Advances in Energy Research, *Vol. 5, No. 3 (2017) 207-217*
DOI: https://doi.org/10.12989/eri.2017.5.3.207

Impact of energy efficiency improvement on greenhouse gas in off-season tomato farming: Evidence from Punjab, Pakistan

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(Received June 11, 2017, Revised December 9, 2017, Accepted December 22, 2017)

Abstract. Energy consumption in agriculture is responsible for greenhouse gas emission but it can be reduced after efficient utilization of energy inputs. Therefore, the present study aims for the estimation of energy efficiency and extent of greenhouse gas reduction after benchmarking of inefficient farms in off-season tomato in Punjab province of Pakistan. Primary data were collected from 70 farmers with simple random sampling. By using data envelopment analysis, the average value of technical, pure technical and scale efficiency was 0.80, 0.92 and 0.87, respectively while increasing, constant and decreasing return to scale was observed in 33, 26 and 11 farmers, respectively. Total input energy was reduced by 12,688.91 MJ ha^{-1} (13.89%) if inefficient farms used the energy inputs according to recommendations or benchmarking. A major portion of energy saving comes from fertilizers (68.79%) followed by diesel (15.70%), chemicals (5.91%), machinery (4.37%) and water (4.00%). Total greenhouse gases reduction was 499.17 kg CO_2 eq.ha^{-1} (14.57%) as a result of improvement in energy efficiency or benchmarking of inefficient farms. Agricultural extension staff should visit the vegetable farms on regular basis and give necessary information about efficient utilization of energy inputs. The government should create awareness about the optimum use of input through seminars and pamphlets.

Keywords: benchmarking; data envelopment analysis; energy efficiency; environment; vegetables

1. Introduction

Tomato (Lycopersicon esculentum) is a major vegetable and their production improves the income and employment opportunities for rural areas (Moghaddam *et al.* 2011). It ranked second after potato with 124.75 million tones production. It is a necessary human diet due to usage in different forms. It is a source of vitamins, calcium, health acids, fiber, iron, potassium and Lycopene which was useful against cancer (Ogunniyi and Oladejo 2011, Umar and Abdulkadir 2015).

Agriculture plays a double role like consumer and supplier of energy or bio-energy. At present, the increasing consumption of energy in agriculture was due to rising population, struggle for

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http://www.techno-press.org/?journal=eri&subpage=7 ISSN: 2287-6316 (Print), 2287-6324 (Online)

better living standard and scarcity of agricultural land. In agriculture, energy is an inevitable part of crop production process in the form of various inputs like human, pesticides, fertilizers, electricity, and machinery. Efficient use of energy is a prerequisite for sustainable production in agriculture because it decreases air pollution, financial savings, and preservation of fossil resources (Pahlavan *et al.* 2011).

In Pakistan, 20.9% of gross domestic product comes from agriculture with the help of 43.5% labour force working in this sector (Government of Pakistan 2016). Vegetables had 0.41 million ha area out of 23.40 million ha total cropped area in Pakistan. Annual vegetable production was 13.67 million tons (Muhammad *et al.* 2015). In 2013-2014, tomato covered 63,200 ha in Pakistan with 599,700 tones production while the area under tomato was 7,800 ha in Punjab with 100,100 tones production (Government of Pakistan 2015).

Punjab province has a good climate for vegetables in normal and in the off-season. In the off-season, vegetables are grown under plastic tunnels. Plastic sheet in tunnel maintains the temperature and save solar energy as well (Muhammad *et al.* 2015). The area under plastic tunnel showed an increase in Pakistan. Its produce reached the vegetable market 7 to 14 days earlier and gives 2 to 3 times more yield (Iqbal *et al.* 2009).

More quantity of agricultural inputs is required to fulfill increasing demand. Different energy inputs like petroleum, diesel or fuel are also needed for agricultural production. Utilization of energy inputs evolved greenhouse gases (GHG) (Khoshnevisan *et al.* 2014). The temperature of earth rises due to the greenhouse effect. Food production system faces new challenges due to climate change and rapid increase in population. It explored the importance of food security and protection of natural resources. Environmental damages can be reduced by efficient utilization of energy in agriculture (Khoshnevisan *et al.* 2013a).

Global warming is a primary environmental problem in the world. Approximately 10 to 12% GHG emissions come from the agriculture sector. Different agricultural practices such as production, transportation, storage, input distribution and their usage with machinery were responsible for GHG emission. Accounting GHG emission from different tillage operations, pesticides, irrigation, and fertilizers is helpful for the selection of substitutes like renewable energy and biofuel (Pishgar-Komleh *et al.* 2012).

The estimation of energy inputs in agriculture was difficult as compared to industrial sector (Kizilaslan 2009). Data envelopment analysis (DEA) has been used by many researchers for the estimation of efficiency in agricultural crop production. This technique is widely used by businesses and organizations. DEA is non-parametric and relies on linear programming for estimating production frontier which further estimates the relative efficiency for DMUs (decision-making units) in case of multiple inputs and outputs (Khoshnevisan *et al.* 2013a).

Energy efficiency was calculated for greenhouse tomato, tomato, wheat, greenhouse cucumber, canola in Iran (Monjezi *et al.* 2011, Mousavi-Avval *et al.* 2011, Pahlavan *et al.* 2011, Khoshnevisan *et al.* 2013a, b, Moghimi *et al.* 2013, Rahbari *et al.* 2013, Khoshnevisan *et al.* 2014). However, the reduction in GHG emission due to energy efficiency was estimated for wheat and cucumber in Iran (Khoshnevisan *et al.* 2013a, b). No research study was available about the estimation of energy efficiency in off-season tomato production under the plastic tunnel in Pakistan.

Pahlavan *et al*. (2011) accounted energy efficiency for the cultivation of tomato in greenhouse structure in Iran. Leading consumed inputs were electricity, diesel, and chemical fertilizers. Mean technical (TE), pure technical (PTE) and scale efficiency (SE) scores were 0.82, 0.94 and 0.86, respectively. It shows a 25.15% reduction in total input energy for an energy efficient farmer while tomato yield remained constant.

Similarly, Rahbari *et al.* (2013) found efficiency in the use of energy inputs for greenhouse tomato in Esfahan, Iran. Total input energy consumption was 8936.68 GJ ha^{-1} with large share comes from diesel. Mean TE, PTE, and SE were 92.48%, 99.55% and 92.81%, respectively. The decrease in energy consumption was 50770 GJ ha^{-1} after the efficient working of inefficient farmers.

Due to air pollution and climate change (Moghaddam *et al.* 2011), it is useful to improve the energy use efficiency and reduction in GHG emission. Present paper aims for the estimation of energy efficiency in off-season tomato production, decrease in energy consumption after benchmarking of inefficient farms and estimation of the GHG decrease due to efficient use of energy. It provides useful insight to inefficient farmers about the nearest efficient farm with benchmarking.

Table 1 Energy equivalents for agricultural inputs and tomato output

Energy source	Unit	Energy equivalent (MJ $unit^{-1}$)	Reference
		Inputs	
1-Chemicals	kg	101.2	Ozkan *et al.* (2011)
2-Labour	h	1.96	Heidari and Omid (2011)
3-Machinery	h	62.7	Cetin and Vardar (2008)
4-Fertilizer			
Nitrogen	kg	66.14	Ozkan *et al.* (2011)
Phosphorus	kg	12.44	Ozkan *et al.* (2011)
Potassium	kg	11.15	Ozkan *et al.* (2011)
Farmyard manure	kg	0.3	Esengun *et al.* (2007)
5-Seeds	kg	1.00	Cetin and Vardar (2008)
6-Water for irrigation	m^3	0.63	Ozkan *et al.* (2011)
7-Diesel	l	56.31	Ozkan *et al.* (2011)
		Output	
Tomato	kg	0.8	Ozkan *et al.* (2011)

Table 2 Coefficient of GHG emission for agricultural inputs

Inputs	Unit	GHG emission coefficient (kg CO_2 eq. $unit^{-1}$)	Reference
		Inputs	
1-Chemicals	Kg	2.47	Nalley *et al.* (2011)
2-Machinery	MJ	0.071	Khoshnevisan *et al.* (2014)
3-Fertilizer			
Nitrogen	Kg	1.3	Khoshnevisan *et al.* (2014)
Phosphorus	Kg	0.2	Khoshnevisan *et al.* (2014)
Potassium	Kg	0.2	Khoshnevisan *et al.* (2014)
Farmyard manure	Kg	0.126	Pishgar-Komleh *et al.* (2013)
4-Diesel	L	2.76	Khoshnevisan *et al.* (2014)

2. Material and methods

Simple random sampling was used for the collection of primary data about input use and output from off-season tomato growers in Punjab, Pakistan in 2014. Mian Shadi agriculture farm in Mamunkanjan, district Faisalabad has the status of pioneer in off-season vegetables in Punjab. Kamalia, district Toba Tek Singh is considered as the hub of off-season vegetables in Punjab. Therefore, district Faisalabad and Toba Tek Singh were selected and the sample size was determined by using formula (Samavatean *et al.* 2011, Nabavi-Pelesaraei *et al.* 2013a)

$$n = \frac{N \times s^2 \times t^2}{(N-1)d^2 + s^2 \times t^2} \tag{1}$$

where n shows the required size of the sample, N shows the size of the target population, s^2 is the variance in the population about studied qualification, t shows the value of t-statistics at 5% level of significance (95% confidence limit) which is 1.96, d is possible error which was 5%. The required size of the sample was 65 but the sample size was increased to 70 for good results.

2.1 Energy inputs and output

First, the average amount of different inputs was calculated by using primary data. Total physical amount of inputs and output was converted into energy (MJ ha^{-1}) form by multiplying it with energy equivalent (Table 1).

2.2 Greenhouse gas (GHG) emission

The total amount of different inputs was multiplied by their GHG emission coefficient (Table 2) for the estimation of the total amount of GHG emission in off-season tomato production.

2.3 Data envelopment analysis (DEA)

DEA method was used for TE, PTE and SE estimation. An efficient unit can obtain the same amount of output with the reduction in inputs (input oriented), or increase in output by using same inputs (output oriented) (Khoshnevisan *et al.* 2013a). The present study deals with input-oriented approach due to many inputs and a single output.

Commonly used DEA models are Charnese Coopere Rhodes (CCR) and Bankere Charnese Cooper (BCC). Production frontier in the CCR model was spanned by the linear combination of available DMUs, while production frontier in the BCC model was spanned by convex hull of available DMUs. Constant (CRS) and variable (VRS) returns to scale were assumptions used in the CCR and the BCC models, respectively. TE of a DMU reflects the actual production as compared to maximum production potential. The TE (θ_c) is simply a ratio between the sum of weighted outputs and inputs (Khoshnevisan *et al.* 2013a)

$$\theta_j = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} u_s y_{sj}} \tag{2}$$

where θ_j shows the score of TE for unit j; x and y shows the input and output; s shows the number of inputs (s=1,2,3,…,m), and v and u represents the weights of input and output, respectively; r

shows output numbers (r=1,2,3,….,n) and j shows jth DMUs (j=1,2,3,., k). CCR model (Input oriented) of TE is expressed as (Khoshnevisan *et al.* 2013a)

minθ

s.t.

$$Y\lambda \geq Y_0$$
$$\theta X_0 - X\lambda \leq 0$$
$$\lambda \geq 0$$

where Y_0 shows the s×1 vector of original output and X_0 shows the m×1 vector of original inputs. Y denotes the s×n matrix of outputs and X denotes the m×n matrix of inputs of all n units used in the sample. λ represent a n×1 vector of weights and q represents a scalar which lies between 0 and 1 which reflects the score of efficiency of each DMU. θ shows the TE of DMU under evaluation DMUo and λ is the intensity of efficient DMUs in projecting inefficient DMUs on the efficient frontier, also known as convexity constant. The value of optimal efficiency θ will be less than or equal to 1. DMUs having θ<1 are inefficient and DMUs having θ=1 made a set of boundary points on the frontier (Khoshnevisan *et al.* 2013a).

TE estimated by CCR model has both the TE and SE. Therefore, Banker *et al.* (1984), cited in Khoshnevisan *et al.* (2013a) developed BCC model for the estimation of PTE. It explored that a change in inputs causes a disproportionate change in output. Generally, PTE score is greater than TE score from CRS because of its more flexible nature and it envelops the data in a tight way. This relationship provides a way for the estimation of SE in case of the oth DMU as

$$\theta_j = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} u_s y_{sj}} \tag{3}$$

where SE=1 interprets as scale efficiency (or CRS) and SE<1 denotes scale inefficiency. Scale inefficiency of a DMU pointed out the presence of either increasing (IRS) or decreasing (DRS) returns to scale. However, the score of SE cannot explore the presence of IRS or DRS. For this, NIRS ((non-increasing return of scale) is used in a DEA model. A comparison between efficiency score obtain from BCC and NIRS model is made for the detection of IRS or DRS. If efficiency score from BCC and NIRS are equal then it indicates the presence of DRS otherwise there exist IRS. Energy saving target ratio (ESTR) shows the level of inefficiency in energy use and it is expressed as Khoshnevisan *et al.* (2013a)

$$ESTR_j = \frac{(Energy\ saving\ target)_j}{(Actual\ energy\ input)_j} \times 100 \tag{4}$$

where the total amount of reduction in energy inputs without reducing the level of output is called as energy saving target. Its percentage value lies between zero and 100. The high value of ESTR denotes the higher inefficiency in energy use or higher saving in energy use. The data were analyzed by using the DEA software EMS (Efficiency measurement systems), SPSS-15 and Microsoft Excel.

3. Results and discussion

3.1 Energy results

Table 3 Energy saving (MJ ha^{-1}) in the light of recommendations

Input	Present use (MJ ha^{-1})	Standard deviation	Target use (MJ ha^{-1})	Energy saving (MJ ha^{-1})	ESTR (%)
1. Seed (kg)	0.25	0.10	0.25	0.01	3.21
2. Labour (hours)	5957.25	1306.91	5802.57	154.68	2.60
3. Fertilizer (kg)					
Nitrogen	46108.00	15551.14	38498.66	7609.35	16.50
Phosphorus	5655.37	2254.61	5073.03	582.34	10.30
Potassium	676.01	580.14	574.52	101.49	15.01
Farmyard manure	3102.93	2142.94	2667.04	435.89	14.05
4. Chemicals (kg)	8248.57	2960.43	7498.31	750.25	9.10
5. Machinery (hours)	3759.27	1637.84	3204.65	554.62	14.75
6. Diesel (l)	13177.41	5880.14	11185.00	1992.41	15.12
7. Water (m^3)	4691.32	1413.42	4183.45	507.86	10.83
Total Input energy (MJ ha^{-1})	91376.38	18730.74	78687.48	12688.91	13.89
Total output energy (MJ ha^{-1})	56764.64	11332.89	No change in input-oriented DEA		

Table 3 represents the summary of energy use in the form of various inputs in off-season tomato production. Standard deviation shows a large variation in energy inputs and output. This large variation supported the concept of inefficiency. It indicates a potential for the improvement of energy efficiency in the region.

Different energy inputs are seed, labour, fertilizer, chemicals, machinery, diesel and water. Total consumption of input energy was 91376.38 (MJ ha^{-1}) while total energy from output was 56764.64 (MJ ha^{-1}). It is existing input energy consumption in the presence of energy inefficiency. Table 2 also shows the situation of input energy if the recommendation for efficient energy use will be adopted. But it is better to discuss this part of Table 2 after discussing the concept of energy efficiency and benchmarking.

3.2 DEA results

3.2.1 Benchmarking

Benchmarking means the comparison of the performance of an individual production unit with its nearest best possible competitor within the same group. The score of TE from BCC model or VRS was used for benchmarking (Khoshnevisan *et al.* 2013a). Table 4 shows the score of TE for 14 selected DMUs taking from BCC model. Out of 70 DMUs, 43 DMUs were found technical efficient while 27 DMUs shows inefficiency in the use of energy inputs. Benchmarking provides an opportunity to inefficient DMUs for the selection of input composition of efficient DMUs. For example, DMU6 was inefficient due to TE (0.8358<1). For best practices, DMU6 can use the composite DMU formed by the combination of DMU7, DMU17 and DMU43. Benchmarking shows that DMU should use 32% input of DMU7, 16% inputs of DMU17 and 51% inputs of DMU43 to achieve best production frontier. DMU23 and DMU43 appear equally 24 times in the benchmarking of inefficient DMUs followed by DMU47 (16 times) and DMU 52 (7 times). On the basis of frequency in the benchmarking, DMU23 and DMU43 were most efficient followed by DMU47 and DMU52.

Table 4 Results of technical efficiency analysis

DMU	TE (%)	Frequency in reference set	Benchmarks
1	100	0	
2	100	0	
3	100	0	
4	100	0	
5	100	0	
6	83.58		7 (0.32) 17 (0.16) 43 (0.51)
.	.	.	.
23	100	24	
.	.	.	.
43	100	24	
.	.	.	.
65	100	0	
66	91.05		10 (0.03) 17 (0.07) 23 (0.37) 28 (0.09) 43 (0.07) 47 (0.37)
67	86.53		23 (0.22) 43 (0.33) 47 (0.44)
68	81.01		23 (0.05) 43 (0.33) 47 (0.10) 57 (0.52)
69	100	0	
70	79.40		23 (0.31) 43 (0.33) 47 (0.36)

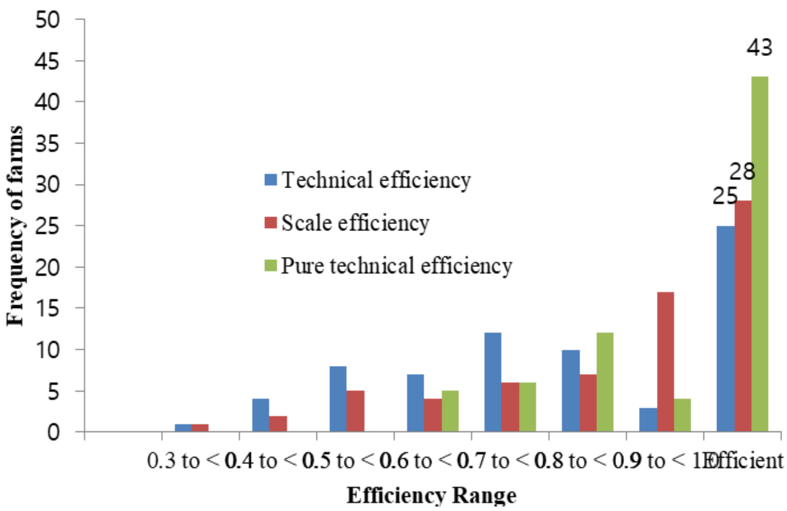

Fig. 1 Frequency distribution for off-season tomato farmers

3.2.2 Efficiency estimates

The CCR models give the score of TE and BCC model gives the score of PTE while SE was determined by the scores of CCR and BCC models. The score of efficiency was divided into different ranges as explored by Fig. 1. Number of energy efficient farmers was 43 (61.43%), 28 (40%) and 25 (35.71%) with respect to PTE, SE and TE, respectively. Remaining farmers were inefficient with different efficiency scores (Fig. 1).

Table 5 shows that the mean of TE (CRS), PTE (VRS) and SE were 0.80, 0.92 and 0.87, respectively. The mean TE shows the possibility of 20% reduction in energy inputs for a technically efficient farmer while output and technology remain constant. Presence of inefficiency in energy inputs was also found in wheat in Iran (Khoshnevisan *et al.* 2013a). The energy efficiency was estimated for some crops such as paddy (0.77) by Chauhan *et al.* (2006), kiwifruit (0.94) by Mohammadi *et al.* (2011), canola (0.74) by Mousavi-Avval *et al.* (2011), tomato (0.82) by Pahlavan *et al.* (2011), wheat (0.82) by Khoshnevisan *et al.* (2013a) and cucumber (0.68) by Khoshnevisan *et al.* (2013b).

The equal score of CCR and BCC model shows CRS. CRS in wheat production was also mentioned by Khoshnevisan *et al.* (2013a). The unequal scores of CCR and BCC models depict VRS but not describe whether it is IRS or DRS. The NIRS was used for the detection of IRS or DRS. NIRS model represents only DRS. A nearly same score of TE from BCC and NIRS models denotes the presence of DRS for a DMU. A different score of TE from BCC and NIRS models represents IRS for DMU (Khoshnevisan *et al.* 2013a). IRS, CRS and DRS were found in 33, 26, 11 farms, respectively. IRS shows the possibility of increasing output with the addition of more inputs.

Table 5 Analysis of TE, SE and returns to scale

DMU	TE			SE (CRS/VRS)	Return to scale
	CRS	VRS	NIRS		
1	0.52	1.00	0.52	0.52	IRS
2	0.50	1.00	0.50	0.50	IRS
3	1.00	1.00	1.00	1.00	CRS
4	0.38	1.00	0.38	0.38	IRS
5	0.42	1.00	0.42	0.42	IRS
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
65	0.73	1.00	1.00	0.73	DRS
66	0.85	0.91	0.85	0.94	IRS
67	0.82	0.87	0.82	0.95	IRS
68	0.63	0.81	0.63	0.78	IRS
69	1.00	1.00	1.00	1.00	CRS
70	0.73	0.79	0.73	0.92	IRS
Average	0.80	0.92	0.81	0.87	Total
Maximum	1.00	1.00	1.00	1.00	IRS=33
Minimum	0.38	0.60	0.38	0.38	CRS=26
SD	0.19	0.12	0.20	0.17	DRS=11

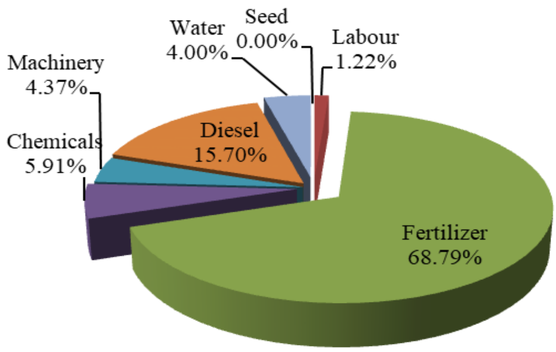

Fig. 2 Contribution of inputs in total energy saving in off-season tomato production

Table 6 GHG emission based on present and target energy inputs

Inputs	GHG emission (kg CO_2 eq.ha^{-1})		Decrease	Decrease (%)
	Present	Target		
1-Chemicals (kg)	201.32	183.01	18.31	9.09
2-Machinery (MJ)	266.91	227.53	39.38	14.75
3-Fertilizer (kg)				
Nitrogen	906.27	756.70	149.57	16.50
Phosphorus	90.92	81.56	9.36	10.29
Potassium	12.13	10.31	1.82	15.04
Farmyard Manure	1303.23	1120.16	183.07	14.05
4-Diesel (l)	645.88	548.23	97.65	15.12
Total GHG emission (kg CO_2 eq.ha^{-1})	3426.66	2927.49	499.17	14.57

3.2.3 Energy saving from efficient use of energy inputs

Energy saving is the amount of energy save if all farmers became efficient and follow the recommendation of study about the use of energy inputs. Table 3 shows the present and target consumption of energy as well as energy saving according to BCC model. The target use of input energy was 78,687.48 MJ ha^{-1} when all DMUs were operating at energy efficient level (after benchmarking). It depicts a 12,688.91 MJ ha^{-1} (13.89%) reduction in energy inputs keeping output constant. Khoshnevisan *et al.* (2013a) reported a 2.6% decrease in total input energy after improving energy efficiency in wheat production. ESTR ratio in off-season tomato was maximum (16.50%) for nitrogen followed by diesel (15.12%), potassium (15.01%), machinery (14.75%), farmyard manure (14.05%), water (10.83%), phosphorus (10.30%), chemical (9.10%), seed (3.21%) and labour (2.60%). Major reduction in fertilizer was also reported by Khoshnevisan et al. (2013a). Labour was the least disturbed factor after the improvement of efficiency which was good for employment generation in this sector. The improvement in total input energy was 25.15% in tomato (Pahlavan *et al.* 2011). Fig. 2 explored the contribution of individual inputs in total energy saving taken in percentage. It was different from ESTR for each input because it compares the decrease in energy of a specific input as a percentage of total decrease in energy while ESTR shows the percent reduction in the energy of a specific input as compared to its initial use.

3.3 GHG reduction in off-season tomato production

Table 6 compares the emission of GHG by means of the efficient and inefficient use of energy inputs. At present, total GHG emission was 3,426.66 kg CO_2 eq.ha^{-1} but it becomes 2,927.49 kg CO_2 eq.ha^{-1} if all farms operate at energy efficient level. So, it depicts a reduction of 499.17 kg CO_2 eq.ha^{-1} (14.57%) in GHG emission due to energy efficient farming (after benchmarking). More emission was reduced from fertilizers followed by diesel, machinery and chemicals. GHG emission reduction was 1.48% in wheat (Khoshnevisan *et al.* 2013a).

4. Conclusions

The present research estimated the energy efficiency in off-season tomato by using primary data from 70 farmers in Punjab. Energy saving and the GHG reduction were calculated subject to recommended or efficient use of energy inputs by inefficient farmers (by benchmarking). Technically efficient farmers were 35.71% and 61.43% on the basis of CCR and BCC model, respectively. Mean value of TE, PTE and SE was 0.80, 0.92 and 0.87, respectively. Total input energy was reduced by 13.89% after efficient utilization of energy inputs. Share in energy saving was more from fertilizers (68.79%) followed by diesel (15.70%), chemicals (5.91%) and machinery (4.37%). The total GHG reduction was 14.57% after an improvement in energy efficiency. Agricultural extension staff should visit the vegetable farms on regular basis and give necessary information about efficient utilization of energy inputs. The government should create awareness about the optimum use of input through seminars and pamphlets.

Acknowledgments

The research described in this paper has no funding support from any organization.

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