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Research Article

ENERGY ASSESSING AND OPTIMISING ENERGY EFFICIENCY OF PEAR ORCHARDS IN NORTH-WESTERN INDIA

[a]J S Brar, [b]Pankaj Das*, [c]Trina Adhikary, [d]S Khehra
[a]Department of Fruit Science, Punjab Agricultural University, Ludhiana–141001 (India).
[b]Division of Sample survey, ICAR–IASRI, Library Avenue, PUSA, New Delhi, 110012 (India).
[c]College of Horticulture & Forestry, Punjab Agricultural University, Ludhiana–141001 (India).
[d]Farm Advisory Service Centre, Punjab Agricultural University, Taran Taran–143401 (India).

ABSTRACT

The data envelopment analysis (DEA) approach was applied to differentiate the efficient pear orchardists from inefficient ones in order to recognize wasteful energy use and greenhouse gas emissions in north–western India. The energy inputs and output were audited by using data collected from 31 orchardists through face–to–face interviews. An average total energy input (EI) of 33269MJ ha–1 was used to produce 44360 MJ ha–1 of total energy output (E_O) having 0.478 kg MJ–1energy productivity (E_P). The pear cultivation was energy efficient with specific energy (E_S) of 1.567 and net energy (E_N) 11090.9 MJ ha–1. The chemical fertilizers (~35 %) and irrigation water (23.2 %) had the highest contribution toward EI. DEA explicated 12 decision making units (DMUs) as an efficient, whereas 19 as an inefficient. The average technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) of pear orchards were 0.880, 0.977, and 0.897, respectively. The energy use efficiency (EE) and energy productivity (E_P) can be 30.75 %, and 25.07 % higher with the use of the optimum quantity of energy inputs than the existing quantity. Direct (E_D), indirect (E_{ID}), renewable (E_R), and non–renewable energy (E_{NR}) also exhibited 12.91, 10.62, 12.35, and 12.21 % improvement with optimum use of energy inputs. Inefficient orchardists can save 10.92 % of energy by following pear production practices adopted by efficient orchardists. The output energy (E_O) was about 21% higher in efficient orchardists than inefficient ones. An average of 37.4 % less greenhouse gas (GHG) emissions was determined in the case of efficient units as compared to inefficient ones.

KEYWORDS: Data envelopment analysis, Pear, DMU, Energy Optimization, Green House Gas.

INTRODUCTION

Pear is one of the most important fruits of temperate regions and globally, it is in 4th position among all fruits concerning its distribution [1]. The wider adaptability of pear to soil and climatic conditions makes it one of the preferred deciduous fruits in the world. In, India, pear cultivation is generally done in northern hilly regions especially the states of Jammu & Kashmir, Himachal Pradesh, and Uttarakhand. It ranked 2nd among all temperate fruits with 48,000 hectares of the total area under pear cultivation in India. In, Punjab, the North–West Indian state having a sub–tropical climate and plain topography, pear cultivation with varieties of low chilling requirements is being done commercially. The major area is under cultivar Patharnakh (*P. pyrifolia* Burm. F. Nakai) and it is primarily cultivated in Tarn–Tarn and Shri Amritsar Sahib Districts. Being a high–yielding fruit tree requires intensive management operations and inputs including chemical fertilizers, pesticides, herbicides, diesel fuel, electricity, labor, etc. Widespread variability in the productivity of orchards is generally witnessed every year. Many pear growers use inputs and employ management operations either without consultation of horticulture experts or do not follow the recommended package and practices for the cultivation of pear in the state. Keeping in view this fact, the survey of the pear growing districts was carried out to assess the input use and output generated from commercial orchards. With the technological advancement and developments in the agricultural production system the energy use on different inputs has augmented remarkable [2]. Efficient use of energy resources in agriculture ensures savings of fossil fuel resources, reduction of GHG emissions and pollution, and financial savings [3]. To feed the rising global population, the intensification in agriculture compelled us to use fossil fuel, agrochemicals, farm machinery, electricity, etc. intensively to get higher productivity and crop production. This intensified agricultural production system led to several issues related to human health, natural resources, and the environment. Therefore, the effective use of energy inputs is of prime significance for sustainable agriculture as it offers monetary savings, conservation of fossil resources, and reduction in air pollution [4], [6], [7].

The data envelopment analysis (DEA); a non–parametric technique is used to determine the productive efficacy of decision–making units (DMUs). This technique has two models; constant returns to scale (CRS) and variable returns to scale (VRS). This technique permits the DMUs for various gateways simultaneously. The efficiency of each DMUs unparalleled based on an average performance but on an ideal performance of units [8], [9]. Many researchers used DEA in various agricultural enterprises for input energy (IE) auditing. Input–output energy offers an opportunity to appraise economic analysis to the policymakers and farm planners [10]. In earlier and recent studies, analysis of energy to evaluate the energy efficiency of the production system in different orchards viz. cherry [11], [12], citrus [10], apricot [13], [14], walnut [15], apple [16], plum [13] has been done in various countries. Nevertheless, no investigations have been done on the energy inputs–output analysis of fruit crop production in India. Therefore, the objective of the present investigation was to make an input–output energy analysis of pear production in Punjab a north–west Indian state. DEA to differentiate the efficient and inefficient fruit growers and to optimize the energy inputs for kiwifruit [17] and apple [18] production in Iran, respectively. The greenhouse gases (GHGs) absorb and emit radiation within the thermal infrared range in the atmosphere and these GHGs significantly affect the earth’s temperature The temperature of the earth’s atmosphere is rising with industrial development and increasing population pressure. In the agriculture sector, GHG emissions are also rising and the research on GHG emissions in agricultural production is of immense importance. Another objective of the study was to measure efficient and inefficient pear orchardists' greenhouse gas (GHG) emissions. In GHG emission determination, the input units used were diesel fuel, machinery, chemical fertilizers, pesticides, farmyard manure, electricity, and human labour and the output used was pear fruit yield. Pishgar Komleh et al. [19] also determined the energy consumption and CO_2 emissions from three farms of variable–sized potato farms in Esfahan province, Iran. The objective of this study is to audit and optimize the energy requirements as well as greenhouse gas emission under the current scenario of global warming so that sustainability in resource conservation can be achieved.

MATERIAL AND METHOD

2.1. **Design of Experiment**

Data relating to this investigation collected from 31 pear orchards in the Shri Amritsar Sahib and Tarn–Taran districts of Punjab. This study area is situated in northwest India within latitude 29.30^0 – 32.32^0 N and longitude 73.55^0–76.50^0 E. The topography of the area is plain with fertile sandy loam soils having pH around 8.0 and EC between 0.2–0.4 ds/m. The average rainfall in the area of study is around 650 mm per year. For recording data, a questionnaire was prepared which include every input used and output produced in the orchards. A physical interview was led to fill the questionnaire in 2020–21. For estimation of reliability of a psychometric test of samples, the Cronbach technique was used with the calculation of Cronbach’s alpha as 92% [20]. The selection of this region of Punjab state was principally done owing to its major area of pear production and similar soil and climatic conditions. This fact allows better validation of the assumptions of DEA that all units should operate in a relatively homogeneous region so that the pear grower’s technical efficiency may not be adversely affected [17].

2.2 Calculation of energy efficiency and energy indices

To energy equivalents for each agricultural input and output were calculated by using standard conversion factors [21]. The quantitative data of different energy inputs consumed per hectare orchard area was recorded. This includes; human labour, diesel fuel, machinery, chemical fertilizers, farmyard manure, electricity, pesticides, and other chemicals, whereas the pear fruit yield was recorded as a single output from the orchard. For inputs and output, the energy equivalents are considered by coefficients of energy equivalent as given in table 1. The muscle power consumed in the field works for crop production is energy equivalent to human labour. The capacity to spend average energy for one hour in agricultural operation is a muscle power and on average, a labourer exerts for eight hours daily, so the energy equivalent was calculated per hour basis. The energy equivalents for chemical fertilizers were converted based on the active ingredient present. The energy equivalent of farmyard manure (FYM) is associated with the mineral elements energy that had been released from FYM per kilogram. The heating value and the energy required for direct availability of their energy to the growers equates to electricity and diesel fuel [21]. By using energy equivalents of inputs–outputs indices (Table 1), the ratio of energy or energy use efficiency (E_E), energy productivity, specific energy, and net energy were calculated as per the methods described by Rafiee et al. [22] and Mohammadshiraji et al. [23].

- $E_E = E_E$ [MJ ha^{-1}]/ E_I [MJ ha^{-1}]
- E_P = Pear fruit output [Kg ha^{-1}]/ I_E [MJ ha^{-1}]
- $E_S = I_E$ [MJ ha^{-1}]/ pear fruit output [Kg ha^{-1}]
- $E_N = E_O$ [MJ ha^{-1}]– I_E [MJ ha^{-1}]/

In agriculture, the energy demand can be divided into direct (E_D), indirect (E_{ID}), renewable (E_R), and non–renewable (E_{NR}) to get an apparent idea of different forms of energy. In the present investigations, the human labour, irrigation water, diesel fuel, and electricity were considered D_E sources, whereas, FYM chemical fertilizers, biocides (pesticides, herbicides, fungicides), and machinery were considered E_{ID} sources. Human labour, irrigation water, and FYM were also regarded as Renewable energy (RE) sources. Likewise, electricity, diesel fuel, chemical fertilizers, machinery, and biocides were considered E_{NR} sources.

Table. 1 Energy coefficients and energy output/input in various operations in pear production

A.	Inputs		EE	Input units	Average Energy (MJ/ha)
1	Human labour	h	1.96 (Mobtaker et al. [24])	827.12	1621.24
2	Machinery	h	62.7 (Rafiee et al. [22])	23.94	1501.26
3	Diesel fuel	l	56.31 (Rafiee et al. [22])	58.06	3269.39
4	Electricity	kwh	11.93 (Mobtaker et al. [24])	103.3	1241.73
5	Chemical Fertilizer				
	Nitrogen (N)	kg	66.14 (Mousavi-Avval et al. [23])	123.43	8164.08
	Phosphorus (P)	kg	12.44 (Unakitan et al. [25])	75.46	938.79
	Potassium (K)	kg	11.15 (Pahlavan et al. [26])	220.87	2462.78
6	Farmyard manure	kg	0.303 (Demircan et al. [11])	8505.78	2577.25
7	Biocides				
	Insecticides	kg	101.2 (Mousavi-Avval et al. [23])	12.84	1299.78
	Fungicides	kg	189.1 (Pathak et al. [27])	6.74	1225.57
	Herbicides	kg	238.3 (Ozkan et al. [10])	5.22	1243.39
8	Irrigation	m^3	1.02 (Mohammadi et al. [17])	7572.5	7724.03
	Total energy inputs				33269.28
B.	Total energy outputs	kg	2.09 (Ozken et al. [10])	21225	44360.25

2.3. DEA approach

To measure the relative efficacy of several producer units, the DEA technique has been used wildly [28]. The CCR and BCC models for DEA application. The CCR model is based on CRS (Constant Returns to Scale) model; whereas, the VRS (Variable Returns to Scale) model is the based–on BCC model. Both models of DEA were applied in the present study to the identification of efficient and inefficient pear growers based on energy consumption. To find out the lowest energy–consuming inputs for a given output, the DEA technique exploit the selected variables. The efficient frontiers are formed on this basis and the orchards within the frontier are considered efficient, whereas the orchards not on the frontier are categorized as inefficient ones. Human labour, diesel fuel, machinery, chemical fertilizers, farmyard manure, pesticides, herbicides, and electricity are input variables and pear fruit yield is the output variable used to find the efficiency frontier. For defining the relative efficiency, an arithmetical coefficient is given to every unit.

The selected orchardists using an identical input for pear production in their respective orchards are Decision Making Units (DMUs). Therefore, one pear orchard is referred to as one DMU. The technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) of pear orchards were calculated by using CCR and BCC models. As per the input–oriented model, the capability of a DMU to produce maximum output with a given set of inputs and technology is represented as Technical Efficiency (TE). On the other hand, in the output–oriented model, technical efficiency is the maximum possible reduction in inputs to produce efficient output [15]. The former model is considered more appropriate as there are multiple–input used, while in the latter model only single–output (fruit yield) is used. Moreover, in the agricultural production system, a producer has better control over input used rather than output produced [17]. Hence, technical efficiency is an index to measure the efficiency of units based on the CCR model. Technical efficiency values vary between zero and one. The performance of DMU is best on the production frontier and has no reduction potential if the TE of DMU is one (TE=1). The TE<1 expresses input inefficiently DMU. Mathematically, TE can be determined as per the following formula [25]:

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + u_3 y_{3j} + \ldots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + v_3 x_{3j} + \ldots + v_m x_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \qquad \text{(Eq.1)}$$

where, u_r= weight given to output *n; y_r*= amount of output *n; v_s*= weight given to input n; x_s= the amount of input *n; r*= number of outputs (*r ¼ 1, 2, ., n*); *s*= number of inputs (*s ¼ 1, 2, ., m*) and *j*, represents jth of DMUs (*j ¼ 1, 2, ., p*). Eq.2 is a fractional problem, so it can be translated into a linear programme problem (Charnes et al., 1978)

$$\begin{aligned} &\text{maximize } \theta = \sum_{r=1}^{n} u_r y_{rj} \\ &\text{subject to} \sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_r x_{rj} \le 0 \\ &\sum_{s=1}^{m} v_s x_{sj} = 1 \\ &ur \ge 0,\ vs \ge 0 \ and \ (i \ and \ j = 1, 2, 3, \ldots, p) \end{aligned} \qquad \text{(Eq.2)}$$

where θ is the technical efficiency, the CCR DEA model that is input–oriented assumes CSR; constant returns to scale [30]. The efficiency of larger producers is almost equal to small producers in inputs to output conversion [17]. Pure technical efficiency (PTE) is the technical efficiency of the BCC model and the Technical Efficiency (TE), could separate both technical (TE) and scale efficiencies (SE) [31]. The scale of inefficient orchards is only compared to efficient orchards of a similar size in this model [32]. The DMUs with PTE values less than 1 are categorized as inefficient units. The BCC model; the input–oriented model can be defined by a dual linear programming problem [17], [33].

$$\begin{aligned}
&\text{Maximize } z = uv_i - u_i \\
&\text{subjected to } vx_i = 1 \\
&-v\mathbf{X} + u\mathbf{Y} - u_0 e \leq 0 \\
&v \geq 0,\ u \geq 0 \text{ and } u_0 \text{ free in sign}
\end{aligned} \qquad \text{(Eq.3)}$$

where z and u_0 are scalar and free in sign, u and v are output and input weight matrixes, and $\boldsymbol{Y}$ and $\boldsymbol{X}$ are corresponding output and input matrixes, respectively. The letters x_i and y_j refer to the inputs and output of j^{th} DMU. The inefficiency of a DMU is primarily due to the insufficient scale of an orchard and inappropriate input use. The BCC model calculates only pure technical efficiency, whereas the CCR model calculates both technical as well as scale efficiency of DMUs. In the present investigations, both CCR and BCC models were calculated to find scale efficiency [34]:

$$\text{Scale efficiency (SE)} = \frac{\text{Technical efficiency (TE)}}{\text{Pure technical efficiency (PTE)}} \qquad \text{(Eq.4)}$$

The ranking of efficient DMUs was done based on their average cross–efficiency score (ACES). The ACES was calculated by averaging each column of the cross–efficiency matrix. The DMUs with high ACES are better performers and truly efficient [24]. The inefficiency level was calculated by the energy–saving target ratio (ESTR) for each DMU [35].

$$\text{Energy saving target ratio } (\text{ESTR}_j) = \frac{(\text{Energy saving target})_j}{((\text{Actual energy input})_j)} \qquad \text{(Eq.5)}$$

2.4. Greenhouse gas (GHG) emissions:

The GHG emission sources in the agricultural production systems are production, transportation and storage, and fossil fuel combustion [36], [37]. In the present assessment of GHG emissions, the standard coefficients were applied for major GHG emitting inputs for pear production (Table 2). The quantity of GHG emissions for efficient and inefficient units was calculated by multiplying the input application rate with the corresponding emission coefficient for comparison.

Table 2. Greenhouse gas (GHG) emission coefficients of agricultural inputs

Input	Units	GHG coefficient (kg CO_{2eq} $Unit^{-1}$)	Reference
1. Machinery (h)	MJ	0.071	Dyer and Desjardins [38]
2. Diesel fuel (l)	L	2.76	Dyer and Desjardins [38]
3. Chemical fertilizers			
a. Nitrogen	Kg	1.3	Khoshnevisan et al. [28]
b. Phosphorus (P2O5)	Kg	0.2	Khoshnevisan et al. [28]
c. Potassium (K2O)	Kg	0.2	Pishgar-Komleh et al. [19]
4. Chemicals (kg)			
a. Pesticides	Kg	5.1	Lal [36]
b. Fungicides	Kg	3.9	Lal [36]
5. Electricity	kW/h	0.608	Khoshnevisan et al. [28]

RESULTS AND DISCUSSION

3.1. Energy consumption pattern for various inputs used

Data in Table 1 revealed the average total energy consumed by various inputs used and operations employed for pear production. Besides this, table 3 provides an overview of total energy consumption pattern. The total energy consumed on all inputs was 33269.28 MJ ha^{-1} and the highest energy consumption was recorded in chemical fertilizers (11565.6 MJ ha^{-1}) followed by irrigation water (7724 MJ ha^{-}) and out diesel fuel (3269.4 MJ ha^{-1}), which accounts for 34.73, 23.22 and 9.83 %, respectively. Among chemical fertilizers, nitrogen was the largest consumer of energy with 24.54 % consumption of total energy inputs required for pear production (Fig.1). The total average energy output produced was 44360.25 MJ ha^{-1}. The variability in input use by pear orchardists was very high, particularly in the use of nitrogen, potassium, farmyard manure, diesel fuel, electricity, and biocide use. The average energy use efficiency, energy productivity, specific energy, and net energy were 1.33, 0.638 kg MJ^{-1}, 1.657 MJ kg^{-1} and 11091 MJ ha^{-1}, respectively. Fadavi et al. [39] in West Azarbaijan province, reported that the maximum portion of energy consumption in golden and red delicious apple production was incurred on packaging (57%) followed by irrigation (16%) among all I_E units. They also calculated the total energy input (101,505 MJ ha–^{1}), energy productivity (0.23 kg MJ^{-1}), net energy (– 56.320 MJ ha^{-1}), and output–input energy value (0.44) in apple production. Whereas, Ogunlade et al. [40] reported total I_E consumption of 46.64 GJ ha^{-1} in sweet oranges in Nigeria with human labour as the highest energy consumer (35%) followed by diesel oil and machinery (38%). They calculated 31.3 GJ ha^{-1} net energy, 0.88 kg MJ^{-1} energy productivity, and 1.67 energy output–input ratio. The efficient consumption of inputs such as fertilizers, diesel fuel, biocides, etc. may contribute to reducing the wasteful energy use in pear production. Namdari et al. [41] also reported that diesel fuel was the highest energy consumer followed by chemical fertilizers and irrigation water for citrus production in Iran.

Table 3. Total energy consumption pattern in pear production

A.	Inputs	Mean + S.E$_M$	Max	Min
1	Human labour	1621.24± 144.44	2098.38	1340.64
2	Machinery	1501 ± 245.52	2069.1	1034.55
3	Diesel fuel	3269.39 ± 684.67	5039.75	2203.13
4	Electricity	1232.44 ± 317.66	1850.34	706.49
5	Chemical Fertilizer			
	Nitrogen (N)	8164.08 ± 2016.66	14660.76	5791.29
	Phosphorus (P)	938.79 ± 189.24	537.41	1368.4
	Potassium (K)	2462.78 ± 861.45	4365.23	970.05
6	Farmyard manure	2578.10 ± 637.99	4920.98	1449.45
7	Biocides			
	Insecticides	1299.78 ± 356.48	1986.05	547.49
	Fungicides	1225.57 ± 484.62	2046.38	227.38
	Herbicides	1243.39 ± 754.37	2383	0
8	Water for irrigation	7724 ± 1203.39	9945	5355
	Total energy inputs	33269.28		
B.	Total energy outputs	44360.74		

S.E$_M$: Standard error from mean

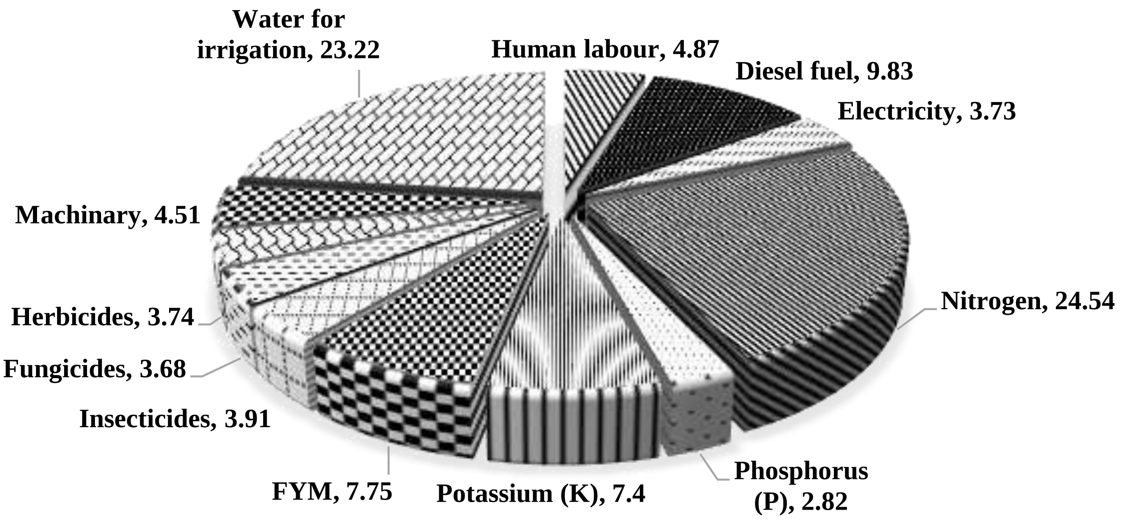

Figure 1. Share of energy consumption on various inputs in pear production (%)

3.2. Output energy and energy use efficiency indices

The efficiency score distribution of DMUs in pear production to identify the efficient and inefficient growers are presented in Fig.2. The technical (TE) and pure technical (PTE) efficiency grades were attained by using CCR and BCC models Among a total of 31 DMUs investigated for energy efficiency, 24 DMUs (77.42 % of total units) had a PTE score of 1. Moreover, among these PTE orchardists, 12 orchardists (50 % of orchards with a PTE score of 1) had technical efficiency (TE) score of 1. The scale efficiency (SE) of 12 orchardists had a score of 1. Among inefficient DMUs 3 and 7 had technical and pure technical efficiency scores between 0.8–8.9 and 0.9–0.99, respectively. Based on PTE, additional DMUs were included inefficient orchards owing to more flexibility in the calculation of efficiency in PTE (because it is used from a variable return to scale). About one–third of total pear producers would be efficient by the same approach to the energy consumption of efficient units. The data presented in Table 4 portrayed the three estimated determinants of efficiency as an outcome of the models (2) and (3) and Eq. (4). The average, standard deviation, minimum and maximum scores for TE, SE, and PTE of pear orchardists are presented in this table. The respective score for TE, SE, and PTE was 0.8799, 0.8969, and 0.9768 with a respective minimum score of 0.4560, 0.5655, and 0.8044 and a maximum score of 1 in each. Hence, the investigation revealed variable energy use patterns by different orchardists. This might be due to the different levels of education and knowledge of orchardists. The minimum score for TE was less than PTE because the TE determined the efficiency rate by a constant return to scale (CRS).

Table 4. Average technical (TE), pure technical (PTE) and scale efficiency (SE) of pear orchardists (31 units) TE, SE and PTE

Particular	Average	SD	Min	Max
Technical efficiency (TE)	0.8799	0.1518	0.4560	1
Scale efficiency (SE)	0.8969	0.1278	0.5655	1
Pure technical efficiency (PTE)	0.9768	0.0559	0.8045	1

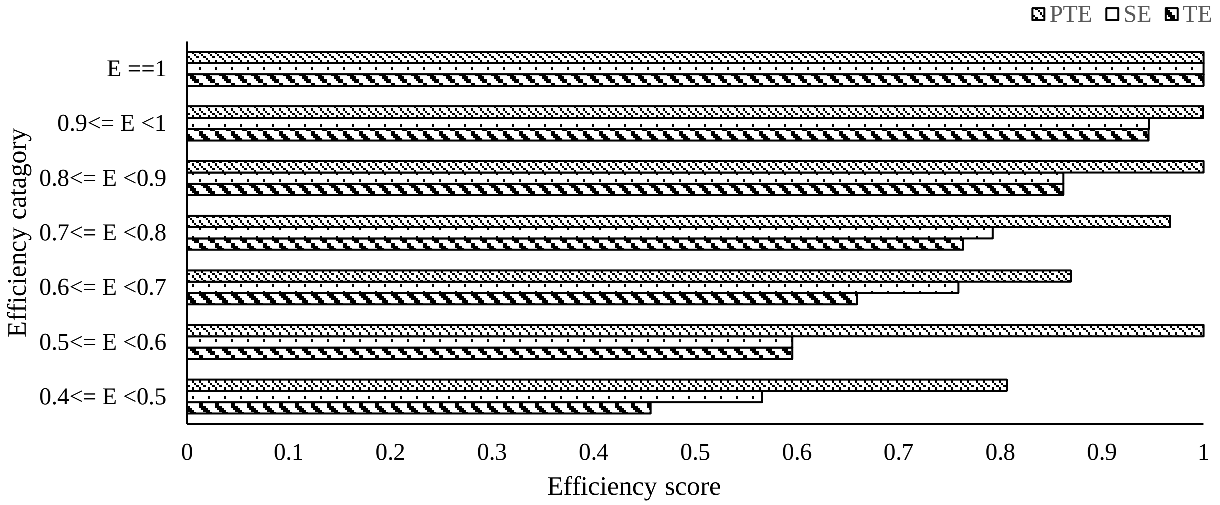

Figure 2. Efficiency score distribution of DMUs in pear production

3.4. Ranking the efficient orchardists

To determine the cross–efficiency score, the CCR Model was used in each cell of the cross–efficiency matrix. Based on their average cross–efficiency scores (ACES) the ranking of the extreme DEA efficient orchardists was done. The ACES for 12 truly most efficient orchardists are presented in table 5 and based on efficiency, all the efficient orchards were compared together. The data revealed that orchardists No. 22, 23, 07, 08, and 15 had the maximum ACES (0.706, 0.695, 0.692, 0.686, and 0.686), respectively, so these orchards can be standards or benchmarked for efficient pear production practices. For efficient energy use, the other orchardists particularly inefficient ones must use the inputs close to these orchards.

Table 5. Average cross efficiency (ACE) score for 12 truly most efficient Farmer based on the CCR model

Orchardist No.	22	23	7	8	25	10	3	14	27	9	11	24
ACE	0.706	0.695	0.692	0.686	0.684	0.659	0.644	0.634	0.628	0.616	0.599	0.579

3.5. Comparison of efficient and inefficient orchardists based on input use

The amount of physical input and output for the 12 most efficient and inefficient pear orchardists is presented in Table 6. The data exhibited that the efficient orchardists used less quantity all inputs than inefficient ones. Maximum difference (25.82 %) was observed in the use of biocides (insecticides, fungicides, and herbicides) followed by chemical fertilizers use (14.96 %), electricity (13.91 %), and irrigation water (13.10 %). The use of human labour, machinery, farmyard manure, and diesel fuel were also 11.82, 8.90, 5.49, and 4.08 % less by the efficient orchardists, respectively as compared to inefficient ones. The injudicious use of biocides especially for the management of insects and diseases leads to high I_E consumption in this zone.

Excessive use of chemical fertilizers and irrational use of irrigation water also contributed to high I_E consumption in inefficient orchards. Likewise, the machinery used for frequent inter–cultivation of orchards and disproportionate use of human labour also increased I_E consumption in inefficient orchards. Technical training of pear orchardists regarding the management of orchards focussing on integrated pest and disease management practices will help reduce I_E costs.

Table 6. Amount of physical input and output for 12 truly efficient farmers and inefficient farmers

Input	A: 12 Truly most efficient farmer (unit/ha)	B: Inefficient farmer (unit/ha)	Difference (%) ((B-A)/B) *100
Human labour(h)	819.78	929.68	11.82
Diesel fuel (L)	60.54	63.12	4.08
Electricity(kWh)	101.63	118.06	13.91
Chemical Fertilizer (kg)	406.77	478.35	14.96
FYM (kg)	8793	9303.72	5.49
Biocides (kg)	22.02	29.68	25.82
Machinery(h)	24.21	26.57	8.90
Irrigation water (L)	9.92	11.41	13.10
Output(kg)	25258.13	20875.58	-20.99

The optimal I_E requirement and the extent of energy that can be saved in pear orchards are presented in Table 7. The data revealed that the total amount of optimum I_E requirement for pear production was 27345.8 MJ ha^{-1}. With optimum energy requirement, the total energy saving was 10.91 %. The highest energy saving (23.83%) had been obtained in biocides (pesticides, fungicides) followed by 15.61 % in electricity. Judicious use of biocides alone can contribute 26.81 % to total energy savings. Proper use of chemical fertilizers and irrigation water may contribute 23.01 and 18.34 %, respectively to the total I_E savings for the production of pear in North–West India. In a similar study, Mousavi–Avval et al. [23] reported an 11.3 % saving of total energy for apple production. Mohammadi et al. [17] reported 12.2 % savings of the total I_E to produce kiwifruit in Iran.

3.6. Improvements in energy indices

For pear production, the improvements in energy indices are illustrated in Table 8. The quantity of energy use efficiency (E_E) for present and the optimum levels was calculated at 0.923 and 1.333, respectively, presenting a 30.75 % improvement. The energy productivity and net energy also show the possibility of 25.07% and 56.41 % improvement with optimum use of energy in pear production, respectively. The direct, indirect, renewable, and non–renewable energy presented in the same Table 8. exhibited a higher quantity in present energy use as compared to optimize energy use. The direct, indirect, renewable, and non–renewable energy was found to be 12.91%, 10.62%, 12.35%, and 12.21 % less than optimum energy use, respectively. The total energy saving with optimum use of inputs was 21.66 % in comparison to existing energy use. The optimum use of biocides, electricity, machinery and diesel fuel for target units was the main reason for the high difference in non–renewable energy consumption, whilst, the optimum use of human labour, farmyard manure, and irrigation water was the main reason for the difference in renewable energy. Hence, the DEA technique would save non–renewable resources by energy optimization in pear orchards in North–West Indian conditions. Mohammadi et al. [17] also studied the optimization of energy use in Kiwifruit production and found that the energy use can be increased to 13.86% with an improvement to the value of 1.75 by optimization of energy inputs. In a similar study, Mousavi-Avval et al. [23] also measured the present (1.16) and target (1.31) use of energy for apple production. Mobtaker et al. [24] reported an improvement of E_E by 10.6% by energy optimization of alfalfa production. The energy use efficiency for mandarin and orange were 0.77 and 0.99 and, respectively. Out of total energy inputs, the non–renewable (E_{NR}) and renewable (E_R) form of energy input was 67.14% and 33.07 %, respectively [41].

Ozkan et al. [42] reported 95.90% of total energy input as a non–renewable (E_{NR}) form of energy input as compared to only 3.74% for the renewable (E_R) form in citrus production.

Table 7. Optimum energy requirement and saving energy for fruit production

Input	Optimum energy requirement (MJ ha^{-1})	Total energy use (MJ ha^{-1})	Saving energy (MJ ha^{-1})	Saving energy (%)	Contribution to the total saving energy (%)
Human labour	1447.01	1621.24	174.23	10.75	5.20
Diesel fuel	2963.02	3269.39	306.37	9.37	9.15
Electricity	1047.87	1241.73	193.86	15.61	5.79
Chemical Fertilizer	10794.84	11565.65	770.81	6.66	23.01
FYM	2339.20	2578.10	238.90	9.27	7.13
Chemical	2870.54	3768.74	898.20	23.83	26.81
Machinery	1348.39	1501.26	152.87	10.18	4.56
Irrigation water	4534.92	5149.35	614.44	11.93	18.34
Total	27345.79	30695.46	3349.67	10.91	100.00

3.7. Setting realistic input levels for inefficient orchardists

Data in Table 9 (Annexure I) presents the pure technical efficiency (PTE), actual energy use (AEU), and optimum energy requirement (OER) from different sources of energy for every individual inefficient pear orchardist. To optimize energy consumption on different inputs in pear production without decreasing the output yield, the ESTR percentages for 19 inefficient orchardists are also given in Table 9. The range of energy saving for inefficient orchardists is 3.87% to 46.42 %. The Average and standard deviations are 17.84% and 10.99%, respectively. The highest percentage of energy–saving was for orchardist no. 31 whereas the lowest energy saving was for orchardist No. 2. To differentiate the efficient growers from inefficient ones, wasteful usages of energy by inefficient growers on different I_E units were identified to suggest reasonable savings in energy uses from effective sources. Fadavi et al. [39] in apple farms, the VRS analysis exhibited 41 DMUs were efficient out of a total of 80 DMUs. From inefficient DMUs, the 87.8% total energy suggests that 12.2% savings of overall resources could be achieved by enhancing the performance of these DMUs to the maximum level. Fadavi et al. [39] suggested the highest portion of the total energy saving is from diesel (39.7%) followed by packaging (28.1%) in apple farms. In pear, for higher production, the requirements of energy inputs particularly insecticides, pesticides, chemical fertilizers, irrigation, etc. are required and with good agricultural practices and judicious use of inputs, energy can be saved. The use of the energy inputs such as chemical fertilizers (particularly nitrogen) by all the DMUs nearby to optimal DMUs can save energy sources. Appropriate time, number, and method of chemical sprays can be proposed to optimize the number of chemicals used and machinery and diesel fuel used to spray these chemicals close to the highest energy–efficient orchardists.

Table 8. Improvement in energy values for pear production

Items	Units	Present quantity	Optimum quantity	Difference	Difference (%)
Energy use efficiency (EUE)	-	0.923	1.333	0.41	30.75
Energy productivity (EP)	Kg MJ^{-1}	0.478	0.638	0.16	25.07
Specific energy (SE)	MJ kg^{-1}	1.567	1.082	-0.48	-44.82
Net energy (NE)	MJ ha^{-1}	11090.9	25443.7	14352.7	56.41
Direct energy (DE)	MJ ha^{-1}	11282.7	9992.8	-1289.9	-12.91
Indirect energy (IDE)	MJ ha^{-1}	19413.7	17352.9	-2060.7	-10.62
Renewable energy (RE)	MJ ha^{-1}	9348.7	8321.1	-1027.5	-12.35
Non-renewable energy (NRE)	MJ ha^{-1}	21346.7	19024.6	-2322.1	-12.21
Total energy input	MJ ha^{-1}	33269.2	27345.7	-5923.5	-21.66

3.8. GHG emissions results

Table 10 demonstrated the quantity of GHG emissions from efficient and inefficient orchards. The GHG emissions of 12 truly most efficient and inefficient orange producers were calculated as 6404.63 kg CO2eq ha–^{1} and 10233.45 kg CO2eq ha–^{1}, respectively. The data revealed that the total GHG emissions of inefficient units were about 37.4 % higher than efficient orchardists.

The maximum difference was recorded in chemical (fungicides and pesticide use) by 12 truly most efficient and inefficient units. The GHG emission in the use of biocides; fungicides (46.69 %) and pesticides (41.71 %) were highest among all inputs used for pear production in inefficient units as compared to efficient units. Similarly, the GHS emission in case of chemical fertilizer use was also higher in the range of 36.79 to 42.91 % by the inefficient orchardists. Likewise, the difference of 35.69% and 32.29 % was determined in the use of machinery and diesel fuel, respectively.

Therefore, judicious use of agrochemicals (pesticides and chemical fertilizers) and accordingly their application by using machinery and diesel fuel can be proposed to reduce GHG emissions. The amount of GHG emission from different energy inputs for 12 truly most efficient and inefficient units is presented in Fig.3.

The results illustrated that the GHG emissions of Nitrogen were highest followed by diesel fuel for both groups of orchardists. The use of fertilizers like Phosphorus, Potassium; pesticides, and fungicides also contributed to higher GHG emissions in addition to electricity both in the case of efficient and inefficient units. Hence, the consumption of nitrogen, diesel fuel, potassium, fungicides, pesticides, and electricity consumption should be decreased in all the units and the application of the data envelopment analysis method can improve energy efficiency and GHG emissions significantly. Pishgar–Komleh et al. [19] also reported the highest rate of GHG emissions from chemical fertilizers for potato production followed by diesel fuel.

In another study, the highest GHG emissions were determined from electricity in wheat production [28].

Table 10. GHG emission of 12 truly efficient farmers and inefficient farmers

Parameter	12 Truly most efficient farmer (kg CO_{2eq} ha^{-1})	inefficient farmer (kg CO_{2eq} ha^{-1})	Contribution in GHG emission (%)	Saving in GHG emission (%)
Input				
Machinery(h)	20.63	32.07	0.32	35.69
Diesel fuel(L)	2005.14	2961.48	31.31	32.29
Chemical Fertilizer				
Nitrogen (kg)	1926.49	3047.99	30.08	36.79
Phosphorus (kg)	182.17	285.71	2.84	36.23
Potassium (kg)	497.7	871.74	7.77	42.91
Chemicals				
Pesticides (kg)	747.71	1282.88	11.67	41.71
Fungicides (kg)	283.24	531.34	4.42	46.69
Electricity(kW/h)	741.55	1220.24	11.58	39.23
Total GHG emissions	6404.63	10233.45	-	37.41

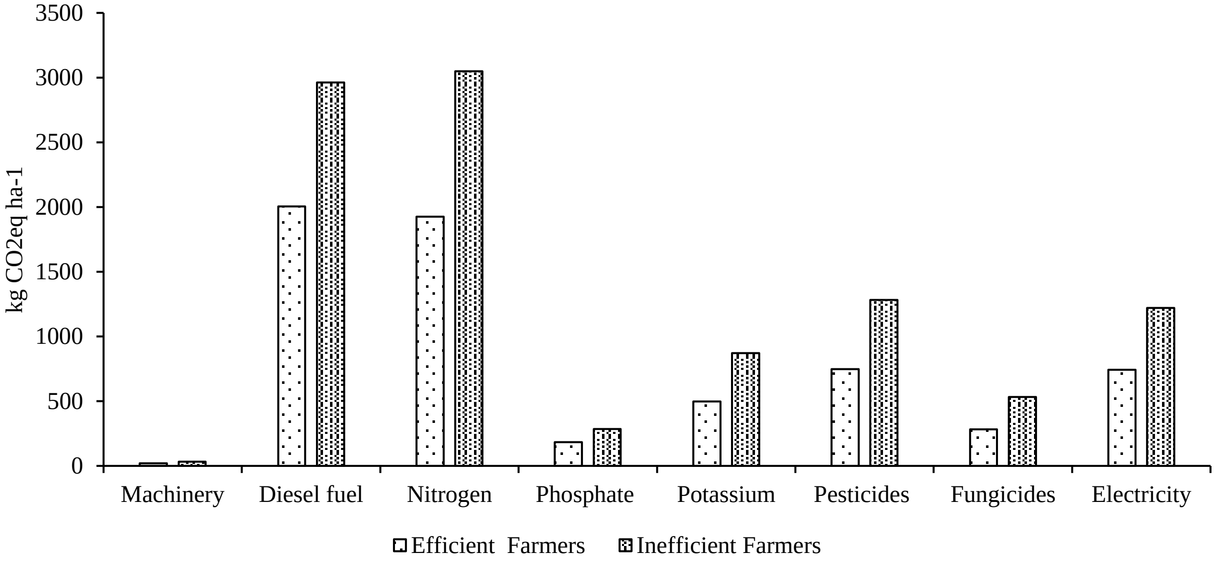

Figure 3. The quantity of GHG emissions by the producers

CONCLUSION

In the present investigation, a non–parametric technique of Data Envelopment Analysis was employed to analyze the efficiency of pear orchardists in North–West Indian conditions. Out of 31 orchardists selected for the investigations, 24 and 12 orchardists were purely technical and technically efficient, respectively. The technical, purely technical, and scale efficiency scores were found to be 0.879, 0.976, and 0.896, respectively. The Average pear yield was 25.25 and 20.87 ton ha^{-1} inefficient and inefficient orchards, respectively. Thus, about 21 % of yields are less in inefficient orchardists. About 10.9 % of total energy consumption in the present condition could be saved. The difference in energy use efficiency, energy productivity, and specific energy was calculated at 30.75 %, 25.07%, and 44.82 %, respectively. The comparative results of GHG emissions for 12 truly efficient orchardists and inefficient orchardists revealed the amount of CO_2 emission in efficient units was 37.41 % less than inefficient orchardists. Hence, the DEA technique may prove highly significant for the optimization of energy requirements and GHG emission under the current scenario of global warming, the need of sustainable resource conservation, and optimum crop production techniques.

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Annexure I

Table 9: The source wise actual and target energy use for inefficient farmers (Based on BCC model)

Actual energy requirement (MJ ha^{-1})													
DMU	PTE	Human labour	Diesel fuel	Electricity	N	P	K	FYM	Insecticides	Fungicides	Herbicides	Machinery	Irrigation
1	0.88	220.01	3315.25	1480.27	8385.73	1368.4	4365.23	2460.49	1328.25	909.50	2383.00	1645.88	5610.00
2	0.81	221.28	3470.10	1614.85	9954.48	1273.86	4047.45	3247.85	1138.50	1591.63	2085.13	1645.88	6120.00
4	0.91	193.06	2977.39	1286.83	9925.96	955.39	2977.05	2460.49	1138.5	2046.38	1191.50	1489.13	4590.00
5	0.80	211.19	3068.89	1562.36	14660.76	1368.40	4365.23	2460.49	1986.05	1819.00	1906.40	1567.50	6120.00
6	1	200.70	3470.10	1850.34	8385.73	821.04	2525.48	3247.85	1960.75	1819.00	893.63	1645.88	5610.00
12	0.90	210.45	3751.65	1513.92	7187.77	985.25	2776.35	2415.76	1960.24	2046.38	1191.50	1708.58	6120.00
13	0.99	196.69	3392.68	1480.27	6456.59	985.25	1873.20	2898.91	1251.84	909.50	2383.00	1567.50	5610.00
15	1	186.59	3251.90	1009.28	8214.59	834.78	2174.25	2174.18	745.84	1819.00	1191.50	1504.80	5100.00
16	0.99	211.92	3223.75	807.42	9241.41	895.68	2174.25	2415.76	1327.74	1318.78	1191.50	1410.75	4080.00
17	1	212.66	2956.28	1614.85	6160.94	895.68	2776.35	2657.33	1121.30	1591.63	2383.00	1316.70	6120.00
18	1	197.22	2984.43	1009.28	6653.82	716.54	2776.35	2898.91	1074.74	909.50	1787.25	1348.05	5100.00
19	1	222.46	4420.34	908.35	5791.29	1028.24	2174.25	2415.75	1644.50	1136.88	0.00	1912.35	4590.00
20	1	181.48	2365.02	706.49	8214.59	1074.82	1873.20	2174.18	1201.24	1136.88	1191.50	1034.55	3570.00
21	1	190.61	3660.15	807.42	7969.87	895.68	1572.15	1449.45	1074.74	909.50	1042.56	1598.85	4080.00
26	1	212.58	3097.05	941.99	7187.77	1074.82	2174.25	2657.33	1897.5	1364.25	1191.50	1473.45	4080.00
28	1	186.20	2815.50	1614.85	6792.58	716.54	1764.82	1691.03	1012.00	1136.88	1191.50	1348.05	6120.00
29	1	180.81	2442.45	1110.21	9702.74	626.98	2017.70	2898.91	1138.50	567.53	1042.56	1301.03	5610.00
30	1	218.29	3336.37	1110.21	6792.58	537.41	2017.70	3140.48	1265.00	794.90	2383.00	1504.80	5610.00
31	1	217.95	2442.45	1513.92	7393.13	716.54	2174.25	2174.18	1189.10	954.98	1191.50	1301.03	5100.00
Average	0.96	203.80	3181.15	1260.16	8161.70	935.33	2557.87	2523.12	1339.81	1304.32	1464.29	1490.78	5207.37
S.D.	0.07	13.90	480.83	336.84	1963.99	225.66	824.92	467.24	356.71	441.11	627.53	189.05	803.47

Optimum energy requirement (MJ ha^{-1})												
Human labour	Diesel fuel	Electricity	N	P	K	FYM	Insecticides	Fungicides	herbicides	Machinery	Irrigation	ESTR (%)
201.30	3315.25	1146.52	8385.73	1127.18	3022.93	2460.49	1210.39	909.50	1286.37	1540.64	4993.26	11.57
221.28	3470.10	1507.98	9954.48	1204.66	3673.07	3130.55	1138.50	1186.72	1848.82	1625.61	6041.78	3.87
183.75	2779.12	1009.76	9916.98	955.39	2966.88	2312.53	1012.22	871.20	1036.36	1346.93	4435.05	7.70
209.84	3068.90	1273.62	12392.04	1203.49	3700.21	2460.49	1486.48	1047.29	1418.60	1501.86	5568.76	14.03
156.25	2370.84	801.06	8385.73	821.04	2525.48	1988.93	842.568	272.51	866.93	1120.48	3865.87	25.94
146.50	2423.68	824.24	2614.05	985.25	956.11	1874.44	1413.34	1231.62	968.10	1154.72	4760.00	39.27
185.50	3281.64	1184.05	6456.58	985.25	1489.11	2898.91	754.44	89.22	2292.75	1478.49	4608.08	11.38
182.43	2875.93	899.62	8214.59	811.59	2174.25	1926.51	745.84	1819.00	621.075	1342.82	4845.96	6.19
187.21	2342.16	580.31	9180.34	852.08	2174.25	2415.76	1327.74	-76.12	761.56	1015.29	2881.84	16.45
169.74	2469.86	1614.85	4817.12	895.68	2776.35	2420.02	713.46	741.46	1919.41	1136.92	5966.40	13.98
172.96	2714.23	903.70	6653.82	716.54	2282.58	2898.91	989.10	432.97	1354.77	1289.89	4699.78	8.55
168.91	3774.90	764.86	5791.29	1028.24	1573.55	1464.99	1265.52	607.46	-822.47	1624.70	3281.08	21.80
131.08	1810.70	530.14	8214.59	973.03	1644.90	1734.32	768.19	1136.86	1191.50	743.14	2566.07	13.26
161.79	3595.78	807.42	6919.22	659.84	1572.15	1227.80	740.62	283.64	620.56	1598.85	3962.33	12.28
156.39	2342.05	698.32	4195.55	911.59	2174.25	2657.33	1658.87	1364.25	358.44	1099.56	2784.40	25.41
150.90	2815.50	1551.03	6792.58	599.53	1764.82	1273.20	207.02	624.90	716.11	1254.48	6120.00	9.55
131.81	1931.12	202.36	9105.38	626.98	2017.70	2898.91	880.37	-102.57	415.30	989.01	2805.99	23.52
170.41	2817.36	699.29	4381.53	537.41	1961.73	2059.79	873.96	487.01	2068.59	1152.61	3533.59	27.75
108.93	745.34	934.52	6266.32	716.54	1848.43	429.48	509.75	345.28	-518.51	569.53	2172.24	46.42
168.26	2681.29	943.87	7296.73	874.28	2226.25	2133.33	975.71	698.58	968.65	1241.36	4204.87	17.84
27.23	694.27	356.24	2314.75	192.10	713.41	674.36	349.75	504.29	781.56	284.29	1210.19	10.99