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Optimization Approach for Improving Energy Efficiency and Evaluation of Greenhouse Gas Emission of Wheat Crop using Data Envelopment Analysis

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Received: 15 May 2019; Accepted: 15 June 2019; Published: 20 June 2019

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Abstract: Energy is a major component in enhancing agricultural productivity for the rapidly growing world population. From that fact, a comprehensive analysis of energy inputs and outputs is required to conserve energy for future generations without threatening the food supply. Therefore, this study was performed in wheat production across important cropping zones of Punjab, Pakistan. In this study, the energy use pattern of wheat production was analyzed, and the degrees of technical efficiency of Decision Making Units (DMUs) were examined using Data Envelopment Analysis (DEA). Based on the results of the DEA analysis, the inefficient energy inputs were identified and further explored with the core objective of a significant reduction of excess valuable resources. Data were collected from conducting a face-to-face questionnaire of 200 farmers. The farms for sample were chosen randomly by a stratified normal approach. The results disclosed that the input energy of 34,430.98 MJ ha^{-1} was used up for wheat production with an output energy of 48,267.05 MJ ha^{-1}. Energy use efficiency, specific energy, energy productivity, and net energy gain in wheat production were calculated as 1.4 MJ kg^{-1}, 9.27 MJ kg^{-1}, 0.10 MJ kg^{-1} and 13,836.07 MJ kg^{-1}, respectively. The average technical, pure technical, and scale efficiency of DMUs were 0.668, 0.776, and 0.828, respectively, and 0.74% of consulted DMUs were functioning at decreasing returns to scale. Additionally, the significant energy consumption belongs to fertilizer, and diesel fuel, which contribute 65% of the total energy input. If these inputs are applied and managed in line with ours optimize value (29,388.5 MJ ha^{-1}) could save 14.65% resources, which will eventually add the equal quantity in wheat-yield. The total Greenhouse Gas (GHG) emissions were calculated to be 866.43 kg CO_2-eq ha^{-1}. In conclusion, the results of the present study suggest that there is sensible capacity for enhancing the energy efficiency of wheat production in Pakistan by accompanying the recommendations for economical energy management, sustainable and efficient use of energy is extremely encouraged.

Keywords: energy use efficiency; GHG emissions; data envelopment analysis; wheat; Pakistan

1. Introduction

Energy is a vital factor in agriculture, and energy use has raised over the years to fulfill the requirement of the increasing population beneath the pressure of reduced arable land and labor shortage [1,2]. Notwithstanding, the extensive use of energy has seriously intimidated the sustainability of agriculture and environmental protections [3,4]. Efficient use of energy is a fundamental necessity to reduce environmental loss, protect the natural resources, and elevate the development of agricultural sustainability [5–7]. It has been reported that approximately 60% of the world population is ill-fed [8]. Therefore, minimizing energy usage and maximizing energy use efficacy are life-sustaining for food security.

Currently, it is well known that food supplies and crop yield are directly linked with different kinds of energies such as human, animal, hydro, solar, wind, coal, oil and gas, etc. However, along with the energy consumption, agricultural inputs also discharge Greenhouse Gases (GHG) during agricultural operations such as spraying, irrigation, fertilization, harvesting, and land preparation [9,10]. Furthermore, carbon dioxide (CO_2) is also released in the airspace once the fuel is burned by the agricultural machinery that causes various types of pollution [11]. Therefore, it is crucial to understand GHG emissions from different activities and discern the specific areas for emissions reductions.

Energy flow and efficiency of energy consumption is evaluated on the basis of energy input-output studies of crop production [12]. Until now, several studies have explored the use of energy and its efficiency for production of crops at the domestic as well as international levels [13,14], e.g. Indian cotton, potatoes, beans, and wheat [15]; Italian maize, beans, and wheat [16]; Turkish sugar beets, apricots, and cotton [17–19]; Philippines rice [20] and Chinese rice [21]. Among these, only a few have discussed sugar beet and wheat GHG emissions [22,23]. However, only a few reports are available on wheat production; therefore, quantification of energy consumption and GHG emissions in Pakistan is very important.

Wheat is one of the world's major staple crops and a source of 20% of daily protein to approximately 4.5 billion people, with yearly production of 730 million tons worldwide [24,25]. In Pakistan, wheat is a chief staple food and it dominates all crops in acreage (8740 thousand hectares) and production (25,195 thousand tons), throughout the country (Figure 1) and also contributes 1.6% and 8.9% to the country's GDP and value-added agriculture, respectively [26].

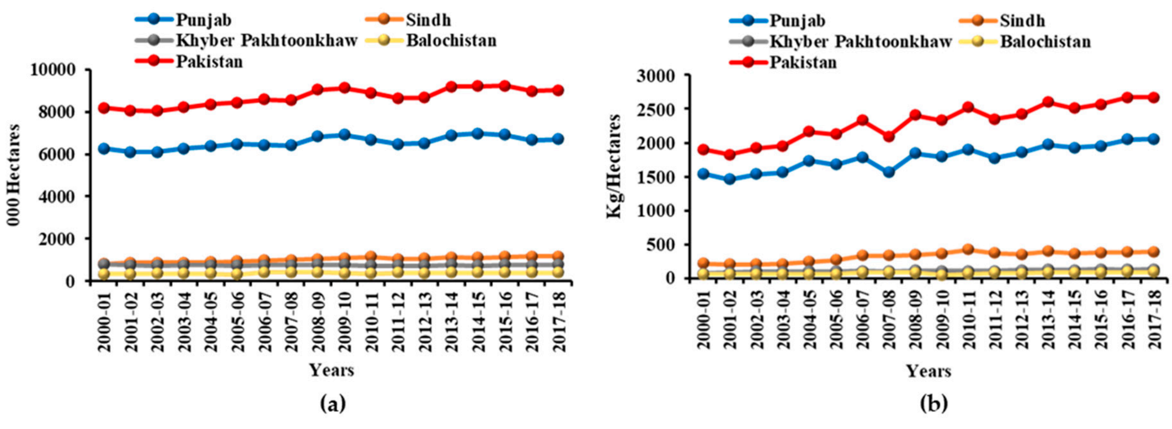

Figure 1. (**a**) Area under wheat crop in each province of Pakistan, 2000–2018; (**b**) Yield of wheat crop in kg per hectares in each province of Pakistan, 2000–2018.

According to an estimate, more than 33 million tons of wheat is required by Pakistan to satisfy its demands in 2030 [27]; however, the production of wheat demands a multitude of energy. In previous studies, wheat production required 9.3 to 53.1 GJ ha^{-1} energy input under multiple experimental and treatment conditions [28–30]. All findings have been corroborated that the wheat production management type, characteristics of the soil, and climatic variability caused variations in the following range: 31.7–148.4 GJ ha^{-1}, 20.0–142.7 GJ ha^{-1}, 1.4–13.0, 1.99-15.8 MJ kg^{-1}, 60–400 kg MJ^{-1}, and 0.44–12.6 to energy output, net energy gains, energy use efficiency, specific energy, energy productivity and energy profitability, respectively [30–33]. Furthermore, by using the Data Envelopment Analysis (DEA) in agricultural production, several researchers showed essential improvements that will build an efficient production system by measuring the efficiency of different entities [34–37].

The lack of research for an improved energy efficiency, with help from DEA application in wheat production, is a concern. Thus, the study is aimed to fill this gap and outline the pattern for energy usage in the production of wheat, analysis of the efficiency, and determination of the optimum demand of energy, and finally, evaluating the greenhouse gas emissions from wheat production in selected cities of Pakistan.

2. Materials and Methods

2.1. Sample and Data Acquisition

Data collection was performed using the multi-stage random sampling technique. For the initial phase, the province of Punjab was selected due to its 53% and 74% contribution to the total agricultural GDP and country's total cereal production, respectively [38]. As wheat is cultivated all over the country (Figure 2), notwithstanding, districts Muzaffargarh, Layyah, Rajan Pur, and D.G. Khan from Punjab were selected purposely in the second stage.

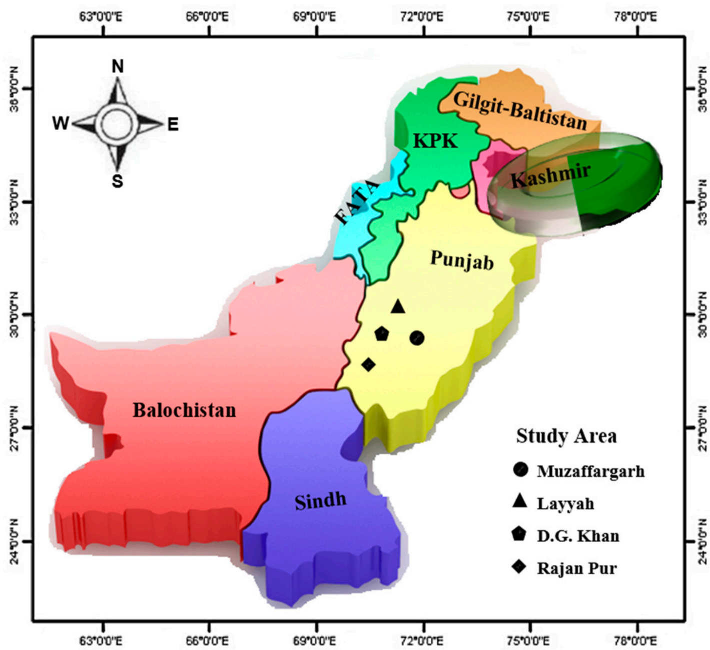

Figure 2. Wheat data collection sites from Punjab province are indicated with different symbols on the Pakistan map.

At the third stage, a village was randomly chosen for data collection in each selected district. Lastly, a total of 200 respondents of wheat were selected randomly using the Neyman method [39].

$$n = \frac{N}{(1 + Ne^2)} \quad (1)$$

n = Number of samples
N = Cumulative number of Decision Making Units (DMUs) of the specific area
e = Error margin, represented in terms of ± 10% (0.10)

2.2. Energy Analysis

The input quantity and energy requirement for each input item were resolute and measured from sowing to maturity at every major stage of wheat production. Usually, inputs used during the wheat growth period include machinery, fertilizer, seed labor, diesel, chemical, and water. The total weight of matured wheat crop (i.e., dry weight) represented the output that constituted both grains as economic yield and straw as the biological yield. The energy inputs and outputs were estimated using energy equivalents derived from the published research articles given in Table 1. These inputs were then multiplied to calculate the energy input of each item by their corresponding energy coefficient. The total input of energy was calculated as the sum of all energy inputs used.

The energy input used for wheat production was divided into two categories, i.e., direct and indirect energy [40]. The category of direct energy use involves seed, water, diesel, and human labor needed for practicing arable farming related to crop production processes, e.g. irrigation, preparation of land, and pest-control spray. The energy embedded in the farm machinery, pesticide and fertilizer was included in the category of indirect energy [41]. The requirements of energy for agricultural products are: (1) renewable energy, i.e., human labor, seed, and irrigation water, and (2) non-renewable energy that includes fuel, machinery, pesticides, and fertilizer [42].

Table 1. Energy equivalents of inputs and outputs in wheat production.

Input-Output (Unit)		Energy Equivalent (MJ Per Unit)	References
1. Inputs			
1. Labor (h)			
	Male	1.96	[43]
2. Seed (kg)		13	[43]
3. Fertilizer (kg)			
	Nitrogen (N)	78.1	[44]
	Phosphate (P_2O_5)	17.4	[44]
4. Chemical			
	Weedicide (kg)	238	[44]
5. Machinery (kg)			
	Tractor	138	[44]
	Plow	180	[44]
	Rotary	148	[44]
	Thrashing (h)	62.7	[44]
6. Water (m^3 ha^{-1})		1.02	[43]
7. Diesel (L)		47.8	[44]
8. Electricity (kWh)		11.93	[44]
2. Outputs (kg)			
	Wheat yield	13	[43]

The grain yield of wheat was converted into energy by using specific coefficients of energy (Table 1). Through multiplication of production quantity with its equivalent energy representative, the total output energy of wheat was calculated. On the basis of input/output energy, net energy (NE), energy use efficiency (EUE), specific energy (SE), and energy productivity (EP) were calculated through accounting method using different equations as follows.

Energy use efficiency was calculated from the ratio of energy output and energy input.

$$Energy\ use\ efficiency = \frac{Energy\ utput\ \left(MJ\ ha^{-1}\right)}{Energy\ input\ (MJ\ ha^{-1})} \tag{2}$$

Energy productivity was measured from the ratio of crop output of wheat and energy input.

$$Energy\ productivity = \frac{Crops\ output\ \left(Kg\ ha^{-1}\right)}{Energy\ input\ (MJ\ ha^{-1})} \tag{3}$$

Specific energy was estimated from the ratio of energy input and crops output.

$$Specific\ Energy\ = \frac{Energy\ input\ \left(MJ\ ha^{-1}\right)}{Crops\ output\ (Kg\ ha^{-1})} \tag{4}$$

Net energy was approximated by the deduction of input energy from output energy.

$$\begin{aligned} Net\ Energy \quad &= Energy\ output\left(MJ\ ha^{-1}\right) \\ &- Energy\ input\left(MJ\ ha^{-1}\right) \end{aligned} \tag{5}$$

2.3. Data Envelopment Analysis

Data envelopment analysis (DEA) is widely used as an arithmetic approach, which was initially developed by Charner (CCR) and continued by Banker (BCC) [45,46]. However, DEA is a conclusion of individual outputs/inputs technical efficiency measures presented by Farrell (1957) and uses numerous output/input to measure the proportional efficiency of per units with respect to multiple performance measures [47,48]. Constant return to scale (CRS) is integral to the CCR model, while variable return to scale (VRS) is integral to the BBC model [49]. DEA involves the evaluation of technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE). Furthermore, DEA used to evaluate Decision-making Units (DMUs) and efficient DMU can produce more output than other DMUs with the same amount of inputs [50]. DEA is applied in two ways; an input oriented model tries to enhance the relative reduction in input variables, while an output-oriented model directly increases the output variables remaining within the envelopment space. In the current work, the input oriented methodology was adopted since it was easily controllable in contrast with the outputs, and wheat yield is the only available output and seed, chemical fertilizers, pesticides, human labor, diesel fuel and water for irrigation were the various inputs. The inefficiency of DMU is caused by inadequate scale of farm and incompatible field operations. Therefore, the ratio of the sum of weighted outputs to the sum of weighted inputs could be used to calculate the TE score as follows:

$$\mathrm{TE}j = \frac{\alpha_1 x_{1j} + \alpha_2 x_{2j} + \ldots + \alpha_n x_{nj}}{\beta_1 y_{1j} + \beta_2 y_{2j} + \ldots + \beta_n y_{nj}} = \frac{\sum_{s=1}^{m} \alpha_1 x_{1j}}{\sum_{r=1}^{n} \beta_1 y_{1j}} \tag{6}$$

Here x and y correspond to the output and input, whereas α and β are the output and input weight, respectively, s is the number of outputs (s = 1, 2, … m), while the number of inputs is r (r = 1, 2, … n), j denotes jth DMUs (j = 1, 2, k), and TEj is the technical efficiency score of the jth DMUs (with the values ranging between zero and one).

As TE was derived from the CCR model, which contains TE as well as SE, that is why the BCC model was intended to calculate pure technical efficiency (PTE, i.e., BCC model's technical efficiency) of DMUs [46], which is calculated under variable return to scale conditions. By following the relationship, the technical efficiency can be calculated by the following equation.

$$\text{Technical efficiency} = \text{Pure technical efficiency} \times \text{Scale efficiency} \tag{7}$$

The DEA model was used to differentiate the efficient and inefficient DMUs, which also enabled rating the inefficient DMUs. Therefore, the inefficiency level of energy usage for the DMUs under consideration during the analysis of efficient and inefficient DMUs was specified by energy saving target ratio (ESTR). The formula is below.

$$ESTRj = \frac{Energy\ saving\ target\ j}{Actual\ energy\ input\ j} \tag{8}$$

In this formula, the total reduction in energy inputs is the energy saving target which could be saved without the requirement of minimization of output level and jth DMU is represented by j. Zero is the minimum value of the energy saving target; therefore, zero and 1 will be the values of ESTRj. Maximum ESTR values will indicate higher inefficiency in energy use and, hence, higher energy savings [51].

2.4. Estimation of GHG Emission

Carbon dioxide (CO_2) is considered as a major source of global warming in different emissions forms through common unit [52]. To estimate the quantity of GHG emissions from inputs in wheat agro systems, the CO_2 emission coefficients used were presented in Table 2. The amount of each input used during agricultural operations was multiplied with respective emission coefficients and GHG emission per unit area (kg CO_2 equivalent per hectare) were calculated. Then, data was analyzed through Microsoft Excel and the results were tabulated by taking into consideration the inputs and input-output values of wheat were determined.

Table 2. The greenhouse gas emission (GHG) coefficients (kg CO_2-eq unit^{-1}) of inputs.

Inputs	Unit	GHG Coefficient	Reference
1. Fertilizer	kg		
Nitrogen (N)	kg	1.3	[11]
Phosphate (P_2O_5)	kg	0.2	[11]
2. Weedicide	kg	6.3	[11]
3. Machinery	MJ	0.071	[53]
4. Diesel fuel	L	2.76	[49]
5. Electricity	Kwh	0.78	[53]

3. Results and Discussion

The data used in the current research was collected from 200 wheat farmers during the production period of 2018 in the Punjab province. The average farm size was 1 ha (ranges between 0.1 and 2 ha) and all the cultivated area was irrigated, and selected farms are private owners.

3.1. Input-Output Analysis of Energy Uses in Wheat Production

For the assessment of energy consumption in wheat production, an input-output energy analysis was conducted. Energy values were calculated with their respective energy coefficients against considered inputs and output, and results were presented in Table 3. In addition, average energy values were considered in order to obtain more realistic results.

Table 3. Input and output energies in wheat production.

1. Inputs	Unit	Quantity per Hectare (Means)	Total Energy (MJ/ha)
Human labor	h	132.5	259.7
Seed	kg	151	1963
Fertilizer	kg	288.45	15,690.09
Nitrogen (N)	kg	175.8	13,729.98
Phosphate (P_2O_5)	kg	112.65	1960.11
Weedicide	kg	5.3	1261.4
Tractor	kg	10.42	1437.96
Plow		4.01	721.8
Rotary		5.87	868.76
Thrashing	h	6.13	384.351
Water for irrigation	m^3	2115.32	2157.626
Diesel fuel	L	145.68	6963.504
Electricity	Kwh	228.23	2722.784
Total Input Energy			34,430.98
2. Outputs (Kg)			
Wheat yield		3712.85	48,267.05

The total input and output energy values were found to be 34,430.97 MJ ha^{-1} and 48,267.05 MJ ha^{-1}, respectively in Table 3. Between the various energy sources, fertilizers have the most eminent energy expenditure and the utmost usage of the chemical fertilizers is 288.45 kg ha^{-1}. From the total energy of fertilizers, the shares of nitrogen, and phosphorus are approximately 39.95%, and 5.61%, which accounts for 45.56% of the total energy usage; while, diesel and electricity share 20.22% and 7.9% in total energy input. Diesel fuel was mainly consumed in threshing and land preparation operation, while electricity was used in the pumping of water for irrigation. The inputs energy consumption of remaining inputs, i.e., machinery (9.91%), seed (5.7%), water (6.2%), chemical (3%), and human labor (1%), were found to be the least demanding energy inputs for wheat production in Pakistan. Similar results were found for energy efficiency in wheat production by Houshyar and Tipi from Iran and Turkey, respectively, where fertilizer, diesel fuel, and electricity consumed about 80% of total input energy [54,55]. Furthermore, our findings are also similar to the energy consumption in wheat production in Sindh province, investigated by Memon [56].

The main calculated energy indices such as energy use efficiency, energy productivity, specific energy, and net energy are given in Table 4. The energy use efficiency in wheat production was found as 1.40. The energy use efficiency of 1.40 observed in the study indicated that the input-output ratio is 1:1.40, which means that with a unit of input, 1.40 times wheat production was achieved. If we compare it with optimum energy efficiency, our results showed that inputs have been misutilised and found unproductive in the study area. Technically the inefficiency may be caused due to mismanagement of resources [57], while from the specific ratio, we found that for the production of 1 kg of wheat 9.27 kg MJ energy is required and the value of energy productivity is 0.10 kg MJ^{-1}. Therefore, the productivity of a unit (1 MJ) energy in the wheat production system of Pakistan was 0.10. Two additional research results for wheat production also revealed the specific energy as 5.24 MJ kg^{-1} and 6.36 MJ kg^{-1} respectively [58,59]. Our findings are similar with a most recent study of wheat crop in Iran, Nabavi-Pelesaraei calculated energy use efficiency as 3.51, specific energy as 9.38 MJ ha^{-1}, and energy production as 0.11 kg MJ^{-1} [43]. The energy efficiency of Iran is more than double as of Pakistan. So, it is concluded that there is a frightening need to regulate the extension service to improve energy efficiency in the wheat production system of Pakistan, with better management and improved production method. Additionally, from our results, the shares of energy consumption in wheat production was consisted of 45% chemical fertilizer, 20% diesel fuel, 10% machinery, 8% electricity, 6% water for irrigation, 5% seed and 1% human labor. The biggest part of energy input is chemical fertilizer, in understanding with the results for canola production found by Mousavi–Avval et al. [37] and for potato production by Mohammadi et al. [60].

Table 4. Energy indices of wheat production.

Item	Unit	Actual Quantity	Optimum Quantity	Difference (%)
Energy use efficiency	-	1.40184963	1.48	22.12
Energy productivity	kg MJ^{-1}	0.107834587	0.12	29.04
Specific energy	MJ kg^{-1}	9.273462515	8.52	−20.6
Net energy gain	MJ ha^{-1}	13,836.0747	10,021.35	18.89

Figure 3 shows the energy usage ratio from direct, indirect, renewable, and nonrenewable energy resources. The results revealed that the share of energy input consumed from direct and indirect energy is (65%) and (35%), while 70% of total energy input used for wheat production was obtained from non-renewable energy resources that were larger than renewable energy (30%). The fertilizer and diesel fuel were the major sources of non-renewable energy in wheat production. Efficient use of farmyard manure to replace fertilizer and diesel fuel can decrease the use of non-renewable energy. Similarly, various investigators revealed that the contribution of indirect energy (82.35%) is higher than that of direct energy (17.65%), and the ratio of nonrenewable energy (74.27%) is more prominent than that of renewable energy (25.73%) for potato production in Iran [60]. Likewise in Turkey, the ratio of indirect energy is maximum than that of direct energy, and the rate of non-renewable energy is maximum than that of renewable energy expenditure for cotton production [18].

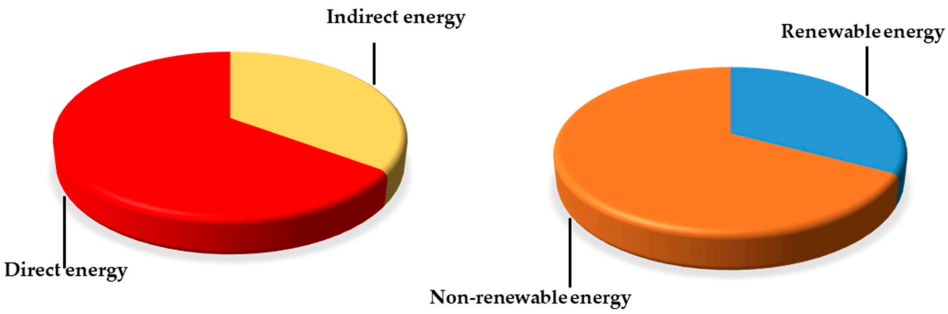

Figure 3. The share of direct/indirect and renewable/non-renewable energy inputs from total energy input in wheat production.

3.2. Data Envelopment Analysis (DEA) Results

The trend of energy utilization in target districts was studied using the data envelopment analysis. As mentioned earlier, the most popular input-oriented CCR model is adopted to estimate technical efficiency. For the input database of the CCR model, labor, seed, fertilizer, chemicals, agriculture machinery, diesel fuel, and irrigation water were considered as input and yield as output. Several authors studied the crop production in the context of energy efficiency using different levels of inputs and outputs in the analysis of data envelopment [36,61,62]. In Figure 4, technically and pure technically efficient DMUs have been marked as they had score of one (i.e., 40 and 46 are efficient DMUs); while 51 DMUs had a scale of one, which suggested their efficiency in productive scales. From the 0.9–1 efficiency score range, 54 DMUs had technical efficiency, 39 DMUs had pure technical efficiency and 67 DMUs had the scale efficiency and it indicates that DMUs can achieve the target output based on their recent agricultural input when benchmarking the efficient producers with identical characteristic. As indicated in Figure 4, 177 (88.5%) DMUs had a scale efficiency in 0.7–1 range with 67 (33.5%) DMUs being in the 0.9–1 range, which suggested that, the DMUs have expedient scale efficiency with respect to pure technique efficiencies. However, 0.668, 0.776 and 0.828 were the average technical, pure technical and scale efficiency of DMUs, respectively, indicating that several DMUs have not applied productive techniques wisely, and still there is much potential to increase their input efficiency. These outcomes were in line with Chuhan et al., where paddy DMUs were 0.77 technical, 0.92 pure technical, and 0.83 were scale efficient [63].

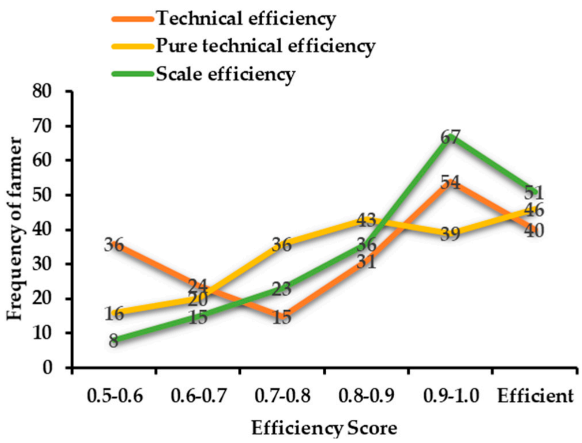

Figure 4. Average efficiency score and frequency distribution of wheat farmers.

Table 5 shows the technical efficiency distribution in respective study area. In the Rajan Pur city, the maximum average technical efficiency score was 0.828, as compared to other sampling at 5% confidence level. The minimum technical efficiency score (0.63) was found in Muzaffargarh city with their scattered technical efficiency up to 0.5. According to the depicted results, Rajan Pur and Muzaffargarh have been found to be the most efficient and inefficient DMUs. In more specific interpretation, Rajan Pur's DMUs display a higher level of technical efficiency than others do because they may have surplus input usage compared to Muzaffargarh. Results have shown an uneven trend of technical efficiency in the studied area, which implies that DMUs are not applying appropriate production techniques in a suitable time and optimum quantity.

Table 5. Frequency distribution and average score of technical scale efficiencies in selected districts of Punjab, for wheat producers (n = 200).

		Sampling Zones			
	Distribution	**Layyah**	**D.G. Khan**	**Rajan Pur**	**Muzaffargarh**
Efficient	1	4	6	16	5
	>0.9	5	8	7	7
	0.8–0.9	8	5	5	3
	0.7–0.8	6	9	8	5
Inefficient	0.6–0.7	13	12	14	11
	0.5–0.6	14	10	0	19
Average		0.684a	0.736b	0.828c	0.642a

Note: Significant difference of means at 5% level were indicated with different letters.

Furthermore, as shown in the Table 6, 149 (74.5) DMUs were functioning at decreasing returns to scale (DRS), 33 (18.5%) were at constant return to scale (CRS) and only 15 (7.5%) DMUs were at increasing return to scale (IRS). All inefficient DMUs in Muzaffargarh and Layyah were functioning at DRS, while only 4 and 11 DMUs in D.G. Khan and Rajan Pur were functioning at IRS, respectively. That is why it is important to decrease the scales of agricultural inputs for these DMUs. Also, the famers located in Rajan Pur had more cross efficiency scores as compared to other sampling districts, i.e., the scores of DMUs with the numbers 15, 17, 30, 32, and 43 were at 0.82, 0.85, 0.87, 0.89 and 0.90, respectively. Whereas in Muzaffargarh, the cross efficiency scores of DMUs were lowest among all selected cities in Punjab, and were found only to be 0.29, 0.38, 0.43, 0.46 and 0.47, respectively. Hence, the wheat production practices in the study area of Rajan Pur can guide the other zones in Punjab province as the agricultural practice used by their DMUs could be a benchmark for inefficient ones.

Table 6. The returns to scale of the queried DMUs in selected districts of Punjab, for wheat producers (n = 200).

	Sampling Zones				
Return to Scale	**Layyah**	**D.G. Khan**	**Rajan Pur**	**Muzaffargarh**	**Total**
Increase	0	4	11	0	15
Constant	7	10	15	5	37
Decrease	43	36	24	46	149
Total number of farmer	50	50	50	50	200

Following the identification of efficient and inefficient DMUs, it was necessary to inspect the usage of input energy in wheat cultivation that will be saved if all the districts use energy efficiently. Table 7 provides the optimum energy requirement and energy savings of inefficient DMUs from different inputs for wheat production based on the results of the CCR model. The outcomes unveiled that the whole optimal energy required for wheat production was 29,388.52 MJ ha^{-1}. In addition, the total saving energy percentage in optimum demand over total factual use of energy was computed as 14.64%, suggesting that, on average, about 5042.45 MJ ha^{-1} of total input energy could be saved by following the recommendations resulted from this study. As noted, during agricultural practices the usage of inputs is more easily controllable by a farmer than outputs. The contribution of the respective resources from total input energy saving and pattern of energy used by efficient and inefficient DMUs is shown in Figure 5.

Table 7. Energy saving target for wheat production.

Inputs	Optimum Energy Requirements (MJ/ha)	Energy Saving Target	ESTR (%)
Human labor	232.56	27.14	10.45051983
Seed	1651	312	15.89403974
Nitrogen (N)	11,254.23	2475.75	18.03170871
Phosphate (P_2O_5)	1636.76	323.35	16.49652315
Weedicide	998.3	263.1	20.85777707
Tractor	1195.35	242.61	16.87181841
Plow	589.02	132.78	18.39567747
Rotary	705.28	163.48	18.81762512
Thrashing	353.52	30.831	8.02157403
Water for irrigation	1935.34	222.2864	10.30235818
Diesel fuel	6478.25	485.254	6.968531934
Electricity	2358.91	363.8739	13.36403892
Total	29,388.52	5042.4553	14.64511318

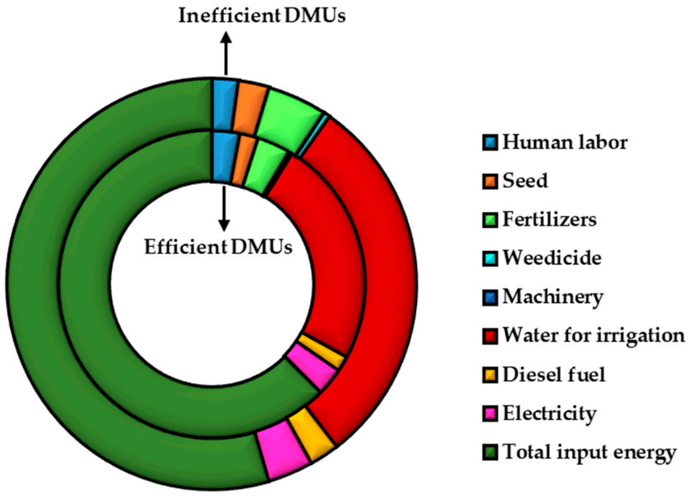

Figure 5. Contribution (%) of agricultural inputs towards total energy use in wheat production by efficient (inner sphere) and in-efficient (outer sphere) DMUs.

It is evident from the data that the largest share to the total saving energy was 56.5% for fertilizer, followed by diesel fuel 10%, machinery 9%, and electricity 7%, as demonstrated in Figure 6. The contributions of seed, human labor, and biocides energy inputs were relatively low, showing that almost all the DMUs have used them in the correct ratios. Saving energy from all these sources provides economic, social and environmental benefits for sustainable wheat production (Figure 6). Similarly, our findings were in agreement with Chauhan et al. [63], where they described that the 33% and 24% contribution of fertilizer and diesel fuel, energy inputs respectively from total energy saving in paddy production. Whereas, Mousavi-Avval et al. reported that the highest contribution of electricity was 78.1% and the lowest was 0.05% by seed energy inputs from total energy saving during soybean production [36].

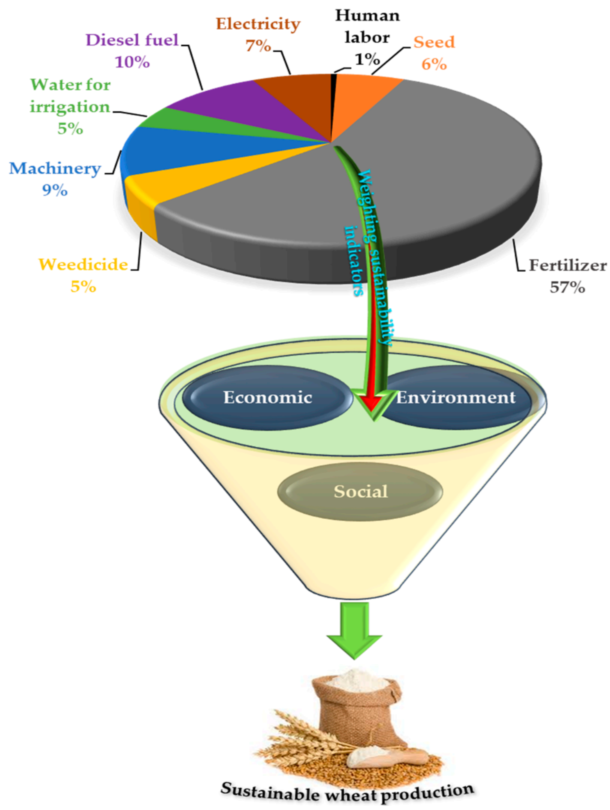

Figure 6. Share of energy saving from various sources for sustainable wheat production.

3.3. Greenhouse Gas Emissions

The result of GHG emissions of the surveyed wheat growing regions of Punjab province are presented in Figure 7. The average CO_2 emission from all the selected areas was 866.43 kg CO_2-eq ha^{-1}. Among all energy resources, fertilizer was the highest contributor to the total amount of GHG emissions, which was 288.45 kg ha^{-1} of wheat accounting for almost 48% of total GHG emissions. Diesel fuel consumption was 145.68 liter CO_2-eq per hectare, the second largest contributor (32%), followed by electricity (12.04%), weedicide (7.05%) and machinery (0.12%). It can be concluded that fertilizer was the most crucial factor in enhancing GHG emissions in the wheat growing areas due to heavy discharge of nitrous oxide. Given that, a little percentage of the nitrogen utilized in the soil is commuted to nitrous oxide, which has maximum potency of global warming that is why nitrogen fertilizer had the major impact on GHG emissions as well. Similarly, tillage operations and tube well irrigations are major contributors to consumption of diesel fuel. Thus, an appropriate method like reduction of weeds, adoption of a formal tillage system to minimum tillage system, prefer chisel plow to formal plow, and followed by canal irrigation to decrease the diesel fuel consumption [64]. Other studies described that nitrogen fertilizer and diesel fuel were the major contributor to GHG emission followed by electricity, such as Mohammadi et al. described that total GHG production was computed to be 1171.1 kg CO_2-eq ha^{-1} [65]. In 2007, Pathak and Wassmann concluded that the Indian wheat agroecosystem produced GHG emission between 1038 and 1624 kg CO_2-eq ha^{-1} [66]. Likewise, in Iran, the GHG emissions in wheat farms were 1137 kg CO_2-eq ha^{-1}, while in Canada, the GHG emissions in the wheat production system were calculated at 410–1130 kg CO_2-eq ha^{-1} [67]. Furthermore, several studies calculated CO_2 emission as 993 kg CO_2-eq ha^{-1} of potato production [68], 1100 kg CO_2-eq ha^{-1} of rice [69], and 1118.94 kg CO_2-eq ha^{-1} from wheat cultivation [70]. It suggests that suitable environmental conditions, peculiarly lower temperature and higher precipitation in Canada compared to Punjab, was the major reason for more prominent GHG emissions in the wheat agro system.

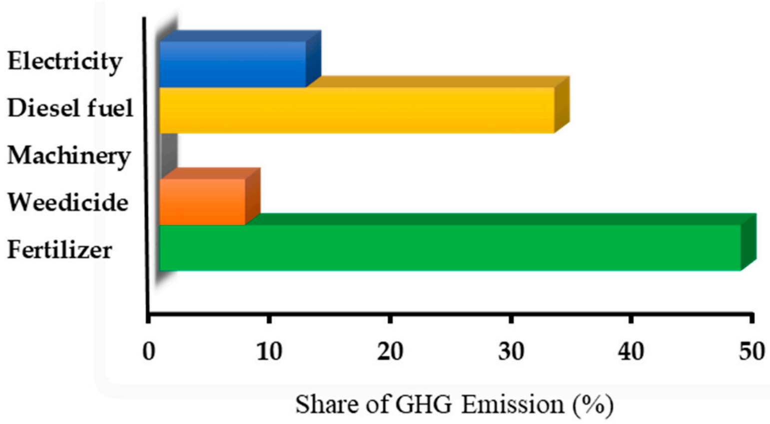

Figure 7. Contribution of GHG emitted from total GHG emissions due to consumption of different energy inputs for wheat production.

4. Conclusions

Input-output energy analysis for crops is a cost-effective approach towards efficient utilization of available resources that can increase the efficiency and sustainability of agricultural crops. However, in developing countries such as Pakistan, mismanagement of inputs leads to the loss of a high fraction of wheat-yield. To identify the possible energy loss, we applied the energy balance at wheat farms and data was analyzed by DEA that provided us with an optimum requirement and energy saving target. The energy consumed for the inputs in the production of wheat crops is 34,430.98 MJ ha^{-1}, with an average wheat yield of 3712.85 kg ha^{-1}. Among all selected districts for the study area, Rajan Pur is the most efficient district, which is working at the frontier line in case of the wheat crop. The DEA approach found an improper and inefficient trend of energy use in wheat production, due to excessive consumption of energy inputs (mainly fertilizer, diesel fuel, and water) in the considered areas. Moreover, we also found a potential for energy improvement in a wheat crop with an optimum value of input energy 29,388.52 MJ ha^{-1} and overall, 14.65% of resources could be saved in the study area if DMUs operate at their efficient level. Furthermore, the average of CO_2 emission for the wheat-growing region was 866.433 CO_2-eq ha^{-1}. From all energy resources in wheat production, fertilizer had the highest emission (48%), followed by diesel fuels and electricity. The major reason for more CO_2 emission was higher energy use. Therefore, to overcome these issues it can be recommended to use bio-fertilizer for soil fertility and solar energy for water pumping, which are very effective in reducing energy consumption. Later on, in order to reduce GHG emissions, it is advised to employ sustainable agricultural approaches; for example, selecting suitable crop rotation for improvement of soil fertility, modifying the planting date in agreement with rainfall occurrence for irrigation and utilization of the conservation tillage system to decrease the diesel fuel consumption and machinery usage for land preparations.

Author Contributions: Conceptualization, Y.W. and S.I.; Methodology, S.I.; Formal analysis, S.I.; Data curation, S.I. and M.A.A.R.; modeling and validation, S.I. and W.W.; Investigation; S.I. and L.B.; Writing—original draft preparation, S.I.; Reviewed and edited the draft, M.I.; Supervision and final draft approval, Y.W.

Funding: This research was supported by grants from the Agricultural Science and Technology Innovation Program of Chinese Academy of Agricultural Sciences (ASTIP-IAED-2018-08).

Acknowledgments: The authors would like to thank the anonymous reviewers for their helpful suggestions regarding the improvement of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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