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Research Paper

Economic Analysis of Greenhouse Gas Emission Reduction Potential, Energy-Use and Sustainability of Maize Production in Karnataka

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ABSTRACT

This study was conducted to examine the energy use pattern, efficiency, sustainability and GHG reduction potential in maize production in Karnataka State through a non-parametric production function (DEA) and threshold dynamic panel model framework. Cross-sectional panel data obtained from cost of cultivation scheme was used for the study. The results illustrated that the total input energies in maize production for the period under study increased from 73.01 thousand MJ ha^{-1}in 2010-11 to 95.03 thousand $MJha^{-1}$in 2017-18. Energy usage pattern indicated that power and electricity consumed for irrigation were the main energy inputs consumed in maize production in the study region. The farmers were technical inefficiency (0.851) implying that 14.9 per cent of the overall resources in the production process could be saved. The total CO_2 emission was calculated as 45.17 thousand kg CO_2 eq ha^{-1}. By energy optimization, the total energy consumption can be reduced to 105.7 thousand MJ ha^{-1} corresponding to total CO_2 emission reduction potential to value at 5.7 thousand kg CO_2eq ha^{-1}. Sustainability of the farm was characterized by positive growth at a low rate of 0.07% per annum and thus, higher efficiency level accompanied by high level of productivity resulted in potential reduction emission level among the farmers. It is, therefore; recommended that government policies should be geared towards practices that tend to improve efficiency and productivity of the farmers through effective extension education.

HIGHLIGHTS

- Total input energies in maize production increased.
- Power and electricity consumed for irrigation were the main input energy consumed.
- Majority of the input's energies were from renewable sources.
- Farmers were inefficient caused by scale and technical (managerial) inefficiency.
- Improved farm level efficiency and productivity could raise the performance of farmers by saving overall resources, significant reduction in emission level and sustainability of the production process.

Keywords*:* Data Envelopment Analysis, Dynamic Threshold Panel Model, Energy-use Efficiency, GHG Emission Reduction Potential, Maize Production

Global climatic changes along with the rapid increase in population and prevalence of food and nutritional insecurity as well as economic crisis have become a contemporary challenge for the sustainability of agroecological systems in most developing countries (Jaiswal and Agrawal, 2020). The recent upsurge in global hunger index indicating that one in ten people remain undernourished around the world projecting a shocking statistic that requires more ambitious action to solve food security and therefore, agricultural production is

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envisaged to be increased by 70 per cent to provide the necessary amount of food (FAO, 2016), whereas 33 percent of global earth soils are already subjected and exposed to degradation which is projected to reach 90 percent by 2050 (FAO, 2021), which poses critical threat to global food security and the universal achievement of Sustainable Development Goals (SDGs).

Thus, the traditional agricultural production systems may not lead to the desired outcome of economic advancement and food security and attainment of the SDGs in the face of the shrinking share of available area suitable for cultivation and production of crops accompanied by the drastic decline in agricultural labour and high cost of human labour. Therefore, agricultural activities tend to depend excessively on non-renewable chemical inputs and energy to maintain its crop production to sustain the demand of food energy which are detrimental to the natural environment. Agriculture production directly depends on the natural resource (soil, water) and a myriad of biological processes, but at the same time a major contributor and culprit to the changes in the components and composition of these resources employed by the sector (Tubiello, 2019). Moreover, the increasing pressure for agricultural commodities to be intensively managed to boost and sustain economic activities significantly influence the ecosystem resulting in environmental imbalances and instability leading to loss of biodiversity, pollution and eutrophication of aquatic habitats and soil aquifers by the leaching of nutrients nitrogen and phosphorus as well as pesticides, which are harmful to the functioning of soil flora and fauna and hence unsustainability of soil ecosystem. Food security and agricultural development goals can be accomplished with minimum environmental cost or without depletion of the natural resource base by adapting to climate change and lower emission intensities per output (Tesfaye *et al.* 2021). Therefore, the need for revolution and intensification of agricultural production systems and its sustainability to meet the demand for economic growth by decoupling the negative externalities is paramount as it serves as the nucleus, pivotal balance and inter-sectoral linkages between the secondary and tertiary sectors of any economy.

In India, agricultural production systems have profoundly undergone tremendous changes in the utilization of resources and inputs since the inception of green revolution technology characterized by the substantial shift in mechanization, chemical fertilizers, high-yielding seeds and pesticides resulting in magnanimous changes in agricultural energy flows (Benbi, 2018) making India as the third-largest emitter of greenhouse gases after China and United States. It is well-established in India by numerous of studies that the dynamics in cropping pattern and sustainability of agriculture is already influenced and impacted by the recent changes in climate aided by greenhouse gas (GHG) emissions (Kumar and Parikh, 2001; Maheswarappa *et al.* 2011; Benbi, 2018) with significant proportion of the emissions occurring at the primary production stage through the use of agricultural inputs (Pathak *et al.* 2010). With the upsurge in population and the need to enhance food production, one has to address the challenge of meeting the growing demand for food production in India while controlling and reducing the GHG emissions from agriculture considering the limited natural resources and the impact of using different energy sources on the environment and human health. It is, however; imperative to investigate energy use patterns and energy efficiency of production systems. There are diverse studies on energy use consumption in Indian agriculture sector (Chhabra *et al.* 2013; Vetter *et al.* 2017; Benbi, 2018, Sah and Devakumar, 2018) but no research has primarily focused on maize being a ubiquitous ingredient in the feed formulation for livestock production with emphasis on energy analysis and GHG emission reduction potential aswell as input-use efficiency and its impact on GHG emission potential. Thus, the aim of this study is to evaluate the input-output energy, and greenhouse gas emission reduction potential, the efficiency of energy consumption, sustainability of maize production and to examine the relationship between input use efficiency on GHG reduction potential through application of econometric modeling in Karnataka state, India.

MATERIALS AND METHODS

The data used in this study was a cross-sectional panel data obtained from cost of cultivation surveys at state level using multi-stage sampling, where districts within states, and villages within districts forms the first and second stage unit of sampling with the ultimate unit of data collection being the household conducted by the Government of India (CSO, 2021). Maize farmer's data for the Karnataka state was extracted for the study for the period of 2010-11 – 2017-18 production seasons. In order to ensure true reflection of the production system and balanced panel, farmers with constant cross-sectional data for the periods within different geographical location across the state were considered for study. In order to calculate input–output ratios and other energy indicators, the data was converted into output and input energy levels using equivalent energy values (Table 1) for each input and the output of commodity (maize) under study. Electricity, quantity of water, diesel consumption as well as direct energy consumed for irrigation were computed as given in each respective equation.

Water and Energy Consumption for Irrigation

Water for irrigation was assumed to be pumped from local agricultural well by electric pumps used by majority of farmers in India (ACM pump series) with given manufacturer specification below. Therefore, the quantity of water and direct energy produced by pumping the water were estimated following Khoshnevisan *et al.* (2013) as expressed in equation 1 & 2.

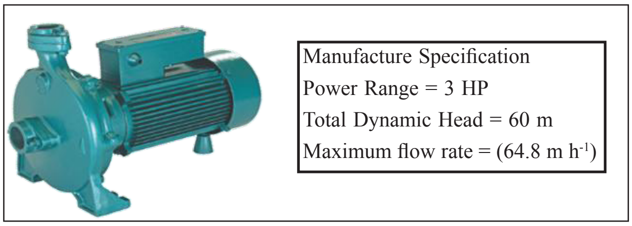


Fig. 1: ACM pump

Total quantity of water (Q) was calculated using the expression:

$$Q = \textit{flow rate} \times \textit{hours used} \times \textit{pump efficiency} \quad \ldots(1)$$

The direct energy dissipated during pumping water was calculated as:

$$DE = \frac{\gamma g H Q}{\varepsilon_p \varepsilon_q} \quad \ldots(2)$$

Where, DE is direct energy (Jha^{-1}), g is acceleration due to gravity (ms^{-2}), H is total dynamic head (m), Q is the volume of water used for one cultivation season (m^3 ha^{-1}), γ is the density of water (kg m^{-3}), ε_p is the pump efficiency (70 – 90%), ε_q is the total power conversion efficiency (18 – 20%).

Electricity Consumption for Irrigation (E)

$$E = \text{power (HP)} \times \text{total hours of irrigation} \times \text{power conversion efficiency} \quad \ldots(3)$$

1 HP = 746 Watt = 0.746 kW

Diesel Consumption (DC)

The consumption of diesel for farm operation was assumed to be under conventional tillage where the basic implement used by farmer were cultivator and disc harrow. Following Goyal *et al.* (2010), maximum fuel consumption of tractor with these implement attached was estimated as 4.1 L/hr . Thus, direct consumption of diesel (DC) was calculated as:

$$DC = 4.1 \times \text{Total machine labour used} \quad \ldots(4)$$

Energy of carbon-based inputs

The fertilizer input energy levels were computed using the equivalent energy values for each input under study (Table 1). Total fertilizer based inputs energies were computed as:

$$\sum_{l=1}^{n} f\ ert(N,P,K)_i \times C_f \quad \ldots(5)$$

Where N,P,K are the quantity used by the farmers, C_f = Energy equivalent coefficient

Mechanical Energy

The machine energy was calculated by using the formula following Hatirli *et al.* (2005) as expressed below:

$$ME = \frac{EG}{TC_a} \quad \ldots(6)$$

Where, G is the weight of the machine (kg), E is the production energy of machine (MJ kg^{-1}yr^{-1})

T is the economic life of machinery used (hr), C_a is the effective field capacity (ha h^{-1}) and expressed below:

$$C_a = \left(\frac{S \times W \times E_f}{10} \right) \quad \ldots(7)$$

Where, S is the working speed (km/h), W is the working width E_f, is the the field efficiency. These calculation were done by assuming a single axle tractor (1745 kg) and standard mould-board plough and disc harrow for conventional tillage practices.

Given the calculated energy equivalents of inputs and the output (Table 1), the energy use efficiency (energy ratio), energy productivity and specific energy were computed using the equations 8 – 10 respectively:

$$Energy\ Ratio = \frac{Total\ Energy\ Output\ (MJ)}{Total\ Energy\ Input\ (MJ)} \quad \ldots(8)$$

$$Energy\ Productivity = \frac{Grain\ Yield\ (kg)}{Total\ Energy\ Input\ (MJ)} \quad \ldots(9)$$

$$Specific\ Energy = \frac{Total\ Energy\ Input\ (MJ)}{Grain\ Yield\ (kg)} \quad \ldots(10)$$

Energy Saving Target Ratio (ESTR)

The energy saving target ratio was computed as given below following (Sadiq *et al.* 2015).

$$ESTR\ (\%) = \frac{\text{Energy Saving target}}{\text{Actual Energy input}} \times 100 \quad \ldots(11)$$

Where energy saving target is the optimum level of energy use without jeopardizing the present output level. A higher ESTR implies higher energy use inefficiency and thus possible higher negative externalities and production cost at the primary stage production process.

Sustainability Index

Sustainability indices for each year was computed (Lal, 2004) as per the Eqn. 12

$$C_s = \frac{(C_o - C_i)}{C_i} \quad \ldots(12)$$

Where C_o and C_i are the output and input, respectively. The carbon-based output includes operations that involved harvesting, threshing and shelling of maize grain and the management of crop residues, whereas the carbon-based inputs included farm operation management practices such as fertilizer application, irrigation and tillage operation.

Greenhouse Gas Emission Estimation

The estimation of GHG emission in the present study only considered emission level at farm gate (cardle-gate). Moreover, we emphasize primarily on CO_2 emission and therefore GHG will be used from here onwards to connotes CO_2 emission. Therefore, CO_2 emission coefficients (Table 2) of agricultural inputs were used for quantifying the GHG emissions of maize production in the studied region by multiplying the inputs application rate by their corresponding emission coefficient.

Fertilizer based inputs

Total GHG from fertilizer based inputs were computed as:

$$GHG_{fert} = \sum_{l=1}^{n} fert(N, P, K)_i \times E_f \quad \ldots(13)$$

Where N, P, K are the quantity used by the farmers, E_f = carbon emission coefficient

Carbon Emission from Burning of Residues

The total biomass or maize straws produced during the production process was computed using the below relationship:

$$\text{Total Biomas} = \frac{\text{Economic Yield (Agronomic Yield)}}{\text{Harvest Index (HI)}} \quad \ldots(14)$$

The value HI of 0.4 for maize was adopted from Maheswarrapa *et al.* (2004). The emission released from burning of remaining straw generated from the biomass produced was estimated using the formula (IPPC, 2007):

$$CE = Total\ Biomass \times Average\ Dry\ Matter\ Fraction \times Fraction\ Actually\ Burnt \times Fraction\ Oxidised \times Carbon\ Fraction \times E_f \quad \ldots(15)$$

CE is the carbon equivalent produced, Dry matter fraction = 0.4, Carbon Fraction = 0.4709, Fraction of oxidation = 0.90, Fraction actually burnt = 0.25 (25%), Carbon emission factor (E_f) = 11.7 gkg^{-1} = 0.0117 $kgkg^{-1}$.

Table 1: Energy equivalent coefficient of inputs

Sl. No.	Inputs	Units	Energy equivalent coefficient (MJ unit^{-1})	Reference
	Machine			
	Tractor and self – propelled	kg yr^{-1}	9 – 10	Kitani (1999)
	Stationary Equipment	kg yr^{-1}	8 – 10	Kitani (1999)
	Implement and Machinery	kg yr^{-1}	6 – 8	Kitani (1999)
1	Human labour	hr	1.96	Kitani (1999)
2	Animal labour (Bullock)	kg	5.05	Hatirli *et al.* (2005)
2	Diesel	l	47.5	Kitani (1999)
3	**Fertilizer**			
	Nitrogen (N)	kg	66.14	Omid *et al.* (2011)
	Phosphate (P_2O_5)	kg	12.44	Omid *et al.* (2011)
	Potassium (K_2O)	kg	11.15	Omid *et al.* (2011)
4	FYM	kg	0.3	Ozkan *et al.* (2004)
5	Water for irrigation	m^3	1.02	Omid *et al.* (2011)
6	Electricity	kWh	11.93	Singh *et al.* (1999)
7	Seed	kg	15.2	Maheswarappa *et al.* (2011)
8	Maize product (output)	kg	14.7	Sadiq *et al.* (2015)

Table 2: GHG coefficient factor

Inputs	Units	GHG Coefficient	Reference
Human labour	H	0.36	Houshyar *et al.* (2015 a&b)
Bullock labour	Kg	2.59	Houshyar *et al.* (2015 a&b)
Diesel	L	2.76	Dyer and Desjardins (2009)
Fertilizer			
Nitrogen (N)	kg	1.3	Lal (2004)
Phosphate (P_2O_5)	kg	0.2	Lal (2004)
Potassium (K_2O)	Kg	0.2	Lal (2004)
Electricity for irrigation (Pump)	kWh	0.241	Singh *et al.* (2002)
Maize product (output)	Kg	0.385	West and Marland (2002)

Energy – Use Efficiency

In this study, a non–parametric production frontier (DEA) model was used to assess efficient and inefficient individual decision-making unit (DMUs) as the estimation procedure is not constrained by any a prior specification of distribution function which is essential for data that may exhibit multicollinearity. The theoretical and mathematical intuition framework of DEA model has been excluded in the present study as the detailed description are given by several authors (Charnes *et al.* 1978; Banker *et al.* 1984; Coelli, 1999). The technical efficiency (TE) that evaluates DMU's ability to achieve maximum output from given set of inputs was computed as expressed in Eqn. 17:

$$Max\ h_k = \frac{\sum_{r=1}^{s} u_{rk}\, y_{rk}}{\sum_{i=1}^{m} v_{ik} X_{ik}} \quad \ldots(16)$$

Subjected to;

$$\frac{\sum_{r=1}^{s} u_{rk}\, y_{rj}}{\sum_{i=1}^{m} v_{ik} X_{ij}} \le 1, \qquad j = 1, \ldots, n \quad \ldots(17)$$

u_{rk}, v_{ik}, $r = 1, \ldots, s$, and $i = 1, \ldots, m$

where '*k*' is the DMU being evaluated in the set of *j* = 1,2,…*n* DMUs; '*hk*' the measure of efficiency of DMU 'y_{rk}' the amount of output '*r*' produced by DMU '*k*' during the period of observation; 'x_{ik}' the amount of resource input '*i*'; 'y_{rj}' the amount of service output 'r' produced by DMU 'j' during the period of observation; 'x_{ij}' the amount of resource input 'i' used by DMU 'j' during the period of observation; 'u_{rk}' the weight assigned to service output 'r' computed in the solution to the DEA model; 'v_{ik}' the weight assigned to resource of input 'i' computed in the solution to the DEA model; 'm' the number of inputs used by the DMUs; and 's' the number of outputs produced by the DMUs.

Total Factor Productivity Changes

Malmquist output-based total factor productivity index was adopted to measure the productivity change. The t index was expressed as:

$$m_o(y_{t+1}, X_{t+1}, y_t, X_t) = \left[\frac{d_0^t(y_{t+1}, X_{t+1})}{d_0^t(y_t, X_t)} \times \frac{d_0^{t+1}(y_{t+1}, X_{t+1})}{d_0^{t+1}(y_t, X_t)}\right]^{1/2} \quad \ldots(18)$$

This measure the productivity of the production point y_{t+1}, X_{t+1} relative to production point y_t, X_t. A value greater than one implies positive TFP from period t to $t + 1$ (Coelli, 1999)

Impact of Resource Use Efficiency on GHG Emission

The impact of efficiency improvement on the level of emission was conducted through cross-farm dynamic panel data framework with threshold effects with endogeneity effect (Seo and Shin, 2016; Law, 2014) and expressed as:

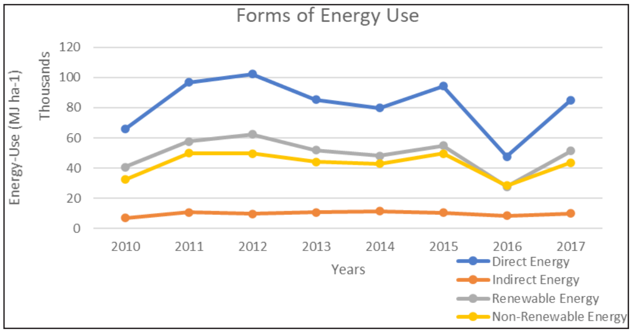
$$CO_{2it} = \begin{cases} (\theta_1 CO_{2it-1} + \theta_{21} E_{it} + \theta_{31} P_{it})\, 1\{q_{it} \le \gamma\} \\ (\theta_2 CO_{2it-1} + \theta_{22} E_{it} + \theta_{32} P_{it})\, 1\{q_{it} > \gamma\} \end{cases} \quad \ldots(19)$$

where, 1 {·} is an indicator function q_{it}, the transition variable and γ the threshold parameter (efficiency). CO_{2it} is the emission level, E_{it} is the energy level, and P_{it} is the farm level productivity. We estimated the equation by GMM, which allows for both contemporaneous regressors and the transition variable to be endogenous.

RESULTS

The quantity of input and output energies in maize production are summarized in Table 3. As illustrated, the total energy input consumption was computed to have increased from73.02 thousand MJ ha^{-1} in 2010-11 to 95.04 thousand MJ ha^{-1} in 2017-18. This result is similar to studies conducted by Sah and Devakumar (2018); Benbi (2018) who reported similar trends of input energy usage in Indian agrarian system. The study result revealed a fairly constant area (average 1.32 ha) under production among the farmers throughout the period under study. Thus, increase in input energies could be due to the urge to increase production of a given piece of land which amounts to overuse of the input. The average maize output in the studied region increased from 3,463 kg ha^{-1} in 2010-11 to 3,683 kg ha^{-1} in 2017-18, corresponding to the total output energy of 50.906 thousand MJ ha^{-1} and 54.141 thousand MJ ha^{-1}, respectively. Input energy consumption was classified as direct-indirect and renewable-non-renewable forms. The analysis revealed that the farmers use inputs that directly emit and release emission into the environment as indicated by highest energy from the direct form of energy (Fig. 1). Based on the results, direct and indirect energy utilized for maize production during production periods under consideration were calculated as 656.642 thousand MJ ha^{-1} representing 89.26 per cent and 78.984 thousand MJ ha^{-1} (10.74%) respectively. However, majority of the input's energies were renewable sources, which is essential for sustainability of the farming ecology.

The results depicted in Fig. 2 revealed that there was a sharp decline in all forms of energy usage in production season in 2016. The usage of non-renewable form of energy increased steadily from 32417. 39 MJ ha^{-1} in 2010-11 production to 43727 MJ ha^{-1} in 2017 -18. This implies a change in the energy use dynamics over the period under study.



Source: *Author's computation*

Fig. 2: Different forms of energy usage in maize production

Further analysis on total energy consumption (Fig. 3) revealed that 55 per cent representing 37.85 thousand

Table 3: Forms of energy in maize production

Year	Total Input Energy (Thousand MJ ha^{-1})	Direct Energy (Thousand MJ ha$^{-1)}$	Indirect Energy (Thousand MJ ha^{-1})	Renewable Energy (Thousand MJ ha^{-1})	Non-Renewable Energy (Thousand MJ ha^{-1})	Output (kg)	Output Energy (Thousand MJ ha^{-1})
2010	73.02	65.940	7.08	40.60	32.42	3463	50.91
2011	107.40	96.69	10.71	57.62	49.78	4288	63.03
2012	112.02	102.15	9.87	62.42	49.60	3259	47.91
2013	96.140	8530.	10.84	51.92	44.22	3992	58.68
2014	91.22	79.74	11.47	48.19	43.034	3732	54.86
2015	104.61	94.21	10.40	54.99	49.62	3364	49.45
2016	56.16	47.61	8.55	27.60	28.56	3208	47.15
2017	95.04	84.98	10.05	51.31	43.73	3683	54.14
Total	735.63	656.64	78.98	394.65	340.97		42.61

Source: *Author's computation.*

MJ ha^{-1} of energy consumed was indirect energy dissipated during pumping water for irrigation during the study period. Electricity consumption used in pumping water also constituted 33 per cent representing 240.98 thousand MJ ha^{-1} of the total energy used. The high consumption of energy of electricity and dissipation of energy from irrigation facilities is due to dropping levels of ground water table and thus higher amount of irrigation hours is required to lift the quantity of adequate water for crop development and hence resulting in heating of irrigation facilities and high consumption of electricity.

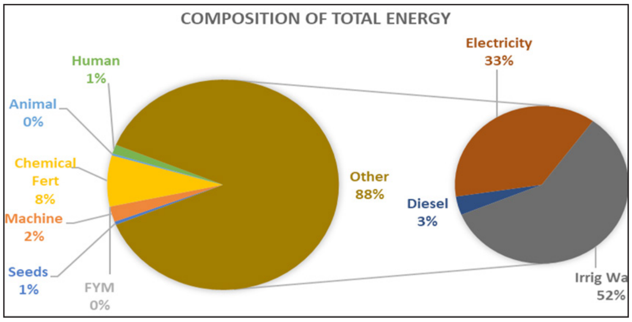


Fig. 3: Composition of inputs in total energy in maize production

The results presented in Table 4 revealed a decreased energy-used efficiency from 2.79 in 2010 to 2.28 in 2017, whiles energy productivity also decreased from 0.047 to 0.039 in the same period implying energy-used inefficiently. On average, 25.43 MJ of energy was consumed to produce 1 kg maize during the period under *t* a growth rate of 1.26 per cent at lower levels of energy use efficiency.

Table 4: Energy indices in maize production

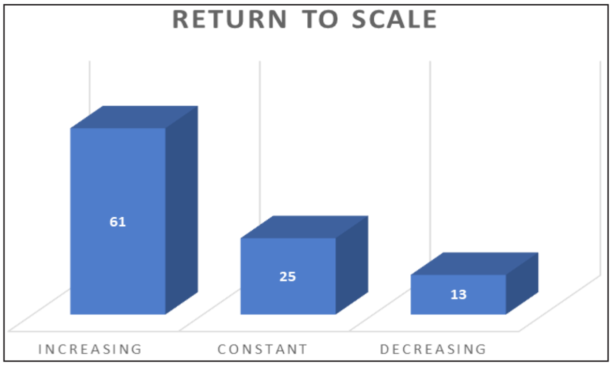
Year	Energy Ratio	Energy Productivity (kgMJ^{-1})	Specific Energy (MJ kg^{-1})
2010	2.79	0.047	21.09
2011	2.35	0.039	25.05
2012	1.71	0.029	34.34
2013	2.44	0.041	24.08
2014	2.41	0.041	24.44
2015	1.89	0.032	31.10
2016	3.36	0.057	17.50
2017	2.28	0.039	25.80

Source: *Author's computation.*

Measuring Input Use Efficiency

The summarized statistics for the estimated measure of efficiency is presented in Table 5. The results revealed inefficient use of resources with an average undulating efficiency score ranging from 0.808 in 2010-11 production season to 0.827 in 2017-18 with highest technical efficiency score of 0.904 recorded during 2013-14. The wide variation in efficiency scores implies that virtually all the farmers were not fully acquainted of the right combination of inputs and thus, adoption of recommended management practices by the farmers through effective off-farm training on input management could save 14.9 per cent of the overall resources employed in the production process. This result support a study conducted by Hamsa *et al.* (2017) who reported similar estimate of technical efficiency (0.83) for rainfed maize production in central dry zone of Karnataka State.

Moreover, considering the total sample size under returns to scale (Fig. 4), majority of the farmers (61%) were operating within the zone of increasing returns to scale and hence, improvement through adoption of the recommended package of practice can enhance farmers to achieve current level of economic output by the same quantity of inputs. However, 13 per cent of the farmers were operating within the irrational zone on the production frontier. Thus, continuous application of resources will only result in high cost of production. Therefore, we can affirm that inefficiency in maize production was due to managerial factors on the scale of operation Hence policy devoted towards extension education through effective farm advisory services to the farmers would be beneficial.



Source: *Author's computation*

Fig. 4: Distribution of scale of production in maize production

Total factor Productivity (TFP)

The Malmquist total factor productivity results presented in Table 6 showed that only 2013 and 2016 had positive average total factor productivity. In general, there was a decline in average total factor productivity of 2.8 per cent during the study period accounted by deficient in pure and scale efficiency changes. The average scale efficiency change was 0.936 indicates disadvantageous conditions of scale size implying that 6 percent reduction in various inputs resources would be possible without affecting their yield level by improving efficiency of the farmers.

Optimum Use of Energy and Cost in Maize Production

The technical efficiency score of less than unity implies the present conditions farm management consumes more energy than required. Therefore, it becomes imperative to evaluate the optimum energy target levels in order to avert wastage of energy as presented in Table 7. As illustrated, total input energy could be reduced to 59.013 thousand MJ ha^{-1} in 2010 while maintaining the current yield level. The results of ESTR indicate that on average 14.38 per cent representing 105.75 thousand $MJha^{-1}$of the total energy use could be saved annually during the period under study without affecting total output. Therefore, it is possible to advise inefficient DMUs, referencing better operating practices followed by his peers in order to reduce the input energy levels to the optimum values while achieving the present output level obtained.

The optimal cost of associated with the optimum input utilization is presented in Table 8. The results showed an increase in cost of production mainly due to high usage of inputs with the urge to increase

Table 5: Decile frequency distribution of efficiency score of maize farmers (DMUs)

Eff Range	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
0.2<=E<0.3	0	0	0	0	0	0	0	1
0.3<=E<0.4	2	0	0	0	1	0	0	3
0.4<=E<0.5	2	1	2	0	5	4	4	2
0.5<=E<0.6	8	3	2	2	6	6	8	5
0.6<=E<0.7	11	6	12	4	7	20	13	17
0.7<=E<0.8	22	8	15	18	11	9	22	11
0.8<=E<0.9	18	13	15	16	15	14	18	9
0.9<=E<0.9	13	27	12	10	17	11	6	9
E==1	23	41	41	49	37	35	28	42
Average	0.808	0.903	0.872	0.904	0.853	0.833	0.809	0.827

Source: *Author's computation.*

Table 6: Malmquist total factor productivity index in maize production

YEAR	Efficiency change	Technical change	Pure Efficiency change	Scale Efficiency Change	Total factor productivity change
2011	0.964	0.812	0.952	1.013	0.782
2012	0.885	0.951	0.964	0.918	0.842
2013	1.285	1.225	1.071	1.200	1.574
2014	0.683	1.139	0.832	0.821	0.777
2015	1.196	0.806	1.171	1.022	0.964
2016	0.934	1.258	0.984	0.949	1.175
2017	0.552	1.624	0.778	0.710	0.970
Mean	0.895	1.085	0.956	0.936	0.972

Source: *Author's computation.*

Table 7: Optimum use and wasteful uses of energy in maize production

Year	Actual energy (Thousand MJ ha^{-1})	Optimum energy (Thousand MJ ha^{-1})	Saving energy (Thousand MJ ha^{-1})	ESTR
2010-11	73.02	59.01	14.00	19.18
2011-12	107.41	97.05	10.35	9.64
2012-13	112.03	97.72	14.31	12.77
2013-14	96.14	86.97	9.16	9.54
2014-15	91.22	77.83	13.38	14.68
2015-16	104.61	87.17	17.44	16.67
2016-17	56.16	45.44	10.72	19.08
2017-18	95.04	78.66	16.3	17.22

Source: *Author's computation.*

output mixed with high levels of technical and scale inefficiency in the production process as revealed by the efficiency and TFP scores. During period under study, by improving technical efficiency and adoption of the recommended agronomic package of practices by the farmers, 19.18 per cent representing 4.178 thousand rupees of the production cost could have been saved to enhance the profit generated and hence increased the livelihood of the farmers.

Table 8: Cost saving potential in maize production

Year	Average Cost (Thousand ₹)	Optimum (Thousand ₹)	Saving (Thousand ₹)
2010-11	21.78	17.60	4.17
2011-12	28.52	25.77	2.74
2012-13	32.26	28.13	4.12
2013-14	38.64	34.95	3.68
2014-15	43.05	36.73	6.32
2015-16	41.46	34.55	6.91
2016-17	34.09	27.59	6.51
2017-18	40.81	33.78	7.03

Source: *Author's computation.*

Greenhouse Gas Emission Reduction Potential

GHG emission was investigated to determine the role of energy utilization in environmental condition of maize production (Table 9). The total greenhouse gas emission of maize production was approximately estimated at 4352.52 kg CO_2eq ha^{-1} in 2010-11 production season to 5030.61 kg CO_2eq ha^{-1}. The results revealed that during the production period under study 14.5 per cent of the total emission equivalent to 5723.20 kgCO_2eq ha^{-1} of could have been saved through optimization of resource use.

The detailed analysis revealed that maximum amount of CO_2 emission due to input use was related to electricity use with approximately 12281.46 kg CO_2 eqaccounting for 54 per cent of the total emission during study period followed by dissipated emission from irrigation facilities contributing 17 per cent. The result is similar to study conducted by Khoshnevisan *et al.* (2012) who reported that electricity consumption was one major

Table 9: Greenhouse Emission Reduction Potential in Maize Production

Year	Total Emission (kg CO_2eq ha^{-1})	Optimum (kg CO_2eq ha^{-1})	Saving (kg CO_2eq ha^{-1})	GESTR
2010-11	4352.52	3517.66	834.87	19.18
2011-12	5810.91	5250.75	560.16	9.64
2012-13	5187.64	4525.02	662.62	12.77
2013-14	5226.39	4727.98	498.40	9.54
2014-15	4954.19	4227.04	727.15	14.68
2015-16	5192.95	4327.08	865.86	16.67
2016-17	3707.71	3000.25	707.46	19.08
2017-18	**5030.61**	4163.93	866.67	17.23
Total Emission	39462.93		5723.203	14.50

Source: *Author's computation, GESTR = Greenhouse Emission Saving Target Ratio.*

contributor to greenhouse gas emission in modern crop production system. Threshing, processing of the grain into seed and burning of straws and other by-products constitute 66 and 33 per cent respectively of the total greenhouse gas emission due to output grain processing. However, by input energy optimization, 31 per cent (1823.65 kg CO_2eq ha^{-1}) of emission due to electricity consumption 10 per cent (558.13 kg CO_2eq) of emission due to irrigation 3 per cent (164.56 kg CO_2eq ha^{-1}) from chemical fertilizers could be saved without jeopardizing economic output from the farm. Moreover, proper management of farm residues can reduce the emission by 14 per cent through burning of farm residues.

Sustainability Index of Maize Production

The sustainability index computed for maize production is presented in Fig. 5.

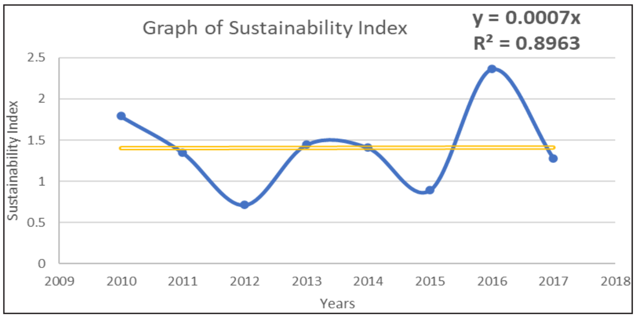


Fig. 5: Sustainability index of maize production

The estimated index revealed a declining but positive sustainability index for maize production during the period under study from 1.79 in 2010 to 1.28 at a growth 0.07 per cent which signifies high usage of energy inputs and declined in energy use efficiency in the production process. This results, however, similar to Benbi (2018) who reported similar pattern of crop sustainability in Indo-Gangetic Plains regions of India.

Impact of Efficiency on GHG Emission Reduction Potential

The results of the estimation procedure of eqn. 20 is presented in Table 10. The p-values of 0.002 for the linearity test implies a significant threshold effect between efficiency level and greenhouse gas emission. The results revealed that input use efficiency have negative impact on the level of emission where at higher level of efficiency, the rate of reduction in GHG emission increases than at lower efficiency level whereas at low efficiency level, an attempt to increase productivity will result in increase in the emission level. Increased efficiency above the threshold level with an improvement in the productivity at the farm level will result in 11.95 kg CO_2eq ha^{-1} reduction in emission levels. It is, therefore, imperative that any policy intends to increase farm level productivity should aim at improving the efficiency of the input use through adoption of recommended package of practice.

CONCLUSION

The study results presented here quantifies the contribution of various farming activities to the C footprint of maize production in Karnataka State of India. The following salient findings were discovered.

1. The results of the study revealed that high levels of input energy during the production

Table 10: Results of Dynamic Threshold Panel Regression

N = 99, T = 8				
Number of moment conditions = 60				
Bootstrap p-value for linearity test = .002				
Lower Regime (γ ≤ 0.843)				
Parameters	**Coefficient**	**Std. Err**	**Z test**	**P>z**
$CO_{2\ it-1}$	0.013	0.005	2.54	0.01
Efficiency	-1802.82	898.39	-2.01	0.04
Energy	0.004	2.17E-05	178.65	0.00
Productivity	67.28	3.91	17.21	0.00
Upper Regime (γ > 0.843)				
$CO_{2\ it-1}$	-0.003	0.007	-0.54	0.58
Efficiency	-2274.59	2336.25	-0.97	0.33
Energy	6.43E-05	3.31E-05	1.94	0.05
Productivity	-11.95	3.01	-3.96	0.00
	0.842	0.08	10.16	0.00

Source: *Author's computation.*

period with 53.64 per cent of the energy from renewable sources of energy with overriding impact on ground water extraction characterized by high consumption of electricity and irrigation hours.

2. There was high level wastage of energy among the farmers accompanied by low level of efficiency. The highest wastage of energy was due to low technological change and scale efficiency change.
3. In terms of energy use efficiency and productivity, that is energy output per unit energy inputs was declining with time indicating high usage of inputs energy. This implies the need for adoption of recommended management practices by the farmers through effective extension training on on-farm input, which are carbon (C)-based operations management.
4. Sustainability which indicates ratio of cost of carbon output to cost of carbon input has an increasing trend over time characterized by positive growth at a low rate of 0.07 per cent per annum for the period under study.
5. Options for reducing of GHGs emission include improving efficiency and productivity of input use among the farmers as it was observed that higher efficiency level accompanied by high level of productivity results in potential reduction emission level among the farmers. Moreover, preventing crop straw burning by using for other productive purposes such as growing mushrooms or bioenergy will reduce emissions and also improve soil cation exchange capacity thereby enhancing the fertility and heath of the soil.

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