0.927456	0.913583	1.000000	0.806930	−0.811037	−0.050413	−0.589646	−0.147828	0.769977	0.882632
LnCOTC	0.874928	0.018987	0.761064	0.907098	0.786073	0.786406	0.806930	1.000000	−0.713478	−0.329076	−0.459461	−0.017641	0.754915	0.893959
LnJOWC	−0.894925	0.057830	−0.679510	−0.845430	−0.876508	−0.902781	−0.811037	−0.713478	1.000000	−0.084093	0.720702	0.252562	−0.544494	−0.705638
LnBAJC	0.007143	−0.099491	−0.076285	−0.149910	0.047342	0.171093	−0.050413	−0.329076	−0.084093	1.000000	−0.507086	−0.097936	−0.206986	−0.288564
LnBARC	−0.687735	0.171388	−0.534348	−0.561099	−0.694457	−0.803282	−0.589646	−0.459461	0.720702	−0.507086	1.000000	0.254074	−0.328505	−0.355587
LnGRAC	−0.089731	−0.086060	−0.041247	−0.095421	−0.142688	−0.180587	−0.147828	−0.017641	0.252562	−0.097936	0.254074	1.000000	−0.076231	0.008133
LnSESC	0.747186	0.023525	0.738316	0.806296	0.736247	0.675243	0.769977	0.754915	−0.544494	−0.206986	−0.328505	−0.076231	1.000000	0.815902
LnLANC	0.896509	0.011763	0.788911	0.948737	0.858545	0.792317	0.882632	0.893959	−0.705638	−0.288564	−0.355587	0.008133	0.815902	1.000000

and findings show that all variables have correlation to each other.

Study methods and data

The study discusses first the unit root characteristics of the variables for the investigation. The position characteristics of the variables need to be evaluated, so the integration order is very critical in deciding the estimator of regression used to predict the long-term coefficients. In such reviews, the unit root tests suggested by Phillips-Perron (P-P) (Phillips and Perron 1988) and Augmented Dickey-Fuller (ADF) (Dickey and Fuller 1979) were employed for stationarity purposes. However, a downside of these two unit root test approaches is that the procedural disruption in the data is not taken into consideration. However, it is very important to remember structural fractures as avoiding this crucial problem will lead to partial predictions of position properties. The unit root tests consequences are displayed in Table 4 and Table 5.

Cointegration technique of Johansen

Following confirmation of the order of integration in the testing parameters, the interaction between the variables of interest is defined to be important. This analysis uses primarily the generalized method of moments approach to estimate the linkages among study variables. This procedure allows to suggest integrating the testing variables if the statistics values expected are larger than the essential values below and above. The reliability of variables can be measured by interference using the method of Johansen cointegration (Johansen and Juselius 1990) and the effects are interpreted in Table 6.

Outcomes of generalized method of moments

The consequences of the generalized method of moments with two-stage least squares are expressed in Table 7.

The outcomes of Table 7 uncover that wheat, maize, sugarcane, cotton, bajra, gram, sesamum crops, and land use have constructive coefficients (0.239427), (0.298582), (0.194686), (0.127512), (0.135428), (0.146281), (0.039616), and (2.485057) with having probability values (0.3762), (0.0435), (0.2287), (0.2303), (0.2272), (0.0192), (0.4535), and (0.0017) correspondingly that demonstrate a positive association with CO_2 emission in Pakistan. The outcomes also uncover that the variables rainfall, temperature, rice, jowar, and barley showed the negative coefficients (−0.159148), (−0.347359), (−0.267527), (−0.611584), and (−0.271918) with probability values (0.6676), (0.4743), (0.1909), (0.0005), and (0.0636) respectively exposed an adversative association to carbon emission in Pakistan. The most difficult task of this century is to sustain economic development and primarily aim at controlling greenhouse gas pollution within major developed countries. Carbon emission is a global challenge, owing to population growth and the energy efficiency in industrial and agricultural production. Furthermore, the environmental development objective of hunger eradication further intensifies agricultural and energy usage to produce more crops, growing emissions of carbon dioxide. Today's increasing world concern is to create a form of food production to ensure food safety and environmental growth, to use modern energy in all agricultural processes, i.e., irrigation, transport, manufacturing, storage, and delivery with energy absorption (Yavuz 2014; Shaari et al. 2014; Ghosh 2018). The major components of fossil fuels, including solid biomass, fluid biomass, biogas, agricultural waste, and urban waste, are part of the combustible renewable energy and waste. Greenhouse gas pollution issues and energy conservation have contributed to the implementation of aggressive biofuel objectives and to the determination of incentive for the biofuel industry in several countries. Meat, fiber, and feed for livestock are a source of biomass. This accounts for the world's fourth largest power source, after crude, carbon which natural gas, and is one-third of the world's primary energy supply. Biomass raw materials are present in solid, gas, and liquid form and can be used to produce heat, power, and transportation fuels via a variety of technologies. Agriculture can increase its commitment to environmental protection by encouraging environmentally friendency and low-carbon agricultural activity and by supporting biofuel development (Bozkurt and Akan 2014; Ben Jebli and Ben Youssef 2019; Ali et al. 2021).

Carbon dioxide may have a direct impact on agricultural products supply owing to its impact on crop yields, crop conditions and insect infestations, soil fertility, and water storage characteristics. Global warming will also have an indirect impact on economic growth, income distribution, and agricultural demand. Furthermore, shifting weather patterns may have a negative effect on the stability of agricultural output and supply. As agricultural production declines, food prices increase and purchasing power diminishes (Edoja et al. 2016; Zhang et al. 2018; Chandio et al. 2018). Agriculture is considered the main source of greenhouse gas emissions since agricultural techniques are inadequate in terms of productivity and food security. Agriculture is often seen as playing a significant part in meeting CO_2 reduction targets. Similarly, farmers depend heavily on the climate, including temperature, precipitation, and floods. It has an effect on agricultural productivity, food supply, commodity price, and other factors, all of which have a negative impact on economic outcomes. Carbon dioxide emissions account for a colossal percentage of total pollution in developing economies. As a consequence of rapid population growth, energy consumption, economic development, and agricultural production are increasing, and CO_2 emissions are increasing with time (Kulak et al. 2013; Li et al. 2014; Ahmada et al. 2016; Flach et al. 2019).

Table 4 P-P unit root test

		P-P unit root test (at level)													
		$LnCO_2e$	**LnRAFL**	**LnTMPE**	**LnWHEC**	**LnRICC**	**LnMAIC**	**LnSUGC**	**LnCOTC**	**LnJOWC**	**LnBAJC**	**LnBARC**	**LnGRAC**	**LnSESC**	**LnLANC**
With constant	***t*-statistic**	−1.3783	−10.3543	−2.1162	−1.4695	−0.4772	1.1353	−0.35810.09080]	−1.6969	−1.6364	−2.7358	−0.2853	−4.7799	−1.7190	−3.0981
	[Prob.]	[0.5853]	[0.0000]	[0.2394]	[0.5405]	[0.8867]	[0.9973]	n0	[0.4265]	[0.4567]	[0.0754]	[0.9194]	[0.0003]	[0.4156]	[0.0332]
		n0	***	n0	n0	n0	n0		n0	n0	*	n0	***	n0	**
With constant and trend	***t*-statistic**	−1.9094	−10.2488	−5.4645	−3.1447	−4.7181	−1.4500	−4.6606	−2.4545	−3.9054	−2.6290	−1.7628	−4.7984	−2.8294	−1.6875
	[Prob.]	[0.6345]	[0.0000]	[0.0002]	[0.1078]	[0.0021]	[0.8331]	[0.0025]	[0.3484]	[0.0192]	[0.2699]	[0.7074]	[0.0017]	[0.1942]	[0.7419]
		n0	***	***	n0	***	n0	***	n0	**	n0	n0	***	n0	n0
Without constant and trend	***t*-statistic**	4.1309	−0.0299	2.7254	2.8629	3.4019	4.6218	3.3297	1.1046	−1.3020	0.1290	−0.8481	−0.2441	1.2995	1.9089
	[Prob.]	[1.0000]	[0.6679]	[0.9981]	[0.9987]	[0.9997]	[1.0000]	[0.9997]	[0.9279]	[0.1756]	[0.7188]	[0.3434]	[0.5932]	[0.9491]	[0.9854]
		n0	n0	n0	n0	n0	n0	n0	n0	n0	n0	n0	n0	n0	n0
At first difference															
With constant	***t*-statistic**	−4.5787	−35.5878	−32.6191	−12.2264	−13.2691	−7.3469	−11.8046	−10.1632	−12.3372	−14.5506	−8.4495	−29.7907	−13.0744	−9.4356
	[Prob.]	[0.0005]	[0.0001]	[0.0001]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0001]	[0.0000]	[0.0000]
		***	***	***	***	***	***	***	***	***	***	***	***	***	***
With constant and trend	***t*-statistic**	−4.6080	−35.1549	−32.2789	−19.8109	−13.0799	−7.7125	−11.7655	−10.7912	−12.1741	−30.2271	−9.1003	−33.8830	−14.5263	−21.6037
	[Prob.]	[0.0029]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
		***	***	***	***	***	***	***	***	***	***	***	***	***	***
Without constant and trend	***t*-statistic**	−3.4156	−36.0312	−11.3403	−9.1855	−9.8579	−6.0044	−6.6116	−9.7970	−11.3011	−14.7272	−8.4523	−27.3565	−7.9053	−8.5565
	[Prob.]	[0.0010]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
		***	***	***	***	***	***	***	***	***	***	***	***	***	***

(*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant

Table 5 ADF unit root test

		ADF unit root test (at level)													
		LnCO_2e	**LnRAFL**	**LnTMPE**	**LnWHEC**	**LnRICC**	**LnMAIC**	**LnSUGC**	**LnCOTC**	**LnJOWC**	**LnBAJC**	**LnBARC**	**LnGRAC**	**LnSESC**	**LnLANC**
With constant	***t*-statistic** [Prob.]	−1.0090 [0.7429] n0	−10.3647 [0.0000] ***	−0.8807 [0.7846] n0	−3.6525 [0.0089] ***	−0.5652 [0.8684] n0	1.9878 [0.9998] n0	−0.8451 [0.7966] n0	−1.3761 [0.5853] n0	−1.2458 [0.6470] n0	−1.6799 [0.4348] n0	−0.5060 [0.8807] n0	−3.7552 [0.0062] ***	−1.9209 [0.3203] n0	−2.6333 [0.0935] *
With constant and trend	***t*-statistic** [Prob.]	−2.6309 [0.2692] n0	−10.2586 [0.0000] ***	−5.4645 [0.0002] ***	−3.1738 [0.1016] n0	−4.6257 [0.0027] ***	−1.5391 [0.8021] n0	−3.1436 [0.1085] n0	−0.6551 [0.9704] n0	−3.9388 [0.0193] **	−1.0123 [0.9322] n0	−2.4315 [0.3594] n0	−3.7711 [0.0271] **	−2.8016 [0.2037] n0	−1.6988 [0.7365] n0
Without constant and trend	***t*-statistic** [Prob.]	2.6409 [0.9976] n0	−0.0304 [0.6676] n0	2.2798 [0.9937] n0	4.6000 [1.0000] n0	2.6347 [0.9975] n0	4.1225 [1.0000] n0	2.6408 [0.9976] n0	1.0193 [0.9167] n0	−1.3249 [0.1689] n0	−0.1036 [0.6428] n0	−0.7137 [0.4022] n0	−0.4325 [0.5214] n0	0.3070 [0.7705] n0	1.8331 [0.9827] n0
At first fifference															
With constant	***t*-statistic** [Prob.]	−4.5578 [0.0006] ***	−9.9917 [0.0000] ***	−4.5606 [0.0007] ***	−8.5139 [0.0000] ***	−7.1498 [0.0000] ***	−3.5234 [0.0117] **	−8.9309 [0.0000] ***	−9.4166 [0.0000] ***	−10.7926 [0.0000] ***	−7.6125 [0.0000] ***	−3.9270 [0.0038] ***	−6.1882 [0.0000] ***	−5.6371 [0.0000] ***	−9.0064 [0.0000] ***
With constant and trend	***t*-statistic** [Prob.]	−4.5787 [0.0032] ***	−9.8776 [0.0000] ***	−4.5305 [0.0041] ***	−3.6408 [0.0388] **	−7.0648 [0.0000] ***	−4.5672 [0.0036] ***	−8.7679 [0.0000] ***	−4.9142 [0.0013] ***	−10.6759 [0.0000] ***	−6.1743 [0.0000] ***	−4.3420 [0.0062] ***	−6.1357 [0.0000] ***	−5.6143 [0.0002] ***	−9.5475 [0.0000] ***
Without constant and trend	***t*-statistic** [Prob.]	−3.4388 [0.0010] ***	−10.1046 [0.0000] ***	−6.4608 [0.0000] ***	−1.3321 [0.1664] n0	−9.7838 [0.0000] ***	0.0367 [0.6884] n0	−7.9920 [0.0000] ***	−9.3185 [0.0000] ***	−10.6527 [0.0000] ***	−7.6982 [0.0000] ***	−3.8915 [0.0002] ***	−6.2411 [0.0000] ***	−6.3814 [0.0000] ***	−8.5564 [0.0000] ***

(*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant

Increasing farm output has decreased deforestation and enhanced development of biofuels to substitute fossil fuels with renewable energy sources. Agricultural planning is an effective method for governing farm aid environmental sustainability (Rehman et al. 2020a, b). Climate change is a serious problem that has a huge impact on today's society and environment. The continuous increase in carbon dioxide emission would raise temperatures and cause long-term climatic variations (Rehman et al. 2021b; Rehman et al. 2021c). Carbon dioxide has a capacity for global change, and certain public health and environmental mitigation issues has a major importance. Carbon dioxide has little impact on a nation, but it is distressing to the entire planet. This problem cannot be dealt with alone by individuals. Collective measures to tackle and reduce climatic change are also needed at global and regional levels (Begum et al. 2015; Hashmi and Alam 2019; de Souza Mendonça et al. 2020). The natural environment has a significant impact on economic operations. It leads straight to the produce of goods and services and supplies indirect energy and commodity products, including carbon sequestration, water purification, flood protection, and nutrient cycling, such as water, wood, and mineral products. Natural resources are also important for global growth and sustainable development not just today but also for subsequent generations (Saudi et al. 2019).

Sustainable development would guarantee that the wellbeing of potential generations does not deteriorate to the extent that tangible and intangible resources are accessible. With this in mind, fossil fuels for at least two purposes are not a viable means of sustainable social change. First, excess usage of fossil fuels that are not green limits the use of unborn fuels. Second, a significant number of greenhouse gases are emitted from the usage of fossil energy, accelerating global

Table 7 Generalized method of moments results

Generalized method of moments (two-stage least squares)				
Variables	**Coefficients**	***S*-error**	***t*-statistic**	**Prob.**
LnRAFL	−0.159148	0.367534	−0.433015	0.6676
LnTMPE	−0.347359	0.480377	−0.723097	0.4743
LnWHEC	0.239427	0.267233	0.895950	0.3762
LnRICC	−0.267527	0.200693	−1.333015	0.1909
LnMAIC	0.298582	0.142693	2.092473	0.0435
LnSUGC	0.194686	0.159003	1.224419	0.2287
LnCOTC	0.127512	0.104493	1.220289	0.2303
LnJOWC	−0.611584	0.159156	−3.842672	0.0005
LnBAJC	0.135428	0.110237	1.228521	0.2272
LnBARC	−0.271918	0.142076	−1.913893	0.0636
LnGRAC	0.146281	0.059690	2.450659	0.0192
LnSESC	0.039616	0.052283	0.757724	0.4535
LnLANC	2.485057	0.734183	3.384792	0.0017
C	6.222625	2.369230	2.626434	0.0126
{*R*-squared}	0.987025	{Mean dependent var}		14.95668
{Adjusted *R*-squared}	0.982340	{S.D. dependent var}		0.783159
{S.E. of regression}	0.104075	{Sum squared resid}		0.389937
{Durbin-Watson stat}	1.309335	{*J*-statistic}		36.00000
{Instrument rank}	15	Prob (*J*-statistic)		0.000000

Table 6 *J*-cointegration test outcomes

Trace test-values				**Maximum eigenvalue test-values**		
H-No. of CE(s)	***T*-statistic**	***C*-value (0.05)**	**Prob.****	**Max-Eigen statistic**	***C*-value (0.05)**	**Prob.****
None	914.4876	-	0.0000	234.3594	-	0.0000
At most 1	680.1282	-	0.0000	163.7552	-	0.0000
At most 2*	516.3730	334.9837	0.0000	114.1662	76.57843	0.0000
At most 3*	402.2068	285.1425	0.0000	87.75980	70.53513	0.0007
At most 4*	314.4470	239.2354	0.0000	77.77493	64.50472	0.0017
At most 5*	236.6721	197.3709	0.0001	71.49621	58.43354	0.0017
At most 6*	165.1759	159.5297	0.0237	58.70068	52.36261	0.0099
At most 7	106.4752	125.6154	0.3986	33.55214	46.23142	0.5547
At most 8	72.92306	95.75366	0.6201	23.42299	40.07757	0.8562
At most 9	49.50007	69.81889	0.6593	20.51488	33.87687	0.7201
At most 10	28.98518	47.85613	0.7691	13.55685	27.58434	0.8519
At most 11	15.42833	29.79707	0.7517	8.319126	21.13162	0.8832
At most 12	7.109205	15.49471	0.5650	5.593503	14.26460	0.6657
At most 13	1.515702	3.841466	0.2183	1.515702	3.841466	0.2183

* signifies at 0.05 level hypothesis rejection; **Signifies the *p*-values of MacKinnon-Haug-Michelis (1999)

climate change and the intense climatic events. The quest for sustainable energies and low carbon resources in modern life has therefore become an interesting matter (Qambrani et al. 2017; Grashuis 2019). In directive to assess the impact on optimal carbon pollution reductions and carbon tax rates of endogenous technological improvements in the macroeconomic climate model, it is suggested that in order to achieve the required limit in the ambient carbon concentration, adopting endogenous innovations would need quicker reductions in emissions. The most critical priority and the largest opportunity for mitigation of emissions is the development of non-fossil energy technology. Lower emissions could result from optimal carbon tax rates and decreased usage of fossil fuels. We also found that this previous research is consistent with the actions of the South Asian countries to preserve economic interests and combat climate change (Andrew et al. 2010; Marron and Toder 2014; Urata et al. 2017; Timilsina and Toman 2018). Figure 2 is clearly expressing the constructive and adversative linkages of carbon emission to major agricultural crops production and land usage in Pakistan.

Conclusion and policy implications

The main motive of current investigation was to observe the carbon dioxide emission and climatic impacts to the major agricultural crops production and land use in Pakistan. We have utilized the time span annual data varies from 1970 to 2019, which is gathered from the Economy Survey of Pakistan and World Development Indicators. All variables' stationarity was rectify by utilizing the unit root tests including P-P and ADF. A generalized method of moments with two-stage least squares technique was applied to demonstrate the variables linkage with CO_2 emission. The consequences of study uncover that the wheat, maize, sugarcane, cotton, bajra, gram, sesamum, and land use have productive association with CO_2 emission having positive coefficients, while rainfall, temperature, rice, jowar, and barley uncovered a adversative linkage to CO_2 emission in Pakistan.

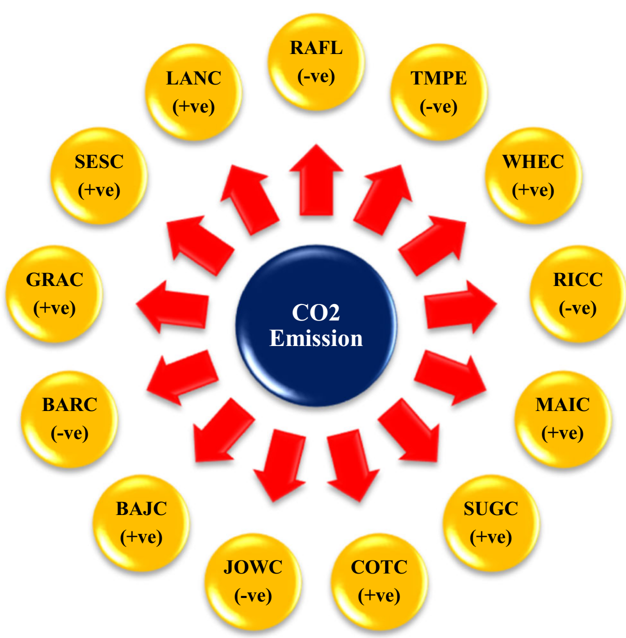

Fig. 2 Variables constructive and adversative interaction to CO_2 emission

Based on the consequences, in order to improve agricultural production and economic development, the Pakistani government must implement potentially conservative measures to decrease carbon dioxide emissions. Because the use of fossil fuels leads to an increase in the production of greenhouse gases (GHG) in the outer atmosphere, which adds to an increase in the earth's surface temperature and pollutes the environment. Climatic change has an effect on human life and the economy, disrupts the earth's climate system, and causes natural disasters such as floods, famine, droughts, and cyclones. Climate change is expected to have a variety of impacts in Pakistan, including decreases in agricultural output, greater improvements in water supply, increased coaster floods and penetration into saltwater, and recurrent severe weather occurrences. Farmers' limited direct market access is a significant issue in agriculture; thus, the role of intermediaries remains critical. Farmers often do not get equal agricultural market pricing. In terms of potential, the agricultural sector not only feeds the local population, but it also has the ability to produce export surplus products, which not only provide food security but also promote foreign exchange gains.

Availability of data and materials Not applicable

Author contribution AR conceived the study, collected the data, designed the econometric methodology, and wrote the original draft; IO reviewed and edited the manuscript; MIA and HM read and made suggestions to improve the quality of the manuscript. All authors read and approved the final manuscript.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Conflict of interest The authors declare no competing interests.

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