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RESEARCH ARTICLE

Do Agriculture Technologies Influence Carbon Emissions in Pakistan? Evidence based on ARDL technique

Rafaqet Ali[1] · Rabia Ishaq[1] · Khuda Bakhsh[1] · Muhammad Asim Yasin[1]

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ABSTRACT

Pakistan is an agrarian country, and the usage of agriculture technologies has increased in this country over the period of time. Extensive use of agriculture technologies may have detrimental impact of environment quality through an increase in carbon dioxide emissions. This study examines the impact of agriculture technologies on carbon emissions in Pakistan by using the annual time series data for the period 1973–2018. For long-run and short-run analysis, autoregressive distributed lag model is applied and the results reveal that cointegration exists among the variables. Long-run results show a significant positive impact of pesticide and economic growth on carbon emission, whereas short-run results confirm the positive effect of economic growth on carbon emissions in Pakistan. This study has important policy implications, such as to increase sustainable economic growth through agriculture sector; there is a need to introduce green technologies that produce less carbon emissions.

Keywords Agriculture technologies · Carbon dioxide emission · ARDL · Pakistan

Introduction

In the current era, more attention has been paid on progress activities such as an increase in technologies and new innovations all over the world. There are many technological advancements in every field of life such as in industrialization, motorization and technological innovations in agriculture sector, etc. This study explores the role of agriculture technologies on carbon dioxide emission in Pakistan. There are many agriculture technologies such as hybrid seeds, vertical farming, soil and water sensors, fertilizers, pesticides and machineries. These technologies and innovations have some positive as well as some negative impacts on the economy and environment (Chandio, et al. 2020a, b; Chandio et al. 2020a; Ozturk et al. 2021). The agriculture sector has positive as well as negative effects on environment; positive effects contain provision of natural life and production of oxygen. Agriculture technologies and innovations are increasing agriculture productivity as well as economic growth (Bresnahan and Trajtenberg 1995). On the other hand, negative effects are approaching from the practices of chemical fertilizer, pesticides, stubble burning, soil tillage etc. (Onder et al. 2011).

Agriculture is important for food, livelihood and nutrition (Rehman et al. 2020a). Industries are mostly depending on agriculture productivity for raw materials (Ozturk 2017; Rehman et al. 2019, 2021e). Agriculture growth has supplementary effects on entire economy due to close linkages with other economic sectors (Pathak et al 2014; Chandio et al. 2021a, b). Pakistan is an agrarian economy; hence, agriculture sector is the backbone of Pakistan (Rehman et al. 2019). More than half of the total labor force is linked with the agriculture sector directly or indirectly, and the agriculture sector has made significant contribution to the GDP of this country.

New technologies and innovations not only increase CO_2 emission but also contribute to greenhouse gas emissions

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✉ Rafaqet Ali
rafaqatashiq@cuivehari.edu.pk

Rabia Ishaq
rabia.ishaq888@gmail.com

Khuda Bakhsh
kbakhsh@cuivehari.edu.pk

Muhammad Asim Yasin
dr.asim@cuivehari.edu.pk

[1] 1Department of Management Sciences, COMSATS University Islamabad, Vehari Campus, Vehari, Pakistan

(GHG). Presently, the world is intensively focusing on sustainable development and controlling environment degradation (Ali et al. 2019; Rehman et al. 2021f; Rehman et al. 2021g). Greenhouse gases include nitrous oxide (N2O), carbon dioxide (CO_2) and methane (CH4) among others. There is more contribution of CO_2 emission in greenhouse gases rather than nitrous oxide (N2O) gases and methane (CH4). The most significant greenhouse gas (GHG) emissions from agriculture are CO_2, N_2O and CH4 (IPCC 2007). Indirect energy usage also increases CO_2 emission which includes production of pesticide, fertilizer and machinery (Ozkan et al. 2004). According to Internal Panel of Climate Change report (IPCC 2007), agriculture sector is the second source of increasing greenhouse gas (GHG) emission.

Agriculture ecosystem and natural environment are diligently related to each other. Carbon emission generated directly through agriculture production. In the process of agriculture production, inappropriate use of land and use of chemical fertilizers and pesticide in huge amount can lead to an increase in the large amount of carbon (CO_2) emission and other greenhouse gas (GHG) emissions that can affect the environment adversely (Chandio et al. 2021a; Rehman et al 2021c). Use of energy as preliminary inputs in agriculture also increases the agriculture productivity (Jaber 2002).

The overuse of pesticides leads to more severe problems such as polluting water and degradation of cropland soils. The elements and substances of pesticides that exist in crops and vegetables transfer into human body and cows' milk and pass on to the newborns as well. In this situation, poisonous effects are transmitted to next generation (Carey 1991). Pesticides also produced emission even during their manufacturing processes in the industries (Audsley et al. 2009). Use of pesticide in vegetables and fruits creates health problems for consumers because of pesticide residues found in fruits and vegetables (Fantke et al. 2012). Climate change also reduced the agricultural productivity due to increasing water scarcity problem, etc. (Antle & Capalbo 2010; Fallaon and Betts 2010).

Agriculture machineries like tractors, etc., also emit gas emission in the process of tillage (Arapatsakos & Gemtos 2008). Selection of inappropriate machinery for tillage has negative impact on the environment. Use of machineries for a long period of time emits more emission, which have detrimental impact on environment (Sarauskis et al. 2014). Agriculture sector also uses energy such as fuel use in machines for manufacturing process, using inputs for agriculture production such as pesticides which encourage emissions (Marttila et al 2001). The usage of energy is also important factor of environment degradation (Murshed et al. 2021).

The objective of this study is to examine long-run and short-run impacts of agriculture technologies on CO_2 emissions in Pakistan. As discussed earlier, agriculture technologies have positive as well as negative effects on the environment and human health (Rehman et al. 2021d). Previous studies also show that the agriculture technologies are increasing carbon emission and greenhouse gas (GHG) emission mostly in developing countries (Eberhardt & Vollrath, 2016; Fantke et al. 2012; Pathak et al. 2014; Rehman et al 2021e). It is pertinent to mention that the level of carbon dioxide emission varies from country to country (Chishti et al. 2021). Pakistan is an agriculture-based country, and agriculture technologies are being used extensively. To the best of our knowledge, there are two studies available on this topic for Pakistan (Rehman et al. 2019; Ullah et. al 2018). However, these studies did not examine the role of pesticide on carbon dioxide emission. Audsley et al. (2009) argue that pesticides produced emissions even during their manufacturing processes. This study departs from previous research include pesticide usage variable along with other agriculture technologies-related variables and overall economic growth in the model. To examine the effect of agriculture technologies on CO_2, latest available time series data and econometric techniques are used.

The remaining study contains the following sections. A brief literature review is given in Sect. 2, whereas model, variable transformation, source of data and econometric research methodology are discussed in Sect. 3. Sections 4 contains the results as well as discussions and conclusion along with important policy implications presented in Sect. 5.

Literature review

The effects of agriculture productivity as well as agriculture technologies on environmental quality have been discussed in this literature. On the other side, agriculture sector is also affected by climate change; for example, changes in rainfall pattern, heat waves, increase in average temperature and drought periods. Keeping in view the objective of this study, we reviewed some important studies which explored the determinants of carbon dioxide emission. A summary of the literature review is given in Table 1. Detailed reviews of the previous literature are also presented below.

Rehman et al. (2021a, b, c, d, e, f, g, h) found positive impact of industrialization, energy import and gross capital formation, whereas negative impact of economic growth on carbon emission in Pakistan by using quantile regression technique. Koondhar et al. (2021) claimed a reduction in carbon emission due to an increase in area of forestry as well as renewable energy; however, agricultural financial development deteriorates environmental quality in China. They applied ARDL technique and used data for the period 1998–2018. Rehman et al. (2021a) applied generalized method of moments (GMM) for analyzing the effect of different crop productions and land use on carbon emission for

Table 1 Summary of literature review

Authors	Country/Period	Econometric Techniques	Findings*
Rehman et al. (2021a, b, c, d, e, f, g, h)	Pakistan/ 1971–2019	Quantile Regression	I, EN and INV ↑CO2 G ↓CO2
Koondhar et al (2021)	China/ 1998–2018	ARDL	AFD ↑CO2 F, RE ↓CO2
Rehman et al. (2021a)	Pakistan/1970–2019	GMM	Mixed effect of CP on CO2
Weimin et al. (2021)	46 developing countries/1990–2016	panel FMOLS, DOLS	G, EN, NIS, FDI ↑co2 RE, GB PIS ↓ co2
Rehman et al (2021b)	China/1988–2017	ARDL, VECM	RF, AVA ↑CO2 LP, CP, TP ↓CO2 in the long run
Hussain and Rehman. (2021)	Pakistan/1975–2019	ARDL,	P, FI ↑CO2 RE ↓CO2
Regmi and Rehman, (2021)	NEPAL/1971–2019	Johensen approach, ARDL, Causality test	FE, EU ↑CO2 G, P ↓CO2
Khan et al (2021)	Canada/1989–2020	dynamic ARDL simulations	R&D, FD, T, EE ↑CO2 ET ↓CO2
Rehman., Ma, H and Ozturk, (2020)	Pakistan/1988–2017	ARDL Causality test	T, RF, WA, MC ↑CO2
Rehman, et al, (2019)	Pakistan/1987–2017	ARDL	G, EN, CA,FO, WA ↑CO2 FG, SD ↓CO2
Anwar et al. (2019)	59 countries/ 1982–2015	Panel DOLS, FMOLS Causality	FR, PS ↑CO2 AVA ↓CO2
Zhang et al. (2019)	China/1996–2015	ARDL, VECM	A ↑CO2 (long and short run)
Ismael et al. (2018)	Jordon/1970–2014	T-Y Causality	FR, AR, WA, S→CO2 G↔CO2
Ullah et al. (2018)	Pakistan/ 1972–2014	Johansen cointegration, ARDL, Causality	N2O-FR, AM, LS, CP, ↑CO2
Appiah et al. (2018)	BICS(Brazil, India, China, and South Africa)/1971–2013	Panel DOLS, FMOLS, Causality	LSI, CPI, G ↑CO2 EN, P ↓CO2
Ghosh (2018)	India/1971–2013	Johansen cointegration, ARDL, Causality	AVA, FD, EN,TR ↑CO2
Liu et al. (2017)	BRICS/1992–2013	Panel OLS, DOLS, FMOLS, VECM	A, EN ↑CO2 RE, PCG ↓CO2
Dogan (2016)	Turkey/ 1968–2010	ARDL	A ↓CO2 (in long and short run_
Edoja et al. (2016)	Nigeria/1960–2010	Causality, Impulse response function	Short run CO2→A & FS

* A; agriculture output, AFD; agriculture financial development, AM; agri-machinery, CA; Crop area, CRP; cereal production, CP; crops production, EU; energy utilization, EI; energy intensity, ET; environment related technologies, EN; energy usage, F; forestry, FD; financial development, FD; food grains, FI; foreign investment, FR; fertilizer, FS; food security, G; economic growth, GB; globalization, I; investment, P; population, MC; maize crop production, NIS; negative innovation shocks, N2O-F; CO2 equivalent of nitrous oxide from fertilizer, LS; livestock, PS; pesticides, PIS; positive innovation shocks, RF; rainfall, RN; renewable energy, R&D; research and development, SD; seed distributions, TR; trade, T; temperature, WA; water availability

Pakistan. They found a constructive role of land use, maize wheat, bajra, sugarcane and cotton crops, and detrimental role of temperature, rainfall, barley, jowar and rice for CO2 emission. Weimin et al. (2021) examined the role of fossil fuel and renewable energy along with GDP, globalization, innovation shocks and FDI on carbon emissions in 46 developing countries. This study found positive impact of GDP, FDI and negative innovation shocks, whereas negative impact of renewable energy and positive innovation shocks on CO_2 emission. According to Rehman et al (2021b), in the long run carbon dioxide emissions are influenced by rainfall and agriculture value added; however, livestock, cereal production and temperature reduce CO_2 emission in China. Hussain and Rehman (2021) claimed a detrimental role of population and foreign investment and constructive role of renewable energy for CO_2 emission in Pakistan in the long run. Regmi and Rehman et al (2021a, b, c, d, e, f, g, h) claimed that in the long run, population and economic growth reduce, whereas fossil fuel energy and energy utilization enhance carbon emission in Nepal. They also found unidirectional causality prevails among the variables. According to the findings of Khan et al (2021), environmental-related technologies reduce carbon emission both in the short and in the long run; however, financial development, research and development, temperature, natural resources depletion and energy intensity erode environment quality. As per the study of Rehman et al. (2020), temperature, rainfall, water availability and maize crops production positively influence carbon dioxide emission in Pakistan. Rehman et al. (2019) found strong long-run positive impact of per capital GDP, energy usage, crop area, fertilizer offtake and water availability on carbon emissions in Pakistan. They claim negative effect of food grains and seed distributions on carbon emission.

Anwar et al. (2019) explored relationship among agriculture value added, agricultural technologies and CO_2 emission for 59 countries by using annual data for the period 1982–2015. They found that nitrogen fertilizer and pesticide effect the environment positively in high-income countries, while agriculture value added leads to a decrease in carbon emission in middle-income countries. Zhang et al. (2019) interpreted correlation among energy consumption, agriculture economic growth and CO_2 emission in the agriculture sector of China during 1996 to 2015. This study practices autoregressive distributed lag (ARDL) and vector error correction mechanism (VECM) techniques. Results indicate positive effect of carbon emission with agriculture productivity (A) in the long run and short run. Ismael et al. (2018) found unidirectional causality from fertilizer, agricultural machinery, water accessibility and subsidies to carbon emissions, whereas two-way causality in economic growth and carbon emission in Jordon. Ullah et al. (2018) provided evidence of long-run impact of agriculture machinery, emissions of CO_2 equivalent of nitrous oxide from fertilizer, biomass burned crop residues, on carbon emission crop productions in Pakistan. They also found bidirectional causality among carbon emission, crop productions, rice area harvested and agriculture machinery. Appiah et al. (2018) examined the linkage in CO_2 emission and agriculture production for five emerging economies (Brazil, Russia, India, China and South Africa) from 1971 to 2013. The results concluded the contribution of livestock production index and crop production index in carbon dioxide emissions. Surprisingly, this study claims a supporting role of energy consumption and population for environmental quality. Ghosh (2018) elaborated the long-run and short-run relationships among carbon emission, agriculture value added, consumption of energy, trade liberalization and financial development in India from the data 1971 to 2013. He claimed that in the long run, consumption of energy, financial development, agriculture value added and trade have positive effects on carbon emission. Liu et al. (2017) concluded the relationship among agriculture, per capita renewable energy, nonrenewable energy and output of BRICS countries from 1992 to 2013. Results demonstrate that both renewable energy and per capita output play a negative role in carbon emissions, while there is positive association among agriculture, CO_2 emission and nonrenewable energy. Dogan (2016) examined the agriculture-induced environment Kuznets curve for Turkey by using annual data 1968–2010. The author concludes that there is positive impact of agriculture on environment quality both in the short and in the long run. Edoja et al. (2016) asserted the relationship among agriculture productivity, carbon emission and food security in Nigeria. The results revealed that there is short-run and negative relationship among CO_2 emissions, food security and agriculture productivity. Unidirectional causality is found from CO_2 emission to agriculture productivity and also from CO_2 emissions to food security.

Model, data and methodology:

Model specification and data

To meet the objectives, this study specifies the following model to envisage the impact of different variables of agriculture technologies on carbon emissions.

$$CO_{2t} = f\left(FER_t, PES_t, TRA_t, GDP_t\right) \quad (1)$$

Here, carbon dioxide emission (CO_2) is a function of consumption of fertilizer (FER), pesticide (PES) and agriculture machinery, which represents as the number of tractors (TRA) and economic growth (GDP). For converting the above functional formed model into econometric models, all the variables are transformed into natural logarithmic form. The advantages of converting variables in natural log form are as follows: Firstly, the results of the coefficients can be interpreted into elasticity. Secondly, nonlinearity (if exists) in the series can be eliminated. (Ali et al. 2019). After transformation, the proposed econometric model is as follows:

$$LCO_{2t} = \alpha + \beta_1 LFER_t + \beta_2 LPES_t + \beta_3 LTRA_t + \beta_4 LGDP_t + \mu_t \quad (2)$$

In the above equation, α is an intercept, β_1, β_2, β_3, β_4 are slope coefficients of respective variables, whereas μ_t is an error term which assumes to have zero mean and constant variance and the subscript *t* represents time series model. The details about the measurements of variables and sources of the data are given in Table 2. This study uses the annual time series secondary data for the period 1973–2018. Data of carbon dioxide emission are collected from BP Statistical

Table 2 Measurements of Variables

Variables	Measurement	Source of data
CO2	Carbon dioxide emission (kiloton)	BP Statistical Review
FER	Fertilizer offtake (ton)	GoP
PES	Pesticide (ton)	GoP
TRA	Number of tractors	GoP
GDP	Real GDP(in local currency unit)	WDI

Note: GoP and WDI stand for Government of Pakistan and World Development Indicators, respectively

Table 3 Results of ADF test

Variables	At level	*p* value	Δ	*p* value	Status
LnCO2	-1.079	0.921	-3.981	0.003***	I(1)
LnFER	-4.806	0.000***	-6.879	0.000	I(0)
LnPES	-3.481	0.052**	-6.756	0.000	I(0)
LnTRA	-5.674	0.000***	-9.848	0.000	I(0)
LnGDP	-1.830	0.673	-4.273	0.001***	I(1)

*, ** and *** show the significance level at 10%, 5% and 1%

Review of World Energy, 2019 (online link: www.bp.com). Data on real GDP variable are retrieved online from World Development Indicators (WDI), published from World Bank, available at (Online link: https://databank.worldbank.org/source/world-development-indicators). Beside this, data regarding tractor, pesticide and fertilizer are collected from Economic Survey of Pakistan published by Ministry of Finance, Government of Pakistan (Online link: http://www.finance.gov.pk/survey/chapters_16/02_Agriculture.pdf).

Econometric methods

Usually time series data contain trends; therefore, it is pertinent to check whether data series have trend or not? Application of ordinary least square technique on non-stationary variables may provide spurious results. To avoid such problem, different econometric tests have been devised in the literature to examine stationarity of the variables that is called unit root analysis. However, augmented Dickey–Fuller (ADF) test, developed by Dickey and Fuller (1979), is widely used in the literature for country-specific time series studies. This study applied ADF test to check the stationarity.

After examining unit root, the next step is to find long- and short-run results. For this purpose, different cointegration techniques are proposed by different econometricians/researchers. Autoregressive distributed lag (ARDL) bond test technique, devised by Pesaran et al. (2001), is one of the latest cointegration techniques and is being extensively used in the literature. Through this technique, both long-run and short-run results can be found. This cointegration technique has numbers of advantage over the other contemporary cointegration techniques. For example, this method is more appropriate for small observations-based study and is applicable if the variables in a model have the mix order of integration. Keeping in view the advantages, this study applies ARDL technique which is based on the following equations:

$$\begin{aligned}\Delta(LCO_2)_t =& \alpha + \beta_1(LCO_2)_{t-1} + \beta_2(LPES)_{t-1} \\ &+ \beta_3(LFER)_{t-1} + \beta_4(LTRA)_{t-1} \\ &+ \beta_5(GDP)_{t-1} + \sum_{i=1}^{p_1}\delta_1\Delta(LCO_2)_{t-1} \\ &+ \sum_{i=0}^{p_2}\delta_2\Delta(LPES)_{t-1} \\ &+ \sum_{i=0}^{p_3}\delta_3\Delta(LFER)_{t-1} \\ &+ \sum_{i=0}^{p_4}\delta_4\Delta(LTRA)_{t-1} + \sum_{i=0}^{p_5}\Delta(LGDP)_{t-1} + \epsilon_t\end{aligned} \tag{3}$$

In the above equation, Δ is showing the first difference, δ_i is showing the short-run dynamic coefficients of ARDL equation and β_{is} are parameters. By following this ARDL equation, we can illustrate the short-run and long-run parameters.

$$\begin{aligned}LCO_{2t} =& \alpha + \sum_{i=1}^{p_1} n_1(CO_2)_{t-1} + \sum_{i=0}^{p_2} n_2(PES)_{t-1} \\ &+ \sum_{i=0}^{p_3} n_3(FER)_{t-1} + \sum_{i=0}^{p_4} n_4(TRA)_{t-1} \\ &+ \sum_{i=0}^{p_5} n_5(GDPPC)_{t-1} + \epsilon_t\end{aligned} \tag{4}$$

The above is a long-run equation of ARDL that tells about the long-run relationships among the variables.

$$\begin{aligned}\Delta(LCO_2)_t =& + \sum_{i=1}^{p_1}\gamma_1\Delta(CO_2)_{t-1} + \sum_{i=0}^{p_2}\gamma_2\Delta(PES)_{t-1} \\ &+ \sum_{i=0}^{p_3}\gamma_3\Delta(FER)_{t-1} \\ &+ \sum_{i=0}^{p_4}\gamma_4\Delta(TRA)_{t-1} + \sum_{i=0}^{p_5}\gamma_5\Delta(GDPPC)_{t-1} + \omega ECM_{t-1} + \epsilon_t\end{aligned} \tag{5}$$

Equation 5 represents the short-run relationships among the variables. The value of ECM in the short-run equation shows the speed of adjustment and also tells about the convergent and divergent from the long-run equilibrium. The value of δ_i lies between 0 and -1. If ECM value comes negative, it shows convergence toward the long-run equilibrium and positive sign with ECM shows divergent from long-run equilibrium.

Some diagnostic tests were also applied to check the accuracy of the model, e.g., heteroscedasticity, non-normality and

Table 4 Lag length selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	56.288	NA	6.33e-08	-2.385	-2.181	-2.310
1	298.374	416.612	2.63e-12	-12.482	-11.254*	-12.029*
2	326.196	41.410*	2.43e-12*	-12.614*	-10.361	-11.783
3	345.258	23.939	3.64e-12	-12.337	-9.061	-11.129

serial correction tests. To check the stability of the model, CUSUM and CUSUMSQ tests are also used.

Results and discussion

Before applying any econometric technique, it is needed to check whether time series data are stationary or not? For this determination, ADF test is applied. This test helps us to understand the selection of further econometric techniques.

The results of unit root test are given in Table 3, wherein Ln abbreviation is used with all the variables, which represents conversion of the respective variables into natural logarithmic form. This table depicts that the variables fertilizer, pesticide and tractor are significant or stationary at level; I (0) with the probability values 0.000, 0.053 and 0.000. Besides this, the variables CO_2 and GDP are significant at first differenced with the probability values 0.003 and 0.001. The results from unit root analysis compel to use ARDL bound test technique on the proposed model because selected variables have mixed order of integration. Before applying ARDL, the lag selection criteria are necessary because optimal lag length helps to have robust results. The results of optimal lags according to different lag selection criteria are given in Table 4.

Bound test is required to check the existence of cointegration in the model. If the value of F-statistics is greater than upper bound I (1), conclusion can be drawn as cointegration among the variables, whereas if the calculated F-statistics values are below that lower bound I (0) we can say that there is no cointegration in the model. The results of calculated F-statistics values along with the lower and upper bound values are given in Table 5.

The value of F-statistics is 6.279 which is greater than upper bound at one percent level; therefore, it confirmed the cointegration in the model. Hence, long-run relationship exists between carbon emission and agriculture technologies.

To measure the impact of agriculture technologies on carbon emission, the ARDL technique is applied and Table 6 shows the long-run impact of independent variables on dependent variables. The above results show that there is a positive role of fertilizer on carbon emissions; however, this relationship is insignificant. According to UN (2015), farmers in developing countries are using synthetic fertilizers indiscriminately. Therefore, there is a possibility of insignificant impact of fertilizer on carbon emission in Pakistan. This finding of this study is not aligned with the finding of Rehman et al. (2019) who found positive significant impact of fertilizer usage on carbon emissions. As far as agriculture machinery is concerned which represents the number of tractors used, there is negative insignificant of tractors on carbon emission. There is a strong significant relationship between pesticide and carbon emission as one percent increase in pesticide brings 0.082 percent increase in carbon emission. Moreover, this relationship is significant at 5 percent level. There are possible reasons of positive relationship between carbon emission and pesticide in Pakistan. The diseases are increasing in crops and plants due to the environmental degradation, and farmers are using more pesticides to protect their crops from the insects. That is the reason for the demand of pesticide, increasing day by day; hence, the usage of pesticides is deteriorating environment quality. Our findings are aligned with the study of Li et al. (2014) who also found positive relationship between pesticide and carbon emission.

There is also a strong significant relationship between real GDP and carbon emission as 1 percent increase in real GDP brings 1.821 percent increase in carbon emission. Developing countries are focusing on high economic growth through

Table 5 Results of Bound test estimation

F-stat	Significance level	Lower bound	Upper bound	Status
6.279	10%	3.03	4.06	Co-integration
	5%	3.47	4.57	
	1%	4.4	5.72	

Table 6 Results of long-run estimation

Variables	Coef	St.Err	t-stat	p value
LnFERTI	0.074	0.132	0.557	0.581
LnTRAC	-0.042	0.058	-0.731	0.470
LnPESTI	0.082	0.041	2.071	\0.046**
LnGDP	1.821	0.349	5.214	0.000*

* and ** represent significance at 1% and 5% level

industrialization and over usage of agricultural technologies for more agricultural productivity. Unsustainable economic growth is one of the main reasons of environment degradation. Our findings also confirm that economic growth deteriorates environment quality in Pakistan. The results are in line with Dogan (2016), and Ismael et al. (2018) and Rehman et al. (2019), however, contradictive with the findings of Hussain and Rehman (2021).

Short-run results describe the relationship among the variables for the short period of time and also describe the speed of adjustment. In short-run results, the value is error correction term (ECM) which is important that tells about long-run equilibrium and shows the convergence/divergence from the equilibrium. The negative value of ECM shows the convergence toward the long-run equilibrium, and the positive value of ECM shows the divergence from the long-run equilibrium.

Table 7 shows the short-run cointegration results among the variables. The results depict that lag value of fertilizer has positive but insignificant impact on carbon emission in the short run. The lag value of pesticide has negative and significant relationship, the lag value of tractor has negative and insignificant relationship with carbon emission, and real GDP has positive and significant relationship with carbon emission. The value of ECM coefficient is -0.312 that is showing convergence toward the equilibrium point and confirms that 31% divergence is adjusted in a year.

Table 8 shows the results of different diagnostic tests. Three diagnostic tests, namely heteroscedasticity, serial correlation and normality tests, are applied to confirm robust results of the ARDL technique. In this table, p value of Breusch–Pagan–Godfrey test is insignificant which shows no heteroscedasticity. Similarly, *p* value of Breusch–Godfrey LM test and Jarque–Bera is 0.341 and 1.632, respectively, which shows that the selected model is free from serial correlation and the series are normally distributed. Figure 1 contains diagrams of CUSUM and CUSUMSQ, and both graphs are between the boundaries of upper bound and lower bound at 5% level of significance that shows the stability of ARDL model. All these diagnostic tests prove that estimations of the model are efficient.

According to the long-run results obtained from ARDL analysis, there is a strong relationship between pesticide, real GDP and carbon emission in Pakistan. The reason behind these results is that basically Pakistan is a developing and agriculture-based country; most of the people belong to the agriculture sector and they want to increase their income through agriculture; that's way they increase the use of agriculture technologies to attain more income. An increase in the use of agriculture technologies day by day, such as

Table 7 Results of short-run estimation

Variables	Coef	St. Err	*t*-stat	*p*- value
ΔLnFERTI	0.023	0.041	0.561	0.579
ΔLnPESTI	0.006	0.014	0.445	0.659
ΔLnPESTI(-1)	-0.023	0.012	-1.894	0.067*
ΔLnTRAC	-0.013	0.018	-0.741	0.464
ΔLnGDP	0.568	0.132	4.301	0.000***
TREND	-0.011	0.003	-3.234	0.003***
ECM(-1)	-0.312	0.068	-4.571	0.000***

* and *** show significance at 5% and 1%

Table 8 Results of different diagnostic tests

	Heteroscedasticity (Breusch–Pagan–Godfrey)	Serial Correlation (Breusch–Godfrey LM Test)	Normality test (Jarque–Bera)	CUSUM and CUSUMSQ
F-stat	1.218	0.851	0.442	Stable
P value	0.296	0.341	1.632	

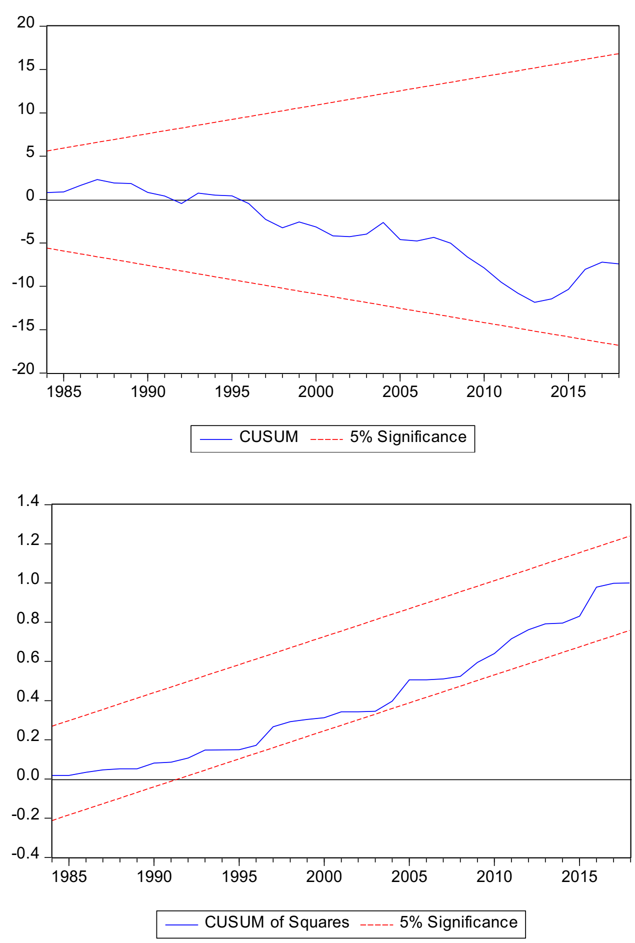

Fig. 1 CUSUM and CUSUMSQ

pesticide and agriculture machineries, causes environmental degradation in terms of carbon emission in Pakistan. Our results are aligned with the findings of Ismael et al. (2018). The economic reason of positive relationship between pesticide and carbon emission is that the farmers are using more energy inputs to cover up the diseases in crops and to increase the productivity. Therefore, the demand for energy inputs (pesticides, etc.) is increasing, and more industries are being built to produce pesticides in economy so in this way carbon emission is increasing during the manufacturing process of pesticide.

Short-run results are given in Table 7 which show the positive role of pesticide and real income on carbon emission in Pakistan. Besides this, fertilizer has positive and nonsignificant relationship, whereas agriculture tractors also have negative and no significant relationship with carbon emission in the short run. The outcome of the study shows that pesticide and GDP have significant and positive relationship with carbon emission in the long run as well as in the short run because of increasing demand of agriculture technologies for the purpose of increasing agriculture production in Pakistan.

Conclusions and policy implications:

In the present era, significant importance is given to environment quality; therefore, numerous studies envisage the role of different factors on environment quality. Among the others, agriculture technologies are also the reasons of carbon emission which is a main source of environmental degradation. This study explores the role of agriculture technologies on carbon emissions in Pakistan. For this purpose, we applied ARDL technique to have long-run and short-run analysis. Besides that, economic growth is also used as control variables. This study found a positive significant impact of pesticides' carbon dioxide emission in Pakistan. However, the role of fertilizer usage and tractors is insignificant. This study also found a positive significant impact of economic growth on environment deterioration both in the long and in the short run. To conclude, both pesticide usage as a proxy of agriculture technologies and economic show contribute to carbon emission. This is because Pakistan is predominantly is agro-based economy and heavily focuses on improvement in agriculture sector. It is important to devise mitigation and adaptation policies without reducing economic growth of a country. Important policy implications are proposed based on the findings. First, to increase the sustainable economic growth through agriculture sector, the government needs to introduce the green technologies (organic pesticides, conservation tillage, etc.) that produce less carbon emissions. Second, Pakistan needs to increase investment in the projects of green energy and should stress out the advantages of investment in green energy projects. This study used only three measures of agriculture technologies. In future, this study can be extended by including other factors of agriculture technologies that have direct or indirect impact on carbon dioxide emission in Pakistan.

Authors Contributions • Rafaqet Ali is a supervisor of Ms Rabia Ishaq, MS (Economics) student for her thesis, and this paper is extracted from her thesis under the supervision of Rafaqet Ali.

• Rabia Ishaq is a student of MS (Economics). She has prepared this paper from her thesis.

• Khuda Bakhsh helped in econometric analysis.

• Muhammad Asim Yasin contributed to the preparation of discussions and conclusion.

Data availability Data CO2 emission is collected from BP Statistical Review of World Energy, 2019, real GDP is collected from World Development Indicators (WDI), whereas data regarding tractor, pesticide and fertilizer are collected from Economic Survey of Pakistan published by the Government of Pakistan.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

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References

Ali R, Bakhsh K, Yasin MA (2019) Impact of urbanization on CO2 emissions in emerging economy: evidence from Pakistan. Sustainab Cities Soc 48 101553

Arapatsakos CI, Gemtos TA (2008) Tractor engine and gas emissions. J Wseas Trans Environ Dev 10(4):897–906

Anwar A, Sarwar S, Amin W, Arshed N (2019) Agricultural practices and quality of environment: evidence for global perspective. Environ Sci Pollut Res 26(15):15617–15630

Audsley E, Stacey KF, Parsons DJ, Williams AG (2009) Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use. Report available online at https://dspace.lib.cranfield.ac.uk/bitstream/handle/1826/3913/Estimation_of_the_greenhouse_gas_emissions_from_agricultural_pesticide_manufacture_and_use%E2%80%902009.pdf?sequence=1

Appiah K, Du J, Poku J (2018) Causal relationship between agricultural production and carbon dioxide emissions in selected emerging economies. Environ Sci Pollut Res 25(25):24764–24777

Antle JM, Capalbo SM (2010) Adaptation of agricultural and food systems to climate change: an economic and policy perspective. Appl Econ Perspect Policy 32(3):386–416

Bresnahan TF, Trajtenberg M (1995) General purpose technologies 'Engines of growth'? J Economet 65(1):83–108

Chandio AA, Magsi H, Ozturk I (2020a) Examining the effects of climate change on rice production: case study of Pakistan. Environ Sci Pollut Res 27(8):7812–7822

Chandio AA, Ozturk I, Akram W, Ahmad F, Mirani AA (2020b) Empirical analysis of climate change factors affecting cereal yield: evidence from Turkey. Environ Sci Pollut Res 27(11):11944–11957

Chandio AA, Jiang Y, Akram W, Adeel S, Irfan M, Jan I (2021) Addressing the effect of climate change in the framework of financial and technological development on cereal production in Pakistan. J Clean Prod 288: 125637

Chandio AA, Jiang Y, Ahmad F, Adhikari S, Ain QU (2021a) Assessing the impacts of climatic and technological factors on rice production: Empirical evidence from Nepal. Technol Soc 66: 101607

Chishti MZ, Ahmad M, Rehman A, Khan MK (2021) Mitigations pathways towards sustainable development: assessing the influence of fiscal and monetary policies on carbon emissions in BRICS economies. J Clean Prod 292 126035

Carey AE (1991) Agriculture, agricultural chemicals, and water quality.Agricult Environ 78–91

Dickey DA, Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74(366):427–431

Dogan N (2016) Agriculture and Environmental Kuznets Curves in the case of Turkey: evidence from the ARDL and bounds test. Agric Econ 62(12):566–574

Edoja PE, Aye GC, Abu O (2016) Dynamic relationship among CO2 emission, agricultural productivity and food security in Nigeria. Cogent Econ Financ 4(1):1204809

Eberhardt M, Vollrath D (2018) The effect of agricultural technology on the speed of development. World Dev 483–496

Falloon P, Betts R (2010) Climate impacts on European agriculture and water management in the context of adaptation and mitigation—the importance of an integrated approach. Sci Total Environ 408(23):5667–5687

Fantke P, Friedrich R, Jolliet O (2012) Health impact and damage cost assessment of pesticides in Europe. Environ Int 49(15):9–17

Ghosh S (2018) Carbon Dioxide Emissions, Energy Consumption in Agriculture: A Causality Analysis for India. J Econ Theory Pract 17(2):183–207

Government of Pakistan (2019) Economic Survey 1980–2019. Pesticide, fertilizer and tractors data. Retrieved from http://www.finance.gov.pk/survey/chapters_16/02_Agriculture.pdf

Hussain I, Rehman A (2021) Exploring the dynamic interaction of CO2 emission on population growth, foreign investment, and renewable energy by employing ARDL bounds testing approach. Environ Sci Pollut Res 1–11

IPCC (2007) Intergovernmental Panel on Climate Change (IPCC) annual report, 2007 available online at http://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html

Ismael M, Srouji F, Boutabba MA (2018) Agricultural technologies and carbon emissions: evidence from Jordanian economy. Environ Sci Pollut Res 25(11):10867–10877

Jaber JO (2002) Greenhouse gas emissions and barriers to implementation in the Jordanian energy sector. Energy Policy 30(5):385–395

Khan MK, Babar SF, Oryani B, Dagar V, Rehman A, Zakari A, Khan MO (2021) Role of financial development, environmental-related technologies, research and development, energy intensity, natural resource depletion, and temperature in sustainable environment in Canada. Environ Sci Pollut Res 1–17

Koondhar MA, Shahbaz M, Ozturk I, Randhawa AA, Kong R (2021) Revisiting the relationship between carbon emission, renewable energy consumption, forestry, and agricultural financial development for China. Environ Sci Pollut Res 1–15

Li W, Ou Q, Chen Y (2014) Decomposition of China's CO 2 emissions from agriculture utilizing an improved Kaya identity. Environ Sci Pollut Res 21(22):13000–13006

Liu X, Zhang S, Bae J (2017) The nexus of renewable energy-agriculture-environment in BRICS. Appl Energy 204:489–496

Marttila V, Granholm H, Nikkola E, Laanikari J, Vainio-Mattila M (2001) Strategy for Renewable Natural Resources in Finland. Report available online at https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/80708/2001_8b_Strategy%20for%20Renewable%20Natural%20Resources%20in%20Finland.pdf?sequence=2&isAllowed=y

Murshed M, Ahmed Z, Alam MS, Mahmood H, Rehman A, Dagar V (2021) Reinvigorating the role of clean energy transition for achieving a low-carbon economy: evidence from Bangladesh. Environ Sci Pollut Res 1–22

Ozkan B, Akcaoz H, Fert C (2004) Energy input–output analysis in Turkish agriculture. Renewable Energy 29(1):39–51

Ozturk I (2017) The dynamic relationship between agricultural sustainability and food-energy-water poverty in a panel of selected Sub-Saharan African Countries. Energy Policy 107:289–299

Ozturk I, Majeed MT, Khan S (2021) Decoupling and decomposition analysis of environmental impact from economic growth: a comparative analysis of Pakistan, India, and China. Environ Ecol Stat 1–28

Onder M, Ceyhan E, Kahraman A (2011) Effects of agricultural practices on environment. Environ Chem 24(4):28–32

Petroleum B (2020) BP Statistical Review of World Energy Report 69th edition.Carbon emission data. Retrieved from https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf

Pathak H, Bhatia A, Jain N (2014) Greenhouse Gas Emission from Indian Agriculture: Trends, Mitigation and Policy Needs. Indian Agricultural Research Institute, New Delhi. Report available online at https://www.researchgate.net/profile/Niveta_Jain/publication/312552724_Greenhouse_Gas_Emission_from_Indian_Agriculture_Trends_Mitigation_and_Policy_NeedsEnter_title/links/5881c57e92851c21ff420969/Greenhouse-Gas-Emission-from-Indian-Agriculture-Trends-Mitigation-and-Policy-NeedsEnter-title.pdf

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Economet 16(3):289–326

Regmi K, Rehman A (2021) Do carbon emissions impact Nepal's population growth, energy utilization, and economic progress? Evidence from long-and short-run analyses. Environ Sci Pollut Res 1–11

Rehman A, Ma H, Ozturk I (2021) Do industrialization, energy importations, and economic progress influence carbon emission in Pakistan. Environ Sci Pollut Res 1–13

Rehman A, Ma H, Ozturk I, Ahmad MI (2021a) Examining the carbon emissions and climate impacts on main agricultural crops production and land use: updated evidence from Pakistan. Environ Sci Pollut Res 1–15

Rehman A, Ma H, Chishti MZ, Ozturk I, Irfan M, Ahmad M (2021c) Asymmetric investigation to track the effect of urbanization, energy utilization, fossil fuel energy and CO 2 emission on economic efficiency in China: another outlook. Environ Sci Pollut Res 28(14):17319–17330

Rehman A, Ma H, Ahmad M, Irfan M, Traore O, Chandio AA (2021c) Towards environmental Sustainability: Devolving the influence of carbon dioxide emission to population growth, climate change, Forestry, livestock and crops production in Pakistan. Ecol Indicators 125 107460

Rehman A, Ulucak R, Murshed M, Ma H, Işık C (2021d) Carbonization and atmospheric pollution in China: The asymmetric impacts

of forests, livestock production, and economic progress on CO2 emissions. J Environ Manag 294 113059
Rehman A, Ma H, Ozturk I, Murshed M, Dagar V (2021e) The dynamic impacts of CO2 emissions from different sources on Pakistan's economic progress: a roadmap to sustainable development. Environ Dev Sustainab 1–24
Rehman A, Ma H, Ahmad M, Ozturk I, Işık C (2021f) An asymmetrical analysis to explore the dynamic impacts of CO2 emission to renewable energy, expenditures, foreign direct investment, and trade in Pakistan. Environ Sci Pollut Res 1–13
Rehman A, Ma H, Ozturk I (2020a) Decoupling the climatic and carbon dioxide emission influence to maize crop production in Pakistan. Air Qual Atmos Health 13(6):695–707
Rehman A, Ma H, Irfan M, Ahmad M (2020b) Does carbon dioxide, methane, nitrous oxide, and GHG emissions influence the agriculture? Evidence from China. Environ Sci Pollut Res 27(23):28768–28779
Rehman A, Ozturk I, Zhang D (2019) The Causal Connection between CO2 Emissions and Agricultural Productivity in Pakistan: Empirical Evidence from an Autoregressive Distributed Lag Bounds Testing Approach. Appl Sci 9(8):1–16
Rehman A, Ma H, Ahmad M, Ozturk I, Chishti MZ (2021g) How do climatic change, cereal crops and livestock production interact with carbon emissions? Updated evidence from China. Environ Sci Pollut Res 1–12
Sarauskis E, Buragiene S, Masilionytė L, Romaneckas K, Avižienytė D, Sakalauskas A (2014) Energy balance, costs and CO2 analysis of tillage technologies in maize cultivation. Energy 69:227–235
Ullah A, Khan D, Khan I, Zheng S (2018) Does agricultural ecosystem cause environmental pollution in Pakistan? Promise and menace. Environ Sci Pollut Res 25(14):13938–13955
UN (2015) The Least Developed Countries Report 2015. Chapter 2. Transforming Rural Economies, Agricultural Productivity: Developments, Determinants and Impacts. New York and Geneva, 2015
World Bank. World Development Indicators: GDP (Constant LCU) data. Available online: https://databank.worldbank.org/source/world-development-indicators (Accessed on 12 December 2019)
Weimin Z, Chishti MZ, Rehman A, Ahmad M (2021) A pathway toward future sustainability: Assessing the influence of innovation shocks on CO2 emissions in developing economies. Environ Dev Sustainab 1–24
Zhang L, Pang J, Chen X, Lu Z (2019) Carbon emissions, energy consumption and economic growth: Evidence from the agricultural sector of China's main grain-producing areas. Sci Total Environ 665(15):1017–1025