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Research Paper

Energy budgeting, sensitivity analysis and greenhouse gas emission from rice (*Oryza sativa*) production system: A case study from the coastal ecosystem of Goa, India

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ABSTRACT

In recent years, energy consumption and greenhouse gas (GHG) emissions are of major concern across the globe. In this context, using data envelopment analysis, a study was carried out during 2019 and 2020 to determine the energy-usage pattern and efficiency of rice (*Oryza sativa* L.) farmers in the coastal state. The results showed that, rice-production systems had energy-use efficiency, energy productivity, net energy, and human-energy profitability of 2.40, 0.16 MJ/kg, 15,728 MJ/ha and 42.8 respectively. Of the 30 farmers, 5 and 21 were judged to be efficient based on technical and pure technical efficiency, respectively. The mean scale efficiency of inefficient farmers was 0.68 which indicated scope for refining agricultural practices to input use. Nitrogen, farmyard manure, and seeds had a positive impact on crop yield, whereas labour and diesel had negative impact on both crop yield and energy, according to the econometric model. The main non-renewable inputs contributing to GHG emissions were found to be nitrogen fertilizer (72.1 kg CO_2 eq./ha), fuel (68.5 kg CO_2 eq./ha), and machinery (68.9 kg CO_2 eq./ha). Indirect (81.7%) and non-renewable (73.8%) energy consumption was found higher. Our findings indicated that, farmers in this region should use conservation tillage and better crop-management strategies to save energy and minimize GHG emissions.

Key words: Energy efficiency, Greenhouse gas, Rice, Sensitivity analysis, Technical efficiency

With the use of non-renewable energy resources such as fossil fuels, machinery, fertilizers, and pesticides, the need for food production in developing countries has increased rapidly (Chaudhary *et al*., 2009). This has put constant pressure on natural resources which has jeopardized agricultural sustainability. Improving energy (input)-use efficiency is one of the criteria for achieving agricultural production sustainability, as it lowers production costs and pollutants. Rice (*Oryza sativa* L.) is Goa's major crop (in 22% of total crop area), and farmers utilize few external inputs, preferring to grow salt-tolerant landraces like 'Korgut'. Though some farmers cultivate improved salt-tolerant varieties ('Goa Dhan 1', 'Goa Dhan 2', 'Goa Dhan 3', and 'Goa Dhan 4'), low yields are harvested due to poor crop management (Paramesh *et al*., 2019). High rainfall encourages the production of only rice during rainy season (*kharif*), and the region's constant anaerobic water-logging offers ideal conditions for greenhouse gas (GHG) emissions from rice fields (Malyan *et al*., 2016). The type of inputs utilized for production, such as fertilizers, pesticides, organic manure, fossil fuel, machinery, and irrigation system, have a significant impact on GHG emissions (Soni and Soe, 2016).

Rice cultivation is energy-intensive, and the use of fertilizers, fossil fuels for machinery, and pesticides has resulted in GHG emissions, which have had a negative impact on the environment. The GHGs absorb and re-emit radiation in the atmosphere, and are the primary drivers of global warming. Emissions of GHG from agricultural practices account for ~17% of total emissions of GHG in India. Several previous research looked at energy use and GHG emissions under various farming methods (Schmer *et al*., 2014). The potato production system, for example, produced 993 kg carbon dioxide equivalent per hectare (CO_2 eq./ha) of GHGs and utilized 47 GJ/ha of energy from various inputs (Pishgar-Komleh *et al*., 2012). When compared to other crops, Soni *et al*. (2013) found that, transplanted rice produced the most GHGs (1,112 kg CO_2 eq./ha).

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According to Firouzi *et al*. (2017), total GHG emissions in solo groundnut and groundnut–bean intercropping systems were 636.14 and 657.36 kg CO_2 eq./ha respectively. However, in order to design mitigation methods, little is known about the energy inputs responsible for GHG emissions from the rice ecosystem in this region.

Data envelopment analysis is commonly used to assess the efficacy of various approaches and technologies (DEA). It is a nonparametric statistical tool that allows us to compare different farmers' production efficiency for different sets of inputs and outputs. The DEA has been applied in agriculture to determine the technical efficiency of tea, orange, coffee (Basavalingaiah *et al*., 2022), and rice (Basavalingaiah *et al*., 2020) production systems owing to various advantages. However, there is a scarcity of data on energy usage and its impact on GHG emissions in the coast rice farming system. In light of this, we expected that efficient utilization of non-renewable external inputs in coastal agroecosystems would result in lower GHG emissions and higher energy productivity. As a result, a study was done to (i) assess energy consumption and GHG emissions from Goa's rice fields, (ii) calculate the efficiency of rice-growers using the DEA approach and (iii) use sensitivity analysis to establish the influence of varying energy inputs on rice yield.

MATERIALS AND METHODS

The study was carried out at Ibrampur village (Latitude 15.7114399, Longitude-73.9300957), Pernem taluka, North Goa district, Goa, India, during October–December 2019. The climate of Goa is hot and humid, with temperatures ranging from 17 to 35°C and precipitation ranging from 2,500 to 3,200 mm/year respectively (Paramesh *et al*., 2020). Lateritic, coastal saline, clay and sandy soils with high ferric aluminium oxide content are found in the region (Paramesh *et al*., 2022). During 2019–20, we used a questionnaire to collect input and output data from 30 rice farmers in Ibrampur village.

Following standard approach, the varied input and output were converted to energy equivalents (Table 1). Labour, machinery, diesel, farmyard manure (FYM), fertilizers, seeds and pesticides were the inputs for rice production, while grain yield was one of the outputs. For the computation of various energy indices, the following equations were utilized (Paramesh *et al*., 2019). Two DEA models, Charnes, Cooper, and Rhodes (CCR) and Banker, Charnes, and Cooper (BCC), were used to assess the effectiveness of several decision-making units (DMUs) in this study.

$$\text{Non}-\text{renewable energy use ratio} = \frac{\text{Gross Energy Output (MJ/ha)}}{\text{Non Renewable Energy Input (MJ/ha)}} \quad (1)$$

$$\text{Energy use efficiency} = \frac{\text{Energy Output (MJ/ha)}}{\text{Energy Input (MJ/ha)}} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Economic output (kg/ha)}}{\text{Energy Input (MJ/ha)}} \quad (3)$$

$$\text{Human Energy profitability} = \frac{\text{Economic output (kg/ha)}}{\text{Labour Energy (MJ/ha)}} \quad (4)$$

$$\text{Net Energy} = \text{Energy input (MJ/ha) - Energy output (MJ/ha)} \quad (5)$$

$$\text{Direct energy} = \text{Labour} + \text{Fuel} \quad (6)$$

$$\text{Indirect energy} = \text{Seed} + \text{Fertilizers} + \text{Pesticides} + \text{Machineries} + \text{irrigation} \quad (7)$$

$$\text{Renewable energy} = \text{Labour} + \text{FYM} \quad (8)$$

$$\text{Non-renewable energy} = \text{Fuel} + \text{Seed} + \text{Fertilizers} + \text{Pesticides} + \text{Machineries} \quad (9)$$

The GHG emissions from non-renewable inputs were calculated in this study by multiplying by their respective coefficients and expressing in terms of CO_2 eq. (Table 6). The GHG emissions were computed per hectare basis.

To determine the link between rice grain yield and energy inputs, the Cobb–Douglas production function was utilized (Ramedani *et al*., 2011). The return to scale represents the sum of coefficients ($\Sigma\, \beta_j$) obtained from regression equations of Cobb–Douglas production function. The sum of the coefficients < or = or >1 represents the decreasing or constant or increasing return to scale respectively.

The impact of different energy inputs on rice yield was evaluated using Cobb–Douglas production function in the following forms:

$$lnY_i = \beta_0 + \beta_1 \ln(DE) + \beta_2 \ln(IDE) + \varepsilon_i \quad \text{(Model-1)} \quad (12)$$

$$lnY_i = \gamma_0 + \gamma_1 \ln(RE) + \gamma_2 \ln(NRE) + \varepsilon_i \quad \text{(Model-2)} \quad (13)$$

where *Yi* denotes ith farmer grain yield, RE, NRE, DE and IDE are renewable, non-renewable, direct and indirect energy respectively, β_i and γ_i are coefficients of variables, β_0 and γ_0 represent constants and ε_i is the error term.

Following equation was used to calculate marginal physical productivity (MPP), which analyses the sensitivity of energy inputs on grain output.

$$MPP_{xj} = \frac{GM\ (Y)}{GM\ (X)_j} \times \beta_j \quad (14)$$

where MPP_{xj} is the *j*th input's MPP, β_j denotes *j*th input's regression coefficient, GM (Y) geometric mean of productivity, GM (X_j) denotes *j*th input's geometric mean.

RESULTS AND DISCUSSION

Energy consumption

Estimated energy inputs and outputs for the rice production system are given in Table 1. Due to transplanting, weeding, fertilizer application, and crop maintenance, the utilization of human labour was fairly high among the various inputs. For field preparation and mechanical harvesting, rice production required a large amount of diesel fuel. The farmers of this region apply FYM (on an average 4.8 t/ha) before puddling and it consumed about 20% of the total energy. The consumption of fertilizers in this region (42 kg/ha) is lesser than the national average of 144.4 kg/ha. The pesticide application was also found lower in this region and farmers did not apply any herbicides to control weeds. The farmers use only insecticides to control brown planthopper (*Nilaparvata lugens* stal) and yellow stem-

Table 1. Quantity and energy coefficients of inputs and output in rice-production of Goa

Input (unit)	Energy equivalent (MJ/U)	Quantity/ unit area (ha)	Total energy equivalent (MJ/ha)
Inputs			
Labour (h)	1.96	337	661
Machinery (h)	62.7	15	964
Diesel (L)	56.3	24.6	1,386
Farmyard manure (kg)	0.47	4,818.9	2,265
Seeds	14.7	60.4	888
Nitrogen (kg)	66.1	55.5	3,670
Phosphorus (kg)	12.4	39.1	474
Potassium (kg)	11.1	57.2	634
Pesticides (kg)	199	1.2	230
Output			
Grain yield (kg)	14.7	1,830.0	26,901

borer [*Scirpophaga incertulas* (Walker)] in this region. Because of lower fertilizer application, growing landraces and poor crop management, the average crop yield was found lower in this region (1,830 kg/ha).

Energy indices

In the rice-production system, the estimated mean energy input and output were 11,173 and 26,901 MJ/ha respectively (Table 2). Renewable energy and non-renewable energy contributed 26.2% and 73.8% of total energy input respectively. Fertilizers (42.7%) had the highest share of non-renewable energy sources, followed by diesel (12.4%) and machines (8.6%) (Fig. 1). Bockari-Gevao *et al*., (2005) estimated a total energy input of 12,400 MJ/ha in rice crop, with chemical fertilizer accounting for the most (7,700 MJ/ha). In rice crop, Agha-Alikhani *et al*. (2013) found a larger percentage share of energy from fertilisers (43%). According to a study conducted in India, irrigation and fertilizers account for a higher percentage of energy in the rice-production system (Chaudhary *et al*., 2017). Tillage and crop-

Table 2. Energy calculations in the rice-production system (n=30)

Item	Units	Quantity/ha
Input energy	MJ/ha	11,173
Output energy	MJ/ha	26,901
Direct energy	MJ/ha	2,047 (18.3%)
Indirect energy	MJ/ha	9,126 (81.7%)
Renewable energy	MJ/ha	2,926 (26.2%)
Non-renewable Energy	MJ/ha	8,247 (73.8%)
Human energy profitability	-	42.8
Energy productivity	kg/MJ	0.16
Energy efficiency	-	0.46
Net energy	MJ/ha	15728
Energy profitability	MJ/ha	1.38
Non-renewable energy ratio	-	7.67

Numbers in parentheses indicate percentage of total input energy

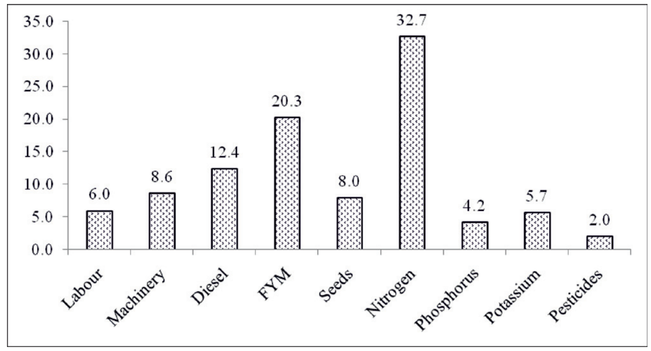

Fig. 1. The share (%) of total mean energy inputs in rice production system

establishment methods such as direct seeding, non-puddled transplanting and puddled transplating also significantly affect the energy input and output in rice-based cropping system (Sarangi *et al*., 2020).

Various energy indices are given in Table 2. The average energy-use efficiency observed was 2.40, indicating that 2.40 units of output were created per unit of input energy, demonstrating that the region's inputs were used efficiently. In Malaysia, Bockari-Gevao *et al*., (2005) found an energy-consumption efficiency of 8.86 for rice growing. Irrigated maize farming in Iran has a 1.86 energy-use efficiency (Lorzadeh *et al*., 2011). The energy productivity recorded in the study was 0.16, this means that 0.16 units of output were achieved/unit of input energy. This finding indicated that, the rice crop's energy production in this location may be improved. Higher usage of fuel, mechanization and reduced crop yields all contributed to lower energy productivity (Soni and Soe, 2016). The mean net energy of rice production for this region was found positive (15,728 MJ/ha) and it increased as long as the energy use efficiency increased. These findings suggested that, energy savings were mostly owing to the adoption of renewable energy sources, such as FYM (Hülsbergen *et al*., 2001). The net energy from rice production observed in Iran's Guilan provinces was 36,927.58 MJ/ha (Kazemi *et al*., 2015). The non-renewable energy ratio calculated for this region was 7.67. The higher value of the non-renewable energy ratio indicates minimum use of fertilizers (Firouzi *et al*., 2017) in this region. Due to reduced crop yield and increased labour use during transplantation and crop care, the mean human energy profitability for this region was found to be lower (42.8). Wheat and rice, according to Paramesh *et al*. (2017), have human energy profitability of 162.9 and 125.4 respectively. The energy profitability recorded was 1.38 which indicated that for every unit of input energy 1.38 units of energy can be saved in the system.

Sensitivity analysis

The Cobb–Douglas production function describes rice output as a function of direct (labour, diesel fuel) and indirect energy sources (fertilizers, pesticides, FYM, and seeds). Regression results indicated that, when all the variables (inputs) were included in the regression equation, they explained 90% of the variation in rice yield (Table 3). The variable with positive and negative coefficients had a positive and negative effect on rice yield, respectively. The result indicated that, the nitrogen fertilizer (6.05) is having higher impact followed by seeds (2.99) and FYM (0.39). However, the direct energy inputs like labour and diesel are having a negative impact. The coefficient of nitrogen fertilizer indicated that, with 1% increase in nitrogenous fertilizer will lead to a 6.05% increase in the rice yield when all the other inputs are adequate. This positive effect indicated the need of nitrogen application to improve the crop yield. Mohammadi *et al*., (2010) suggested that, fertilizer was an important input to enhance the yield of kiwi fruit in Mazandaran of Iran. The MPP values indicate the inputs which are having a greater impact on crop productivity (Table 3). In our study, the values of MPP were found higher for nitrogenous fertilizer (7.57) and seeds (4.46). This implies the increased use of nitrogen and higher seed rate will improve the rice yield considerably in this region. The negative MPP value for labour, fossil fuel and phosphorus indicated that, these inputs were surplus and needed to be reduced. The return to scale in this study was 3.73 which implies that the rice yield increased by 3.73% with a 1% increase in all the energy inputs (Patil *et al*., 2016).

Table 3. Econometric estimation and sensitivity analysis of various inputs in rice production

Energy input source	Coefficients	t value	MPP
Labour	–0.076	–0.11	–0.11
Machinery	–	–	–
Diesel	–0.074	–0.04	–0.10
FYM	0.39	1.35	0.51
Seeds	2.99	5.20	4.46
Nitrogen	6.05	1.01	7.57
Phosphorus	–2.74	–0.66	–4.59
Potassium	–2.74	0.03	0.02
Pesticides	–0.06	–0.84	–0.13
Constants	–44.4	–	–
R^2	0.90	–	–
Return to scale	3.73	–	–

The regression coefficient for IDE and NRE were positive which were significant at 0.01% and 0.001% levels respectively (Table 4). The result showed that NRE (3.73) and IDE (3.15) were having a significant impact on enhancing the rice yield of this region. The return to scale values for (1) and (2) models was positive which indicates an increasing return to scale. The MPP values were also found positive for DE, IDE and NRE. This result revealed that, an additional increase in rice yield will be possible with an increase in these inputs.

Table 4. Econometric estimation of direct energy, indirect energy, renewable energy and non-renewable energy forms in rice production (n=30)

Energy input source	Coefficients	t-value	MPP
Model 1: $lnYi = \beta_0 + \beta_1 \ln(DE) + \beta_2 \ln(IDE) + \varepsilon_i$			
Direct energy	1.20	1.13	1.04
Indirect energy	3.15	3.36**	2.60
Constants	–31.27	–4.80	
R^2	0.59	–	–
Return to scale $(\sum_{i=1}^{n} \beta_i)$	4.35	–	–
Model 2: $lnY_i = \gamma_0 + \gamma_1 \ln(RE) + \gamma_2 \ln(NRE) + \varepsilon_i$			
Renewable energy	–0.14	–0.36	–0.13
Non-Renewable Energy	3.73	6.85***	2.97
Constants	–26.25	–4.01	
R^2	0.66	–	–
Return to scale $(\sum_{i=1}^{n} \beta_i)$	3.59	–	–

**Significant at 0.01% level of significance; ***Significant at 0.001% level of significance

Identification of efficient and inefficient rice farmers

According to the examined data from the BCC model, 21 of the 30 farmers tested were determined to be efficient with a score of 1, while the remaining 9 farmers had a score of 1 and were found to be inefficient in their use of various energy inputs. The PTE from the BCC model had a mean of 0.997 and a standard deviation of 0.005 (Table 5).

However, with respect to TE from the CCR model, only 5 farmers werefound efficient. The average TE computed was 0.738, with a standard deviation of 0.187. The result showed that, the lowest standard deviation was observed in PTE (0.005), followed by TE (0.187) and SE (0.188). For inefficient rice growers, the average scale efficiency was 0.68. This indicates that, there is scope to improve farmers' farming practises in order to enhance crop yields. The average SE was 0.741, which indicated that if inefficient rice farmers of this region manage inputs efficiently, there is ascope for energy conservation. Our result revealed that more number of farmers were found inefficient based on the CCR model as compared to the BCC model. Chauhan *et al*. (2006) also observed that, out of 97 farmers, 36 were efficient according to the BCC model; however, based on the CCR model only 15 were found efficient in the rice-production system of West Bengal, India. Another study in Iran on tomato crops revealed that out of 27 farmers, only 8 were found efficient based on the CCR model; however, in the BCC model 15 were found efficient (Pahlavan *et al*., 2011).

Table 5. Technical, pure technical and scale efficiency of rice farmers (n=30)

DMU	Technical efficiency	Pure technical efficiency	Scale efficiency
1	0.588	1	0.588
2	0.586	1	0.586
3	0.460	1	0.460
4	0.563	1	0.563
5	0.523	1	0.523
6	0.516	0.995	0.518
7	0.613	1	0.613
8	0.552	1	0.552
9	0.592	1	0.592
10	0.552	1	0.552
11	0.537	0.998	0.538
12	0.675	1	0.675
13	0.547	1	0.547
14	0.563	1	0.563
15	0.607	0.996	0.609
16	1	1	1
17	1	1	1
18	0.857	0.989	0.866
19	0.865	0.991	0.873
20	0.844	1	0.844
21	0.840	1	0.840
22	1	1	1
23	0.827	0.981	0.843
24	0.832	0.981	0.848
25	0.831	0.989	0.840
26	1	1	1
27	0.911	1	0.911
28	0.930	1	0.930
29	0.955	0.988	0.967
30	1	1	1
Average	0.738	0.997	0.741 (0.68)
Maximum	1	1	1
Minimum	0.460	0.981	0.460
SD	0.187	0.005	0.188

Figure in the parenthesis denotes the mean scale efficiency of inefficient farmers

Greenhouse gas emission

The GHG emissions were determined based on non-renewable energy inputs (Table 6). The results revealed that, the highest GHG emission in terms of kg CO_2 eq./ha was found with nitrogenous fertilizer (72.1), followed by machinery (68.5) and diesel fuel (67.9). The least GHG emission was observed from insecticides (5.9) due to their less use. The estimated total GHG emission from the non-renewable energy resources for rice production was 233.6 kg CO_2 eq./ha. Our results confirm the findings of Pishgar-Komleh *et al*., (2012) while studying GHG emissions from potato crops in Iran. The continuous flooding, nitrogenous fertilizers, and machinery are responsible for higher GHG emissions from rice. Fertilizer-responsive high-yielding cultivars with low soil fertility result in the use of more chemical fertilisers, resulting in greater GHG emissions. The increased usage of diesel fuel, which results in additional GHG emissions, is due to traditional tillage practises and improved mechanization. Periodic soil testing, as well as the use of organic sources of nutrients such green manure, *Azolla* growing, and FYM treatment, can help to limit the use of fertilizers indiscriminately and improve soil health (Sarangi *et al*., 2014). This finding emphasized the potential for conservation tillage in this location to save energy and reduce GHG emissions by reducing the use of machinery and fossil fuel combustion.

Table 6. Greenhouse gas (GHG) emission coefficients of inputs and estimated GHG from rice production using non-renewable inputs (n=30).

Input	Unit	GHG coefficient (kg CO_2 eq./unit)	(kg CO_2 eq./ha)
Machinery	MJ	0.071	68.5
Diesel fuel	L	2.76	67.9
Nitrogen	kg	1.3	72.1
Phosphorus	kg	0.2	7.8
Potassium	kg	0.2	11.4
Insecticides	kg	5.1	5.9
Total	233.6		

It can be concluded from this study that, the energy productivity of the rice- production system was found lower in this region. The mean scale efficiency of inefficient farmers indicated scope for improving agricultural practices. Nitrogen, seeds, and FYM were found as the most sensitive inputs and have a positive impact on crop yield and energy conservation. Among different non-renewable energy inputs nitrogen, diesel and machinery were contributing more to the GHG emission. Farmers in this region must use conservation tillage and better crop-management practises to save energy and minimize GHG emissions.

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