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Analysis of Energy Efficiency of Agriculture Sector of India Using Data Envelopment Analysis Approach.

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Abstract

India is an agriculture dependent country, growing at a fast pace and so is the food demand and technology usage in the developing sectors. Since the last 10 years energy consumption in India has increased by a compound annual growth rate of 4.11%. This continuous rise in consumption of energy may be attributed to rising population and increasing per capita income of the country. The industry sector provided the most to the total amount of power used in 2020–2021 (41.09%), followed by the domestic sector (25.67%), agricultural (17.52%), and the commercial sector (8.31%). In this paper we have measured the energy efficiency of crop production sector of India. In this regard, 20 Indian states are selected as the study area for the period 2015-20. The Data envelopment analysis (DEA) variable returns to scale (VRS) with input orientation has been used for efficiency measurement of the DMUs. The results of our study show that out of the 20 states, 10 states were energy efficient every year for the period 2015-2020 while 2 states were energy efficient for some part of the period, 8 states could not perform well on the energy efficiency scale continuously every year for the period 2015-2020. Among the poor performing states, Chhattisgarh was found to be the worst.

Keywords DEA, VRS, Energy efficiency, non-discretionary inputs.

INTRODUCTION

India is a developing country with rapidly growing population and increased per capita income causing significant impact on global energy economy. Thus, efficient use of energy is a challenge for the country. All the sector in the country namely agriculture, industry, commercial and residential are facing a steady increase in energy demand which is expected to grow continuously. In 2010-11, the total energy consumption was 540.26 Mtoe, which has increased to 776.58 Mtoe in 2019-20 [[6]]. Data envelopment analysis (DEA) is a linear programming based nonparametric technique for evaluating the relative efficiencies of a homogeneous set of DMUs which utilize multiple inputs to produce multiple outputs [[8]]. DEA has been preferred in various studies as a non-parametric approach as, in parametric models we have to make a clearly specify the production technology as a production function or a transformation function and then a suitable statistical method is used to obtain parameters estimates. Whereas non-parametric approach such as Data Envelopment Analysis (DEA) use no specified explicit function contrarily one makes a general assumption about the underlying technology. In DEA one can construct the production possibility set empirically from observed data. There are many DEA models developed with time, these models with some extensions and applications are mentioned in Cooper et al. (2007) [[11]]. The CCR model and the BCC model are some standard DEA models.

Energy efficiency can be defined as the ability of the producer to reduce the energy input to the largest extent possible, conditional on the given level of output, non-energy inputs and undesirable output. Since, in crop production, DMU input rate can be controlled, but control on output level is not feasible, therefore DEA with an input-oriented model will be most suited [[25]]. Agriculture which is a process of conversion of solar energy into food and fiber through photosynthesis [[10]]. There are two kinds of energy inputs present in agriculture namely direct and indirect energy input. Direct energy inputs are the inputs which form the energy consumed by the farm during operations and can be classified as labor, fuel, machinery, water, and electricity etc. Whereas the Indirect energy input can be defined as the energy consumed during the production process of different input sources e.g., fertilizers, machinery, seeds, and biocides. Agriculture which is mainly an energy conversion process becomes more energy-intensive due to the imbalanced use of fossil fuels, fertilizers, machinery, and electricity to enhance overall production. [[21]].

Several studies are conducted worldwide on energy efficiency measurement in agriculture sector, Stephen et al. proposed a method based on Data Envelopment Analysis (DEA) approach in a cost framework [[5]]. Vlontzos et al. in their study evaluated the energy and environmental efficiency of the primary sectors of the European United member state countries. Their evaluation which is based on a non-radial Data Envelopment Analysis (DEA) model allows for non-proportional adjustments to energy inputs and undesirable outputs and provides different estimations for energy and environmental efficiency scores [[26]]. Nan Li et al. measured the total energy efficiency of each region by using the data of 30 provinces in China from 1997 to 2014, which was decomposed by the Malmquist index of DEA to study its composition [[20]]. Izadikhah et al. presented a new non radial DEA model methodology to evaluate the efficiencies of barley production farms in Iran based on a modification of Enhanced Russell Model (ERM model) in the presence of an undesirable output in a fuzzy environment [[17]]. Belke et al. (2011) evaluated the long-term relationship between energy consumption and real GDP of 25 OECD countries and found it is important that the planning of efficient energy conservation policies consider the consequences of economic growth on energy consumption [[4]]. "In their study for BRICS countries, Camioto et al. used the DEA technique to build an efficiency index that measured each country's efficiency in terms of gross fixed capital formation, workforce, and energy consumption by measuring economic growth without causing the environment any harm through increased CO2 emissions. After that, the Total-Factor Energy Efficiency (TFEE) index was calculated using the DEA's slacks [[7]].

Most of the energy efficiency measurement studies have their work confined either to farm level or single crop data. We haven't yet come across any study yet which measures energy efficiency of crop production sector in India using the non-parametric DEA approach. Thus, our work will help through light on the energy use scenario in crop production sector of India, thereby helping policy maker's design and implement ideas related to efficient use of energy.

MATERIALS AND METHODS

We have collected crop production data of 20 agricultural states of India taking 4 inputs i.e., area, labour, fertilizers and electricity and one output which is crop production from the literature published by various ministries of the government of India, the area and production data was taken from the website https://aps.dac.gov.in/ and the data for labour, electricity and fertilizers was taken from agriculture statistics at a glance which is an annual publication of The Directorate of Economics and Statistics (Department of Agriculture & Farmers Welfare, Government of India) for a period of 5 years from 2015-2020. The states considered for analysis as Decision making units (DMUs) are Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Karnataka, Kerela, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand, West Bengal. The raw data collected was converted into energy form using appropriate energy equivalent. Two inputs fertilizer and electricity are converted into energy equivalent using appropriate energy coefficients whereas the other two inputs i.e., area and labour are taken as non-discretionary and thus do not require to be converted into energy equivalent [[5]]. Fertilizer we have considered only nitrogen as 90% energy comes from it only, energy equivalent used for fertilizers its 66.14 [[1]], which is the most recent and appropriate we found and for electricity we have taken 12.5 MJ kwh [[9]]. The software package used for this study is deaR-Shiny.

We have used input-oriented BCC model with variable returns to scale for our study taking two inputs as non-discretionary, as considering policy makers will be interested in reducing energy consumption and thus some inputs will be excluded from the list such as area, labour etc. The focus area of our work is energy inputs which are non-renewable and their reduction, so reduction of renewables such as land and labour is not being considered here. Thus, we consider these as quasi-fixed and so it is not necessary to convert them into energy. Let us consider there are n DMUs and $\aleph = \{1, \ldots N\}$ denotes the associated index set, assume that DMUs have M outputs, P energy inputs and Q non-energy or fixed inputs where the vector of outputs is $y = (y_1, \ldots, y_M) \in R_+^M$, $x = (x_1, \ldots, x_P) \in R_+^P$ is the vector of energy inputs and $r = (r_1, \ldots, r_Q) \in R_+^Q$ is the vector of fixed inputs. We also define the respective index sets of outputs and inputs as $\mathcal{M} = \{1, \ldots M\}$, $\wp = \{1, \ldots, P\}$, $\mathbb{Q} = \{1, \ldots, Q\}$. We define the model with the production possibility set P for BCC model:

$$P = \left\{\{(x,r,y): y \le \sum_{n\in\aleph} \lambda^n y_m^n \ \forall\, m \in \mathcal{M}, x \ge \sum_{n\in\aleph} \lambda^n x_p^n \ \forall p \in \wp, r \ge \sum_{n\in\aleph} \lambda^n r_q^n \ \forall\, q \in \mathbb{Q}, \quad e = \sum_{n\in\aleph} \lambda^n = 1\,,\ \lambda^n \ge 0\ \forall n \in \aleph\right\} \quad (1)$$

Here intensity vector λ makes assures the convexity of all the given inputs and outputs belong to the P i.e., is the production set, which can be defined as;

$$V(y|r) = \left\{x: y \le \sum_{n\in\aleph} \lambda^n y_m^n \ \forall\, m \in \mathcal{M}, x \ge \sum_{n\in\aleph} \lambda^n x_n^p \ \forall pe \in \wp, r \ge \sum_{n\in\aleph} \lambda^n r_q^n \ \forall\, q \in \mathbb{Q}, \quad \sum_{n\in\aleph} \lambda^n = 1, \lambda^n \ge 0\ \forall\, n \in \aleph\right\} \quad (2)$$

The set $V(y|r)$, represents the set of all variable inputs required to produce output y with quasi fixed inputs. Now using the input distance function given by Shephard (1953) [[23]] let's define the input distance function on the input set $V(y|r)$ as:

$$D_n(x,r,y) = min\{\theta: \theta x \in V(y|r)\} \qquad (3)$$

Now if we have to convert variable inputs into energy, we will take help of energy equivalents $w = (w_1, \ldots, w_N) \in R_+^N$ and since for each DMU we have to minimize the energy consumption. Th energy function can be defined as

$$EC(x,r,w) = \min\{wx: (x,r,y) \in P\} \qquad (4)$$

Here $EC(x,r,w)$ can be defined as the function which seeks to minimize energy consumption. From the definitions of the production set (1) and the energy function (4), computing the energy efficiency for a DMU j with variable returns to scale (Bankers et al), the linear programming can be given by [P1] [[5]]:

$$\begin{aligned} EC^* = min \sum_{p\epsilon\wp} w_p^j x_p \\ s.t. \quad \sum_{n\epsilon\aleph} \lambda^n y_m^n \ge y_m^j \qquad & \forall m \in \mathcal{M} \\ \sum_{n\epsilon\aleph} \lambda^n x_p^n \le x_p \qquad & \forall\, p\epsilon\, \wp \qquad [P1] \\ \sum_{n\epsilon\aleph} \lambda^n r_q^n \le r_q^j \qquad & \forall q \in \mathbb{Q} \\ \mathrm{e}\lambda = 1, \quad \lambda^n \ge 0 \qquad & \forall n \in \aleph \end{aligned}$$

Here w_p^j is the weight of variable input p of DMU j. Let EC* represents the minimum energy consumption done by required to produce output vector y at a fixed input and variable input weight w. If EC^j denotes as the total energy content of then current input levels of DMU j, then its energy efficiency can be measured as

$$\frac{EC^*}{EC^j} = \frac{\sum_{p\in\wp} w_p^j x_p}{\sum_{p\in\wp} w_p^j x_p^j} \qquad (5)$$

Which is the ratio of minimum energy consumed. Here "*" indicates the optimality.

In DEA the multipliers may take on unreasonable values as there is no prior specification of inputs and output weights is required [[24]]. But the multipliers can be bounded by using the dual programming problem. [P2b] gives the dual programme for the envelopment models. Thus, we have

$$D_p(x, r, y) = \min \theta$$

$$s.t. \sum_{n\in\aleph} \lambda^n y_m^n \geq y_m^j \qquad \forall\, m \in \aleph$$

$$\sum_{n\in\aleph} \lambda^n x_p^n \leq \theta x_p \qquad \forall\, p \in \wp \qquad [P2a]$$

$$\sum_{n\in\aleph} \lambda^n r_q^n \leq r_q^j \qquad \forall\, q \in \mathbb{Q}$$

$$e\lambda = 1, \lambda^n \geq 0 \qquad \forall\, n \in \aleph$$

Dual of [P1a]

$$max \sum_{m\in\mathcal{M}} u_m y_m^j - \sum_{q\in\mathbb{Q}} z_q r_q^j - v_0$$

$$s \cdot t \cdot \sum_{m\in\mathcal{M}} u_m y_m^k - \sum_{p\in\wp} v_p n - \sum_{q\in\mathbb{Q}} q_z x_z^k - v_0 e \leq 0 \qquad \forall k \in \mathfrak{K}$$

$$\sum_{p\in\wp} v_p x_p^j = 1 \qquad (6)$$

$$u_m \geq \quad \forall \quad m\in\mathcal{M} \qquad [P2b]$$

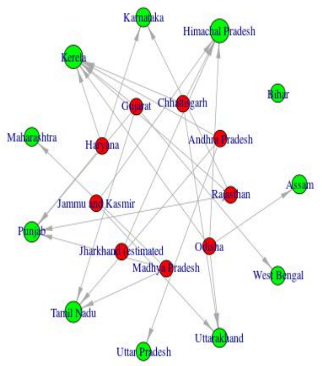
$$v_p \geq \varepsilon \quad \forall \quad p\in\wp$$

$$z_q \geq \varepsilon \quad \forall \quad q\in\mathbb{Q}$$

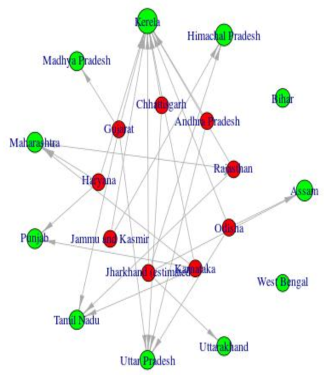
Where free variable v_0 is the dual variable associated with the constraint$e\lambda = 1$ and ε is a small positive number.

RESULTS AND DISCUSSION

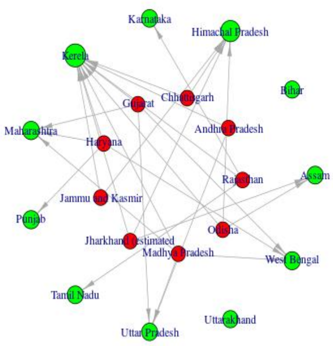
The states Assam, Bihar, Himachal Pradesh, Kerela, Maharashtra, Punjab, Tamil Nadu, Uttar Pradesh, Uttarakhand, and West Bengal have been consistently performing well in terms of energy efficiency for the period 2015-2020. Few states such as Karnataka was found to be energy efficient for the period 2015-16, 2017-18, 2020-21, Madhya Pradesh was found to be energy efficient for the period 2016-17 similarly. Whereas among the energy inefficient states Chhattisgarh was found to be the worst performing every year for the period 2015-20¸The proportion of electric energy consumption of Chhattisgarh every year w.r.t its crop production is high as compared to other states the reason it being the rice bowl of India and rice being a water intensive crop and thus the electricity consumption, making it an energy inefficient crop. The other states with consistently poor energy efficiency performance being Odisha (again a rice dependent state), Rajasthan, Andhra Pradesh, Gujarat, Haryana, Jharkhand and Jammu and Kashmir. We have found that states which have more water dependent cropping pattern such as rice were found to be less energy efficient. Thus, effective use of inputs in crop production has become vital to avoid any upcoming energy imbalances. In our study we have restricted to energy utilized till the farm gate only, as. Many uncertainties get involved once the crop goes out of the farm gate thereby making the data complex and uncertain.



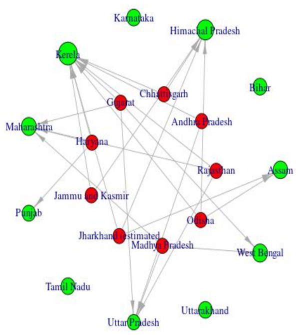
2015-16



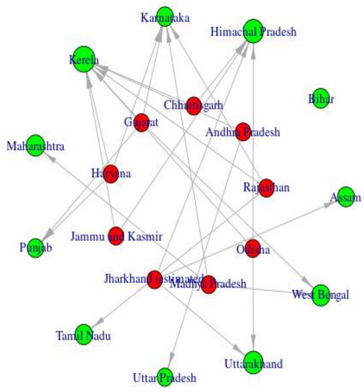
2016-17



2017-18



2018-19



2019-20

Figure 1. Efficiency graph of DMUs 2015-20

Table 1. Efficiency scores of states for the period 2015-20 respectively

DMU	**2015-16**	**2016-17**	**2017-18**	**2018-19**	**2019-20**
Andhra Pradesh	0.36052	0.3179	0.50818	0.41181	0.48381
Assam	1	1	1	1	1
Bihar	1	1	1	1	1
Chhattisgarh	0.19101	0.21526	0.30705	0.136	0.15716
Gujarat	0.42426	0.43558	0.43254	0.37984	0.52778
Haryana	0.73657	0.88464	0.83972	0.81558	0.81232
Himachal Pradesh	1	1	1	1	1
Jammu and Kashmir	0.45398	0.52771	0.49302	0.55427	0.7663
Jharkhand (estimated)	0.49435	0.63132	0.91754	0.57464	0.65188
Karnataka	1	0.93703	1	0.95689	1
Kerela	1	1	1	1	1
Madhya Pradesh	0.61179	1	0.73223	0.66535	0.94941
Maharashtra	1	1	1	1	1
Odisha	0.3489	0.54104	0.3446	0.36929	0.32339
Punjab	1	1	1	1	1
Rajasthan	0.3448	0.59625	0.50581	0.37334	0.45284
Tamil Nadu	1	1	1	1	1
Uttar Pradesh	1	1	1	1	1
Uttarakhand	1	1	1	1	1
West Bengal	1	1	1	1	1

CONCLUSIONS

A huge amount of the Indian population still relies on agriculture primarily for their income, this sector to the has a contribution of around 15-20% in the national GDP of the country, The agriculture sector is emotionally appealing to the Indian masses, so the Indian agencies are prompted to take development measures to empower farmers through various means. Long-term effects of these initiatives, such as excessive subsidies for chemical fertilizers, may hurt farm output even though they are necessary. Our study will help policy makers to identify the areas and to plan efficient energy consumption in the area of crop production. With the growing population of India which is soon going to become first in population beating China the most populous country, it has become very important to improve its energy efficiency feeding the large amount of population. Further extension of the work can be done by considering the uncertainties present in the data also the undesirable outputs such as GHG.

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Data availability statement: The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Author Contribution: Principal Author-A.G.;Supeervision by S.V.

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