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Nexus between economy and environment: Greening India's agriculture to combat climate change

YAZHINI A[1], MALAISAMY A[2]*, RASWANTHKRISHNA M[3], BALASUBRAMANIAN M[4] and VIDHYAVATHI A[5]

Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu

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ABSTRACT

Climate change significantly affects various industries and economic sectors. It is primarily driven by greenhouse gas emissions, which result in global warming and cause shifts in climatic patterns, such as alterations in monsoon cycles and temperature changes. There are many studies related to emission, from secondary sector but the India's agricultural sector contributing 14% to the nation's total emissions is less focused. The present study was carried out in 2024 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu highlights the increasing focus on adopting environmental friendly agricultural practices to achieve SDG 13-Climate Action. It investigates the relationship between carbon emissions intensity (CEI) from India's agricultural production (GVA) and its economy (Trade-NE). Secondary data were sourced from the World Emission Clock, FAO Stat, and GHG platform for the period of 1993 to 2023 for India. The Tapio decoupling study on India's economic growth (Agricultural GDP) and agricultural GHG emissions reveals both negative and positive decoupling. Weak decoupling is most evident in situations where both agricultural GDP and greenhouse gas emissions increase simultaneously but the emissions growth rate is less than the growth rate of GDP. Using the structural vector auto regressive (SVAR) model, the paper illustrates that an immediate increase in CEI reduces the net export (NE) and GDP. Lowering CEI positively impacts the GVA, enhancing resilience to climate change and fostering sustainable growth in agricultural net exports. Sustainable practices like climate-smart agriculture, drip irrigation in paddy cultivation, carbon credit scheme should be focused. Prioritizing these measures is vital for India to meet its emissions reduction targets and to combat climate change.

Keywords: Agriculture, Climate change, Economy, Impulse-response function, Sustainability, Tapio decoupling

The three pillars of sustainability such as economy, society, and environment are all greatly impacted by the agriculture sector (Ancev 2011). The primary sector has a detrimental effect on climate change since it emits between 12–14% of the world's greenhouse gas (GHG) to the atmosphere. Mitigating climate change and global food security challenges can be achieved by the adoption of low-carbon and sustainable agriculture technologies (Pretty *et al.* 2002, Chanda *et al.* 2021). In terms of GHG, India remains in third place (2.6 billion tonnes CO_2 eq/year) (UNFCCC 2021). The report of UNFCCC revealed that the contribution of GHG in agriculture (14%), livestock sector (61.3%), fertiliser (19.1%), rice cultivation (17.5%) and field burning of agricultural residues (2.2%). Low-carbon agriculture is defined as an agricultural system which enables for the efficient production of food, feed, fibre and raw materials while lowering energy inputs and GHG emissions from agriculture and upholding the principles of sustainable development. Thus, economic income, environmental protection and sustainability can be attained at the same time (Saunders and Wreford 2003). The study of low carbon agriculture and its effects on the economy is important in order to meet the following sustainable development goals (SDGs), 8th (decent work and economic growth), 13th (climate action) and 7th (affordable and clean energy). In an effort to seek a more environmental friendly and sustainable future, India has implemented a number of policies, one of which is the carbon market. By setting a price on GHG, the country has made significant progress toward decarbonizing its economy (Benbi 2018, GOI 2023). Emissions from the agriculture sector continue to be a low priority in India, despite projects to offset GHGs being proposed under the clean development mechanism (Ghosh 2010, Ji and Hoti 2022). It's critical to comprehend how emissions from agriculture affect economic growth. The majority of studies focus on emissions from the secondary

[1]Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu; [2]Agricultural College and Research Institute (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Madurai, Tamil Nadu; [3]Amrita University, Coimbatore, Tamil Nadu; [4]ICAR-Indian Agricultural Research Institute, New Delhi. *Corresponding author email: malaisamy@tnau.ac.in

sectors, and only meagre studies depicted the quantitative evaluation of emissions from the agricultural sector and their effects on the economy. Hence, the study aimed to investigate the relationship between GHG emissions from agricultural sector and economy in India.

MATERIALS AND METHODS

The present study was carried out in 2024 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. The secondary data on NE, GDP of India were sourced from different portals such as World emission clock, World bank, Intergovernmental Panel on Climate Change, Ministry of New and Renewable Energy, United Nations Framework Convention on Climate Change, Food and Agricultural Organization of United States Statistics, International Trade Centre, Agricultural and Processed Food Products Export Development Authority for the period of 1993 to 2023.

Calculation of the agricultural carbon emissions intensity

Carbon emission intensity (CEI): Since both crop cultivation and livestock are included in the measurement of agricultural carbon emissions in this study, CEI is calculated as carbon emission per unit of gross domestic product. This indicator is highly significant in determining the economic development of agricultural production and carbon emissions because it can also indicate the efficiency of carbon emissions.

$$I = C/P$$

Where C, Total agricultural carbon emissions (kt); P, Gross agricultural product in a given time period; and I, Carbon emission intensity per unit of agricultural gross domestic product (kt/₹ in million).

Tapio decoupling model: The Tapio decoupling model can be used to understand the development trend of carbon emissions as well as the relationship between economic growth and GHG emissions (Zhang and Sharifi 2024). Based on the decoupling elastic value, Tapio (2005) separated the decoupling state into eight states, viz. Strong decoupling (continuous economic development and contrasted with negative growth in emissions); Weak decoupling (GDP is growing at a faster rate than carbon dioxide emissions); Weak negative decoupling (Negative growth of the economy and the negative increase of carbon emissions); Strong negative decoupling (negative economic growth and a tendency for carbon emissions to increase); Expansive coupling (economic growth and carbon emissions rise approximately at the same pace); Expansive negative decoupling (economy grows at a slower rate than the rate of carbon emissions); Recessive coupling (economy grows negatively and the rate of carbon emissions grows); Recessive decoupling (economic and carbon dioxide emissions rise negatively, but the decline in carbon dioxide emissions happens more quickly than the decline in the economy (Fig. 1 and 2)

Relationship between GHG emission and economic growth: The study specifically looks into how India's agricultural sector is affected by carbon emissions from agriculture, building a structural vector autoregressive (SVAR) model to examine the dynamic interaction between the variables.

$$AZ_t = B_0 + B_1Z_{t-1} + B_2Z_{t-2} + \ldots + B_iZ_{t-I} + u_t,\ t = 1,2,3,\ldots\ldots$$

Since this paper examines a three-variable SVAR model, we set the concrete forms of B_0, Z_i and u_t t:

$$A = \begin{bmatrix} 1 & -a_{12} & -a_{13} \\ -a_{21} & 1 & -a_{23} \\ -a_{31} & -a_{32} & 1 \end{bmatrix},\ t_i = \begin{bmatrix} \gamma_{11}^{i} & \gamma_{12}^{i} & \gamma_{13}^{i} \\ \gamma_{21}^{i} & \gamma_{21}^{i} & \gamma_{21}^{i} \\ \gamma_{31}^{i} & \gamma_{32}^{i} & \gamma_{32}^{i} \end{bmatrix} i=1,2,3,\ldots,$$

P,P is the order of lag

Where ut, Structural perturbation vector; A, Coefficient matrix; Ai, Matrix of variable coefficients of the lag i order, and Zt, Column vector made up of all variables at time. Three constraints must be added to the constraint matrix C in order to identify and estimate a p-order SVAR model of three variables. Equation (1) is converted:

$$Zt = A^{-1}B_0 + A^{-1}B_1Z_t{-}_1 + A^{-1}B_2Z_{t-2} + \varepsilon t, = A^{-1}\, ut$$

Thus, this paper provides the following limits, in conjunction with pertinent economic theories. India's agricultural CEI and agricultural GDP are not immediately apparent because of the long-term, stable equilibrium relationship between the country's carbon emissions and agricultural production, which is represented by the values of $a_{12} = 0$ and $a_{21} = 0$. The trade in agricultural products will not be impacted by the current level of agricultural production because agricultural production typically needs a lengthier procedure; $a_{32} = 0$.

Then, the matrix equation with the constraint is:

$$\begin{bmatrix} 1 & 0 & -a_{13} \\ 0 & 1 & -a_{13} \\ -a_{31} & 0 & 1 \end{bmatrix} t \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{bmatrix} = \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix}$$

The variables selected are total import and export trade of agricultural products (Net export (NE in ₹ in million), agricultural carbon intensity (CEI in kt/₹ in million) and agricultural GDP (VA in ₹ in million). Using Eviews10.0 software, the estimated results of the matrix equation were analysed on the vector auto regressive (VAR) model.

RESULTS AND DISCUSSION

The 2022–23 Union Budget's emphasis on the importance of taking climate action is furthered by India's commitment to become carbon neutral by 2070, as agreed to at COP26. India ranks 7th among the most polluted countries and emits a substantial amount of GHG, as evidenced by reports like the Global Carbon Atlas and the World Air Quality Report. India is still the world's highest emitter of emissions per capita, despite its reduced emissions overall in the energy sector (Bonesmo *et al.* 2012). One of the anthropogenic sources of GHG is agriculture (Norse *et al.* 2012). Although agriculture's portion of global emissions has decreased, it still makes a substantial contribution, mostly through the burning of agricultural residues, rice cultivation, animal management, and nitrogenous fertilizers.

The Environment Kuznet Curve supports the SVAR model's finding that there is an inverse link between economic growth and environmental degradation, especially in agriculture, which has an effect on trade and growth.

Relationship between GHG emission and economic growth

Decoupling method: The amount of GHG released into the atmosphere by farming, fishing, forestry, and animal husbandry activities keeps increasing (Mirolyubova *et al.* 2017). CO_2, CH_4 and N_2O are the gases that are considered to be most harmful in the agricultural sector (Johnson *et al.* 2007). The cultivation of paddy, the raising of animals, the use of fertilizer, and the burning of crop wastes account for the major contributors of the agriculture sector GHG emissions in India. It is anticipated that India's agricultural emissions would continue to rise (Sapkota *et al.* 2019). The decoupling method shows the relationship between changes in agricultural emissions (t/yr) and agricultural GDP (in million).

The largest sources of CH_4 emissions in the agriculture sector were rice cultivation and enteric fermentation. Agriculture accounted for 84% of all N_2O emissions, making it a significant source of emissions (Panigrahy *et al.* 2010). This study showed the decoupling dynamics and the relationship between GDP growth (in million) and agriculture emissions (tonnes/yr) from 1993 to 2022. There are three distinct states of decoupling: weak, strong negative, and strong decoupling. There had been substantial instances of negative decoupling in 2001, 2003, 2010, 2011 and 2013, which suggested that negative economic growth had been accompanied by rising emissions. On the other hand, 2002 witnessed a strong decoupling, marked by continuous economic growth in spite of falling emissions (Fig. 1A). It showed that through sustainable practices like micro-irrigation, organic farming, and agroforestry, which reduced emissions because of reduced usage of water in micro irrigation than the flood irrigation which emits methane gas and agroforestry acts as carbon sink source. The use of renewable energy, such as solar-powered irrigation, and a shift to high-value crops enhanced productivity while minimizing the environmental impact. These initiatives supported economic growth with lower carbon emissions. Weak decoupling was evident in the other years, with steady economic growth and slower than emissions increasing rate. The significance of understanding decoupling processes in order to direct sustainable development plans is emphasized by this analysis.

There are three stages of decoupling, recessive; strong negative; and weak decoupling in the dynamics of decoupling between carbon emissions (tonnes/yr) and economic growth (in millions)

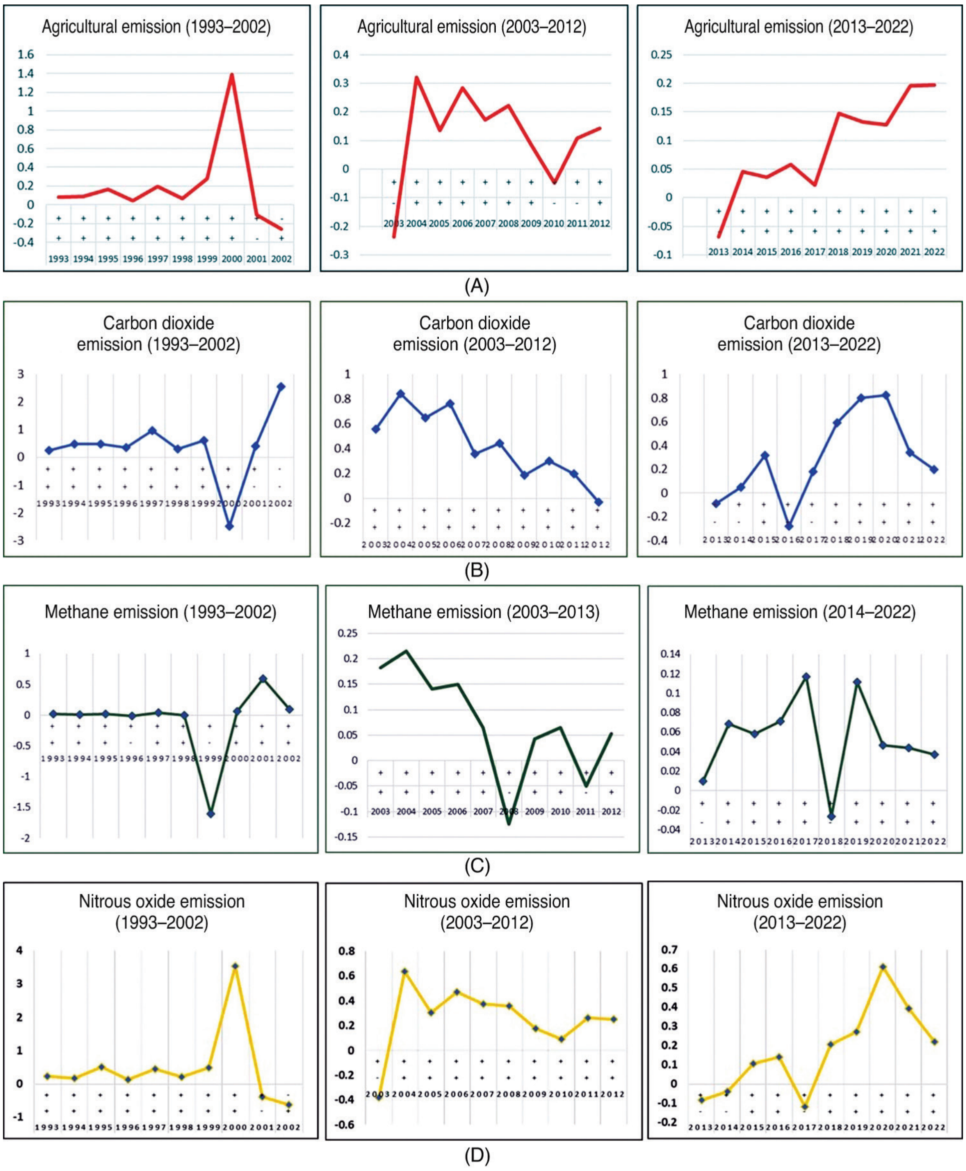

Fig. 1 (A) Decoupling between agricultural GHG emission and economic growth, (B) Decoupling between agricultural carbon di oxide emission and economic growth, (C) Decoupling between agricultural methane emission and economic growth, (D) Decoupling between agricultural nitrous oxide emission and economic growth.

(Fig. 1B). There have been significant instances of negative decoupling with growing emissions and declining economy in 2001, 2013, 2014 and 2017, whereas 2002 had a recessive decoupling, with a drop in both the economy and emissions; however, the emissions fall at faster rate. Weak decoupling was seen in the remaining years, with steady economic development and slower growth in emissions. This showed that attempts to reduce agricultural carbon emissions may be substantially more successful during recessions, providing possibilities to look into low carbon agriculture (Kumar and Aravindakshan 2022).

The emission of methane from rice field is high where Datta *et al.* (2011) showed that the rice-rice rotation system had higher global warming potential (GWP) (8.62 Mg CO_2/ha). Fig. 1C depicts the decoupling between total agricultural methane emissions (tonnes/yr) and economic growth (in million). Enteric fermentation by ruminants, which is the largest natural source of CH_4, accounts for around 44% of animal emissions (Kumara *et al.* 2023). There are two main decoupling states, weak and strong negative. Instances of strong negative decoupling with negative economic development and growing methane emissions were seen during 1999, 2008, 2011, 2013 and 2018. Weak decoupling was seen in other years, with steady economic development and slower growth in emissions. Fig. 1D depicted that there were three decoupling states, strong; strong negative; and weak decoupling between nitrous oxide emissions (t/yr) and economic growth (in millions). There was a severe negative decoupling in 2001, 2003, 2013 and 2014, indicated with an increase in emissions and a decrease in the economic development. The year 2002 exhibits a strong decoupling, with continuous economic growth occurring in spite of a reduction in emissions of nitrous oxide. Weak decoupling was seen in the remaining years, with steady economic development and slower growth in emissions.

SVAR-Impulse response function and variance decomposition: The impulse response function is used to investigate the interaction between the environment and the economy (Zang *et al.* 2022). The first step is to determine the cointegration between the gross value of agricultural output (GVA-₹ in million), trade in agriculture (NE-₹ in million), and the carbon emission intensity (CEI-kt/₹ in million). Once this is done, SVAR and the impulse response function are used to analyse the long and short-term relationship.

Unit root test: To avoid the occurrence of "pseudo-regression," which could arise from instability in the time series variables, it was imperative to assess the stationarity of the variable sequences lnne, lnva, and lncei. Augmented Dickey-Fuller (ADF) test, a unit root test technique, was employed in this paper. ADF test, critical value and *P* value are found to be significant. According to the unit root test results, D2cei, D2lnne, and D2lnva were all second-order differential sequence stationary sequences with test values of the ADF less than 1% at the significant level. This demonstrated that the initial sequence variable satisfies the prerequisites needed to construct the SVAR model. The stationary sequences were D2cei, D2lnne, and D2lnva.

Lag order determination: The lag order was determined using akaike information criterion (AIC), Schwarz based criterion (SBC), likelihood ratio (LR) to develop an ideal SVAR model and to increase the efficacy. Based on the test results, it is known that the AIC and SBC test results are optimal when the hysteresis order is of the second order; hence, two is the optimum hysteresis order.

Cointegration test: At the 5% significance level, the maximum feature root and feature root trace tests and their results showed a cointegration relationship between lnne, lnva, and CEI; that is, a long-term trend in India's agricultural production and trade, as well as its agricultural carbon emissions intensity.

Using Eviews10.0 software, the estimated results of the matrix equation were analysed on the VAR (2) model of the composition of three variables as follows:

$$\begin{bmatrix} 1 & 0 & 0.246^{***} \\ 0 & 1 & 1.847 \\ 1.44^{***} & 0 & 1 \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{bmatrix} = \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{bmatrix}$$

where the predicted coefficients passed the test at 1% significance levels, as indicated by the ***. The findings showed that a_{31} = 1.44, or a negative number, suggested that a rise in the intensity of agricultural carbon emissions would reduce in overall trade in agricultural products. Simultaneously, as the total trade of agricultural products increased, India's agricultural carbon emissions grew less. This suggested that the deficit in India's trade of agricultural products led to the substitution of agricultural production. Consequently, there was a decrease in the carbon emissions resulting from agricultural productivity.

Cointegration between CEI, GVA, NE: Climate change impacts the global economy in agriculture by affecting productivity, while agriculture significantly contributes to global warming (Zafeiriou *et al.* 2018). This study examines the effects of agricultural carbon emission intensity (CEI) and growth in agriculture using impulse response functions. The findings showed that agriculture trade volume and GDP are negatively impacted by CEI shocks (Fig. 2A). In case of shock in agricultural output value, trade benefits during the first four periods and stabilizing around the 10^{th} period, whereas the CEI reaction remains steady over time (Fig. 2B), which has been resulted as the GHG emissions are caused by the input-intensive cereal production system and enteric fermentation in livestock (Sapkota *et al.* 2015). Fig. 2C depicts how changes in the total value of agricultural trade affect CEI and agricultural output. Results showed that when agricultural trade is disrupted, agricultural output showed rising trend for the first two periods and then steadily declines until it stabilizes around the 10^{th} period. In contrast, the CEI response is stable for two periods and has negative long-term effects. The carbon emission would lead to decline the economics growth for which low carbon agriculture should be practised to mitigate climate change and increase the economy (Xiong *et al.* 2016).

Variance decomposition using Cholesky (d.f. adjusted) factors: The most significant aspect of Indian agriculture

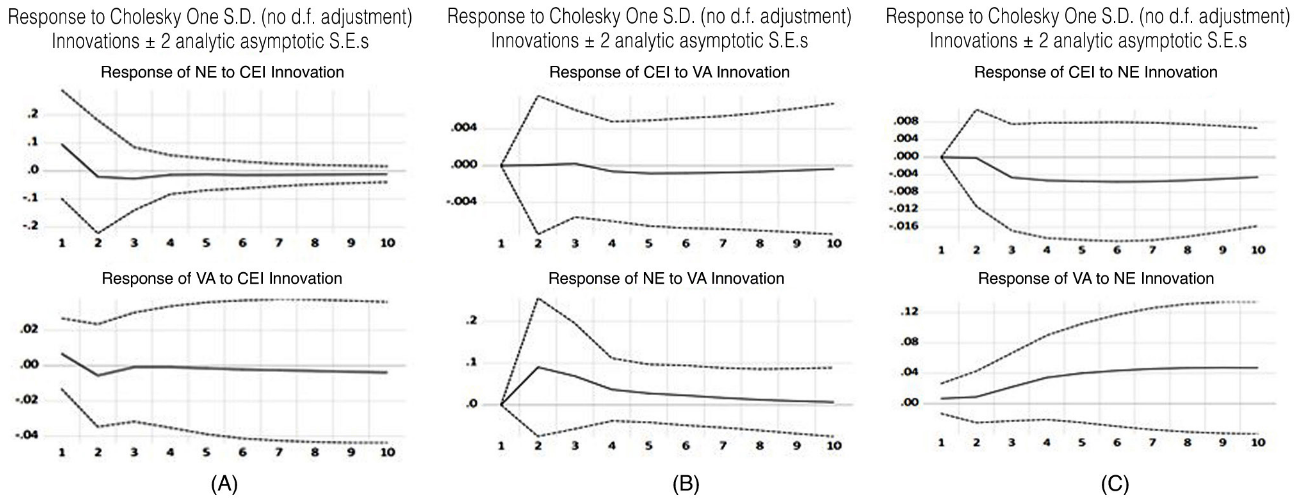

Fig. 2 Impulse response function. (A) Impulse- CEI, Response-GVA and NE; (B) Impulse-VA, Response-CEI and NE; (C) Impulse-NE, Response-CEI and VA.
CEI, Carbon emission intensity; GVA, Gross value of agricultural output; NE, Net export; VA, Agricultural GDP.

is crop-based agriculture, which produced 63% of the country's gross value added in agriculture in 2014–15. Key agricultural emissions include CO_2, CH_4, and N_2O, with CH_4 mainly from enteric fermentation, manure management, paddy cultivation and burning (Qiao *et al.* 2019). Meantime, methane and nitrous oxide are the two primary greenhouse gas emissions from the agriculture industry (Some *et al.* 2019). A lowering CEI over time increases the NE and the agricultural GVA. Reduced carbon emissions, or a declining CEI would strengthens the economic stability, and encourages the development of innovative sustainable agricultural techniques, which raises productivity and competitiveness. Overall, agriculture trade and economic growth benefit from the declining CEI (Table 1).

There are 25 nations in south Asia and the middle-east, such as Egypt, Iran, Pakistan, India, and others, that export a lot of agricultural goods. Trading agricultural commodity leads to transfer of emission, because of this, they were significant exporters of embodied emissions (Han *et al.* 2019, Zhao *et al.* 2020). Decline in NE have impact on CEI and VA, where VA is found to be increasing and there was fluctuation in CEI (Table 2). In general, the diminishing influence of NE on VA and CEI highlights the significance

Table 1 Variance decomposition of CEI

Period	CEI	NE	VA
1	100.0000	0.000000	0.000000
2	99.99180	0.007436	0.000763
3	96.56903	3.422538	0.008437
4	93.30040	6.640839	0.058762
5	90.57454	9.294580	0.130880
6	88.19454	11.61909	0.186369
7	86.17068	13.60464	0.224681
8	84.55032	15.20176	0.247929
9	83.28737	16.45518	0.257451
10	82.31756	17.42519	0.257250

CEI, Carbon emission intensity; NE, Net export; VA, Agricultural GDP.

Table 2 Variance decomposition of NE

Period	CEI	NE	VA
1	5.304948	94.69505	0.000000
2	4.112574	92.36374	3.523687
3	4.157322	90.65366	5.189021
4	4.065691	90.43503	5.499278
5	4.008891	90.36936	5.621754
6	4.024939	90.25849	5.716575
7	4.064484	90.17096	5.764554
8	4.107037	90.11058	5.782383
9	4.150325	90.06206	5.787620
10	4.192244	90.02057	5.787183

CEI, Carbon emission intensity; NE, Net export; VA, Agricultural GDP.

Table 3 Variance decomposition of VA

Period	CEI	NE	VA
1	2.547270	37.462385	94.99034
2	1.802140	33.853207	95.34465
3	1.087947	31.408932	90.50312
4	0.723557	24.46196	82.81448
5	0.534644	21.51581	76.94955
6	0.434556	20.99483	72.57062
7	0.377787	18.49575	69.12646
8	0.347959	15.26490	66.38714
9	0.336129	12.46667	64.19720
10	0.336510	8.24297	62.42052

CEI, Carbon emission intensity; NE, Net export; VA, Agricultural GDP.

of comprehensive strategies for ensuring the sustainability and growth of the agricultural sector.

Asia is expected to continue to be the world's largest food consumer and the primary producer of GHG from agriculture during the next thirty years (Verge *et al.* 2007). The reducing GVA has a substantial impact on lowering agricultural NE and CEI (Table 3). In summary, the diminishing influence of VA on CEI and NE highlights the interdependence of trade dynamics, environmental sustainability, and economic success in agriculture, emphasizing the necessity of comprehensive approaches for addressing these issues.

This study concludes that encouraging sustainability, productivity, and competitiveness can be attained through lowering carbon agricultural practises. Furthermore, it strengthens resilience to climate change, guaranteeing long-term sustainability and promoting sustainable increase in GVA and agricultural net exports. Sustainable practices like climate-smart agriculture, drip irrigation in paddy cultivation, carbon credit scheme, afforestation should be focused (Kakraliya *et al.* 2021, Borychowski *et al.* 2022). The use of low-carbon energy technology, water-saving irrigation techniques, groundwater conservation strategies, and efficient agricultural soil nutrient management makes it possible to reduce carbon emissions without compromising food supply (Huang *et al.* 2022). Prioritizing these measures is vital for India to meet its emissions reduction targets to attain net zero emission by 2070.

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