DATA ENVELOPMENT ANALYSIS AS A TOOL FOR ENERGY EFFICIENCY MEASUREMENT; AN APPLICATION TO THE CROP PRODUCTION SECTOR OF INDIA.

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Abstract: Efficient use of energy is the need of the present generation which is already facing an energy shortage and a boom in population which will surpass China as the most populous country in the world by 2023. Any measure for improvement can only be developed when we can get the analysis of the efficiency measures of the energy consuming sectors. Agriculture is one of the top three energy consuming sectors in India. In this paper we provide a measure of energy efficiency of crop production sector of 20 states of India for 2015-20 considering two major energy inputs fertilizers and electricity and single output crop production, using the Data envelopment analysis Variable returns to scale input-oriented model. The results of our study show that 5 states out of 20 are found to be energy efficient throughout the period 2015-20.

Keywords: DEA, Energy efficiency, non-renewable energy, VRS.

1. Introduction

Efficient use of energy is a challenge for any country, India being no exception considering the continuous population growth and increasing energy demand across all the sectors. 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) can be defined as a non-linear programming technique to evaluate the relative efficiencies of a homogeneous set of DMUs which utilize multiple inputs to produce multiple outputs [8]. It has been long preferred in various studies as a non-parametric approach for efficiency measurement as it uses no specified explicit function contrarily one makes a general assumption about the underlying technology and one can construct the production possibility set empirically from observed data. There are various 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 is the ability by which the producer can 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]. Energy utilised in agriculture can be of two kinds namely direct and indirect energy. Direct energy inputs can be defined as the inputs which form the energy consumed by the farm during operations and are classified as labor, fuel, machinery, water, and electricity etc. Whereas, the Indirect energy input is 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 electricity, machinery, fossil fuels and fertilizers to enhance overall production. [21]. Several studied have been conducted in application of DEA in efficiency measurement but most of them 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.

2.Objectives and Methodology

We have collected crop production data of 20 agricultural states of India taking 2 major energy inputs i.e., fertilizers and electricity and one output which is crop production, data of crop produced was taken from the website https://aps.dac.gov.in/ and the data for electricity and fertiliz ers 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 lndia) 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. 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. 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. Let us consider there are n DMUs and $\aleph = \{1, \dots N\}$ denotes the associated index set, assume that DMUs have M outputs, P energy inputs a where the vector of outputs is $y = (y_1, \dots, y_M) \in R_+^M$ and $x = (x_1, \dots, x_P) \in R_+^P$ is the vector of energy inputs. We also define the respective index sets of outputs and inputs as $\mathcal{M} = \{1, \dots M\}$, $\wp = \{1, \dots, P\}$. we define the model with the production possibility set P for BCC model:

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

Here intensity vector λ 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;

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

$$EC(x, w) = \min\{wx : (x, y) \in P\} \qquad (2)$$

here $EC(x, w)$ can be defined as the function which seeks to minimize energy consumption. From the definition of the production set (1) and the energy function (2), computing the energy efficiency for a DMU j with variable returns to scale (Bankers et al), the linear programming can be given by [P1] [3]:

$$EC^* = min \sum_{p \epsilon \wp} w_p^j x_p$$
$$s.t. \ \sum_{n \epsilon \aleph} \lambda^n y_m^n \ge y_m^j \qquad \forall m \in \ \mathcal{M}$$
$$\sum_{n \epsilon \aleph} \lambda^n x_p^n \le x_p \qquad \forall\ p \epsilon\ \wp \qquad [P1]$$
$$e\lambda = 1, \qquad \lambda^n \ge 0 \qquad \forall n \in \aleph$$

Here w_p^j is the weight of variable input p of DMU j.

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

$$D_p(x,y) = \min \theta$$
$$s.t. \sum_{n \epsilon \aleph} \lambda^n y_m^n \geq y_m^j \qquad \forall\, m \in \aleph$$
$$\sum_{n \epsilon \aleph} \lambda^n x_p^n \leq \theta x_p \qquad \forall\, p \,\epsilon\, \wp \qquad [P2a]$$
$$e\lambda = 1, \lambda^n \geq 0 \qquad \forall\, n \in \aleph$$

Dual of [P1a]

$$max\ z = \sum_{m \in \mathcal{M}} u_m y_m^j - v_0$$
$$s \cdot t \cdot \sum_{m \epsilon \mathcal{M}} u_m y_m^k - \sum_{p \epsilon \wp} v_p n - v_0 e \leq 0 \quad \forall k \in \mathfrak{K}$$
$$\sum\nolimits_{p \epsilon \wp} v_p x_p^j = 1 \qquad (6)$$
$$u_m \geq \varepsilon \quad \forall \quad m \epsilon \mathcal{M} \qquad [P2b]$$
$$v_p \geq \varepsilon \quad \forall \quad p \epsilon \wp$$

Where free variable v_0 is the dual variable associated with the constraint eλ = 1 and ε is a small positive number.

3.Result and Conclusion

India is an agriculture dependent country and the pressure due to the growing population had made the sector more energy intensive due to the excessive and unproportional use of energy inputs to meet the present needs. This study shows that Assam, Bihar, Himachal Pradesh, Kerela and Uttar Pradesh are the only states found to be energy efficient throughout the period 2015-20, whereas Tamil Nadu and West Bengal were found to be energy efficient for the period 2015-16 and 207-18, 2019-20 respectively. Rest of the states could not perform well in the energy efficiency scale. Among the poor performing states Chhattisgarh was found to be worst. Table 1. gives the efficiency scores for all the states calculated. This study will help policy makers to act accordingly thereby preventing misuse of inputs in crop production has to avoid any upcoming energy imbalances. We have restricted our area to energy utilized till the farm gate only owing to the uncertainties involved once the crop goes out of the farm gate.

Table 1. Efficiency scores of DMUs.

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	0.36748	0.31276	0.35542	0.30874	0.40246
Haryana	0.3145	0.32005	0.38472	0.30149	0.3669

Himachal Pradesh	1	1	1	1	1
Jammu and Kashmir	0.45398	0.52771	0.49302	0.55427	0.7663
Jharkhand (estimated)	0.49435	0.62211	0.91754	0.57464	0.65188
Karnataka	0.76584	0.59328	0.92303	0.7817	0.95487
Kerela	1	1	1	1	1
Madhya Pradesh	0.57855	0.63316	0.61457	0.44356	0.66625
Maharashtra	0.76332	0.62161	0.86308	0.90128	0.86363
Odisha	0.3489	0.54104	0.3446	0.36929	0.32339
Punjab	0.31738	0.31604	0.38909	0.30452	0.3603
Rajasthan	0.3448	0.3911	0.48246	0.34383	0.43574
Tamil Nadu	1	0.79856	0.9716	0.8249	0.97525
Uttar Pradesh	1	1	1	1	1
Uttarakhand	0.7278	0.6898	0.79556	0.6065	1
West Bengal	0.96698	0.95595	1	0.89697	1

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DATA AVAILABILITY STATEMENT: The data that support the findings of this study are openly available in agriculture statistics at a glance, an annual publication of The Directorate of Economics and Statistics, Department of Agriculture & Farmers Welfare, Government of India and https://aps.dac.gov.in/.

CONFLICT OF INTEREST; The authors declare no competing interests.

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