EVALUATING ENERGY CONSUMPTION EFFICIENCY IN TOBACCO PRODUCTION: APPLYING DATA ENVELOPMENT ANALYSIS

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Abstract: *Tobacco is considered as one of the most important industrial cash crop and source of livelihood to many families in Pakistan. Considering the contraction of land under tobacco cultivation, the present study is intended to evaluate the production efficiency of tobacco growers in southern Punjab, Pakistan. The Data Envelopment Analysis model was used to investigate energy usage efficiency of tobacco farmers based on seven energy inputs; human labour, farm machinery, irrigation, diesel, fertilizers, chemicals, seeds, and a single output. Moreover, the current study also used DEA – super efficiency to identify and rank efficient and inefficient tobacco producers; and to suggest optimum energy requirements and energy savings potentials. The primary data from 210 tobacco growers were collected in-person interviews by random sampling technique. The findings of the study revealed that average energy consumed in the form of inputs and yield obtained in tobacco production was 52,703.58 MJ/ha*$^{-1}$ *and 3,096.98 MJ/ha*$^{-1,}$ *respectively. Average technical, pure technical, and scale efficiency score was calculated to be 0.902, 0.961, and 0.938, respectively. Likewise, the energy-saving ratio in tobacco production was estimated to be 13.83%, which implies that by adopting the proposed recommendations about 7,121.66 MJ/ha*$^{-1}$ *energy could be saved without compromising the output. Also, fertilizers, chemicals, irrigation, and diesel had the highest share in the consumption of energy inputs. The findings of the study provides pinpoint options to the agricultural polices makers to launch the technical training programs for the tobacco farmers to adopt better management practices to optimize the application of energy inputs to reduce the cost of tobacco production. The agricultural extension department should also visit the tobacco fields to assist the farmers about timely application of inputs and with extension services.*

Keywords: *Energy efficiency, energy inputs, Data Envelopment Analysis, energy consumption, energy saving potentials, energy conservation, slacked based super efficiency.*

JEL Classifications: *Q01, Q56, Q42.*

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Introduction

Tobacco is one of the most important cash crops and is considered as a domineering industrial crop. Tobacco is more proficient than any other crops to produce a massive amount of biofuel if cultivated for energy production instead of smoking (Andrianov et al., 2010). Pakistan is the world's 8th largest tobacco producer

(Shahbandeh, 2020). Over 75,000 farmers are cultivating tobacco in Pakistan. The crop was cultivated about on 51,000 hectars with a total production of 113,000 tones during 2017 (GOP, 2018). Tobacco crop got a significant place in the economy of the country by accommodating 350,000 workers directly and indirectly and is also adding up revenue of over Rs. 300 billion per annum. It is also providing a livelihood to about 1.2 million people in the country (Board, 2018). It is worth mentioning that tobacco has witnessed a decrease in production during 2016 with negative growth of 2.6 percent, over the same period last year (GOP, 2018).

Energy has become the fundamental factor for the socio-economic development of any region, country, or sector. Energy consumption analysis and scientific research on energy efficiency can help policymakers to design future energy policies and strategies (Wei et al., 2020c). Agriculture sector not only consumes energy but also produces energy (Alam et al., 2005). Nowadays the energy demand is escalating at an increasing rate in agriculture due to growing population pressure and high living standards with limited arable land; thus to meet these needs, farmers are applying inputs inefficiently and superfluously, especially when inputs have easy access and low prices. The improvements in energy consumption efficiency can not only be cost-effective but also can reduce energy-related environmental degradation issue, which ultimately contributes to sustainable development (Mousavi-Avval et al., 2011b).

Plenty of studies had estimated energy efficiency for different crops using parametric and non-parametric techniques; such as Kizilaslan (2009) conducted a study using the non-parametric approach to investigate energy consumption efficiency for cherries production in Turkey, Mohammadi and Omid (2010) on greenhouse cucumber in Iran, Singh et al. (1988) in six different agro-climatic zones of Indian Punjab. Ozkan et al. (2004) in greenhouse vegetables, Mandal et al. (2002) on soybean in India, Alimagham et al. (2017) on soybean in Iran, Pishgar-Komleh et al. (2012) on potato crop in Iran, Hatirli et al. (2005) in agriculture production in Turkey, Singh et al. (2004) on wheat production in India, Mohammadi et al. (2008) on potato in Iran, Hatirli et al. (2006) on tomato in Turkey, and Unakıtan and Aydın (2018) established an economic compression and energy use analysis of wheat and sunflower applying energy input-output ratio, energy inputs to output ratio and energy productivity (i.e. yield to energy input ratio).

Data Envelopment Analysis (DEA) is known as a non-parametric approach. DEA classifies efficient and inefficient decision-making units (DMUs) by benchmarking the best DMU. In addition to that, DEA is more superior to the parametric approach because it does not need any predefine assumptions to make a functional relationship among inputs and outputs (Mousavi-Avval et al., 2011b). One of the main advantages of DEA is that it can simultaneously evaluate several inputs and outputs (Zhang et al., 2009). Whereas; parametric models are the instrument for comparing the performance of decision-making units which uses a single input or a single output. However, the assessment of the performance of DMUs by parametric models using multiple inputs and multiple outputs requires the use of the complex process of simultaneous formulas which are fitted to the input-output data (Thanassoulis, 1993). Application of DEA in agriculture also has significant importance; such as Wei et al. (2020a) applied DEA model to find the social economic factors affecting cotton production in Pakistan, Mohammadi et al. (2011) who applied DEA model to analyze energy efficiency in kiwi production to calculated technical, pure technical and scale efficiency score, Kuhn et al. (2018) used DEA to quantify technical and environmental efficiency of livestock farms in China, Heidari et al. (2011) measured technical efficiency of poultry farms, Liu (2015) designed economic efficiency of agriculture using DEA, Mobtaker et al. (2012) used DEA to find energy optimization in alfalfa production, Wang et al. (2018) established a study to maximize agriculture water use efficiency in China, Mousavi-Avval et al. (2011a) used DEA to estimate input cost and apple production in Iran, Khoshnevisan et al. (2013) applied DEA to reduce greenhouse gas (GHG) emissions and energy efficiency in wheat production, Mardani and Salarpour (2015) estimated technical efficiency in potato production in Iran, Nasiri and Singh (2010) calculated energy efficiency for paddy crop in India, Abbas et al. (2018a) carried out a study in Pakistan to optimize energy usage efficiency of corn farms using DEA non-parametric approach.

On the bases of the existing literature only three studies were conducted to just estimate energy efficiency in tobacco production, such as: Loghmanpour-Zarini and Abedi-Firouzjaee (2013), Baran and Gokdogan (2015) and Moraditochaee (2012) calculated energy efficiency in tobacco production by applying simple energy input-output ratio methods but specifically no study has been carried out using DEA non-parametric approach in tobacco production. Moreover, there was no study on the optimization of energy consumption efficiency for tobacco production in Pakistan, either the DEA approach or the input-output ratio method. To shorten this research gap, the current study based on DEA super efficiency approach is unique in this respect in tobacco production. The objectives of the current study are to explore energy consumption patterns for tobacco production and to distinguish the super-efficient farmers by using DEA super efficiency approach, ranking the efficient and inefficient farmers and propose recommendations for the optimum energy requirements and energy savings for tobacco production in the Punjab province of Pakistan.

1. Materials and Methods

1.1 Selection of Study Area and Sampling Technique

The area of the study is located at the center of Pakistan near the river Indus belt. Rajanpur is an important district of Punjab. This district was selected to undertake the current study as all farmers have homogenous playing fields which satisfy the underlying assumption of the DEA model. Therefore, the farmers' technical efficiency will not be exaggerated by external biophysical factors (e.g., soil type, weather, and topography).

In order to draw an accurate sample to represent the population, first of all, an accessible population in which every tobacco grower had an equal and independent chance of being included in the sample was determined. For this purpose, 21 villages from district Rajanpur were selected. As district directorates did not have an updated list of tobacco growers for every village, therefore, these villages were visited in advance to determine the tobacco growers and the area under tobacco cultivation. The lists of tobacco farmers from the 21 villages made the accessible population. Based on the area under tobacco cultivation by each farmer, the accessible population was divided into three strata. Then following the formula applied by Boz (2015) stratified sample size determination formula was used by accepting a 5% error term from the mean and 95% confidence interval:

$$n = \frac{N \sum S_h^2 N_h}{N^2 D^2 + S_h^2 N_h}\ ,\ D^2 = \frac{e^2}{t^2} \tag{1}$$

Whereas n is the prerequisite sample size, N is the number of farmers in the accessible population, N_h represents the number of tobacco growers in each stratum, S_h shows the standard deviation within each stratum, D^2 is the desired variance, e is accepted the error from the mean of the accessible population, t is the t-table value of the accepted confidence interval. Subsequently, the calculated required sample of 210 tobacco farmers from 21 villages was randomly selected for interviews.

1.2 Conversion of Inputs and Outputs to Energy Equivalents

The first-hand data collected from tobacco producers included all kinds of inputs mainly human labour, irrigation water, diesel fuel, farmyard manure, agriculture machinery, seed, fertilizers (including nitrogen, potash, phosphorus) and chemicals in the form of herbicides and pesticides whereas tobacco yield was taken as the output.

Moreover, to estimate the energy efficiency by applying DEA model, the present study converted all the agricultural inputs and outputs data into their respective energy equivalents mega joules (MJ). As the present study is carried out in Pakistan and unfortunately, no study was found that especially calculated coefficients of energy equivalents for Pakistan condition, But, the literature is abundant that suggest the energy equivalents for different agricultural inputs and outputs such as; Mousavi-Avval et al. (2011a), Ebrahimi and Salehi (2015) and Pahlavan et al. (2011) calculated energy efficiency for canola, mushrooms and tomato crops by using these energy equivalents. Moreover, many researchers from Pakistan, such as Abbas et al. (2018b), Kousar et al. (2006), and Afzal and Ahmad (2009) also used these energy equivalents to convert the quantities of physical agricultural inputs and outputs to their respective energy equivalents (MJ). Therefore the present study also used the existing coefficients of energy equivalents to convert the agricultural inputs and outputs to

Tab. 1: Tobacco inputs & outputs energy equivalents

Inputs & outputs	Units	Energy equivalent MJ/unit	References
Inputs			
1. Human labor	Hours (h)	1.96	Ashkan et al., 2016
2. Machinery			
a) Tractor	(h)	93.61	Canakci et al., 2005
b) Others	(h)	62.7	Canakci et al., 2005
3. Diesel	Liters (l)	47.8	Ashkan et al., 2016
4. Water	Cubic meter (m^3)	1.02	Ashkan et al., 2016
5. Fertilizers	Kilogram (kg)		
a) Nitrogen (N)		66.14	Rafiee et al., 2010
b) Phosphate (P_2O_5)		12.44	Rafiee et al., 2010
c) Potassium (K_2O)		11.15	Rafiee et al., 2010
d) Farmyard manure	(kg)	0.30	Rafiee et al., 2010
6. Chemicals	(l)		
a) Insecticides	(l)	238	Erdal et al., 2007
b) Weedicides	(l)	101.20	Erdal et al., 2007
7. Seed	(kg)	25	Moraditochaee, 2012
Outputs			
1. Tobacco yield	(kg)	0.8	Moraditochaee, 2012

Source: own

their respective energy equivalents (MJ/Unit) as presented in Tab. 1.

All the physical inputs and output were converted into energy mega joules per hectare (MJ/ha^{-1}) by simply multiplying the inputs with their respective coefficients of energy equivalents as given in Tab. 1. However, the energy inputs for farm machinery used in tobacco production was calculated by using the method adopted by Kitani and Jungbluth (1999) as given in formula (2):

$$E_M = \frac{w \times E \times t}{T} \tag{2}$$

Whereas E_M is energy coefficient MJ/ha^{-1} for per hour use of farm machinery, w represents the machine weight in kg, t shows machine work time in hours, E denotes the production energy in MJ/hour of the farm machines as given in Tab. 1, and T is the machines economic lifetime (hours). Whereas Tab. 2 shows the total energy equivalents (MJ/ha^{-1}) for each machine that

Tab. 2: Machinery used and energy equivalents for tobacco production

Machine	Weight (kg)	Lifetime (h)	Usage (h/ha^{-1})	Total energy equivalents (MJ/ha^{-1})
Tractor	3,000	10,000	18.70	525.1
Cultivator	500	2,500	3.93	49.28
Disk harrow	575	2,500	4.65	67.05
Trailer	750	5,000	5.41	50.88
Sprayer	400	1,200	4.71	98.43

Source: own

were calculated by using formula (2) following Abbas et al. (2018b) and Mousavi-Avval et al. (2011a).

1.3 Data Envelopment Analysis Approach

Data Envelopment Analysis technique is a non-parametric method to calculate the relative efficiency of each entity in the sample and ranks decision-making units according to their efficiency scores. Moreover, the DEA does not require any assumptions to set a frontier between inputs and outputs (Seiford & Thrall, 1990). The current study used DEA to optimize energy consumption in tobacco production and to rank efficient and inefficient DMUs.

Farrell (1957) introduced a new method to measure efficiency and production function at the micro-level by splitting economic efficiency into technical and allocative efficiency. The author presented a piecewise linear development of the data as the conservation estimate the production function, which envelopes observation points as closely as possible, which was estimated by solving a system of linear formulas. This model had a drawback that it was designed to calculate efficiency for a single input and output frontier (Abbas et al., 2018a).

DEA basic has two renowned models called CCR and BCC. Charnes et al. (1978) introduced Charnes, Cooper and Rhodes (CCR) that was ensemble to calculate multiple inputs and multiple output ratio and works on the assumption of constant return to scale, on the other side Banker et al. (1984) Banker, Cooper and Charnes (BCC) presented the BCC model that is also called a variable return to scale model, that works on the assumption of a variable return to scale. Infact we have more control over inputs instead of the outputs, therefore we preferred an input-oriented model (Pishgar-Komleh et al., 2020; Yang et al., 2020).

Efficiency in the DEA model can be optimized either by reducing inputs to an optimal level by keeping the output constant or by optimizing the output level by keeping the inputs constant. The former is also called input-oriented model while the latter is known as an output-oriented model. Choosing a suitable model from the above two depends upon the objectives of the research and the data characteristics (Zhou et al., 2008). Most of the agriculture-related studies use the input-oriented model because growers can only control the inputs and not the outputs (Pahlavan et al., 2012). Furthermore, The DEA input-oriented technique works on two basic assumptions; (i) contact return to scale, (ii) variable return to scale. Coelli et al. (2005) suggested that DEA-CCR is more suitable when firms are operating at the optimum level. But due to many constraints, such as farm size, financial crisis, credit facility, inputs availability, makes it impossible for the farmers in Pakistan. Therefore, to mitigate these difficulties, Banker et al. (1984) presented the DEA-BCC method. Considering the objective and nature of the study, the current study applies DEA input-oriented CCR, BCC, and Super efficiency approaches to analyze the data using MaxDEA and DEA-Solver-LV (V8) packages. Technical efficiency (TE), scale efficiency (SC), and pure technical efficiency (PTE) and super efficiency are mathematically expressed below in detail.

Technical Efficiency

The technical efficiency is defined as the ratio of the weighted sum of outputs to the sum of weighted inputs (Cooper et al., 2006). The value of TE can be between 0 to 1, DMU with TE value one is efficient, and DMU with TE value lower than one is inefficient and can become efficient by reducing inputs up to optimum level. Technical efficiency can be expressed mathematically as presented in formula (3) (Mousavi-Avval et al., 2011b; Wei et al., 2020b).

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \dots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \dots + v_m x_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}}, \quad (3)$$

where TE_J represents the technical efficiency of DMU, y shows the amount of n^{th} output, x_s shows the amount of m^{th} input, u_r is the energy coefficient of output n, v_s is the energy coefficient for m^{th} input, j is j^{th} DMUs $(j = 1, 2, 3, \dots k)$, r represents the number of outputs $(r = 1, 2, 3, \dots n)$ and s is the number of inputs $(s = 1, 2, 3, \dots m)$. Linear programming (LP) was used to solve this formula, which was introduced by Charnes et al. (1978):

$$Maximize\ \theta = \sum_{r=1}^{n} u_r y_{rj} \quad (4)$$

$$Subject\ to\ \sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \leq 0 \quad (5)$$

$$\begin{gathered} \sum_{s=1}^{m} v_s x_{sj} = 1 \\ (j = 1, 2, \dots, k) \quad u_r \geq 0, \quad v_s \geq 0 \end{gathered} \quad (6)$$

where θ represents technical efficiency and j is the j^{th} DMU. The given model is DEA-CCR model, also named as linear program model. This model assumes that the efficiency is not affected by the operational scale of DMUs, which means small farmers can be equally efficient to the big farmers in the production process (Mobtaker et al., 2012).

Pure Technical Efficiency

Pure technical efficiency can be estimated by using DEA-BCC approach, which is a variable return to scale model. Scale efficiency and technical efficiency can be separated using pure technical efficiency. This model compares efficient and inefficient producers of the same scale, and it is solved by the dual linear program (DPL), mathematically it can be expressed as in below given formulas (Mobtaker et al., 2012):

$$Maximize\ Z = uy_j - u_j \tag{7}$$

$$subject\ to = vx_j = 1 \tag{8}$$

$$\begin{gathered} vX + uY - u_0 e \leq 0 \\ v \geq 0, \quad u \geq 0, \quad u_0 \end{gathered} \tag{9}$$

where x_j and y_j are representing inputs and output of DMUj^{th}, weight matrices are represented by v and u for inputs and outputs respectively, corresponding input and output matrix is denoted by X and Y, whereas u_j is scaler and sign free.

Scale Efficiency

Two main causes of inefficiency are unsuitable scale and inadequate operations of DMU. Technical efficiency can be estimated by using the CCR model while PTE can be obtained from the BCC model (Khoshnevisan et al., 2013); whereas scale efficiency is defined as the ratio of technical efficiency to pure technical efficiency of the DMU, and it can be calculated by formula (10) as presented by Banker et al. (1984):

$$Scale\ Efficiency = \frac{Technical\ efficiency}{Pure\ Technical\ Efficency} \tag{10}$$

Radial Super Efficiency

Determination of the efficient DMUs remained the topic of keen interest for many researchers. DEA models CCR and BCC are used to find the efficient and inefficient DMUs considering the efficiency score one or less than one, respectively. But, there are often more than one DMUs with an efficiency score of one. Thus, the DEA super-efficiency model is used to rank and compare the most efficient DMUs in the sample. Many radial and none radial super-efficiency models had been introduced to find the most efficient DMUs, such as Tone (2001) introduced slacked based non-radial super-efficiency model. In this model DMUs with efficiency value higher than one are considered as efficient, the larger score will make DMU more superior than others in the sample. Considering the objective and the nature of the data, the present study will use the radial DEA input-oriented CCR super-efficiency model introduced by Andersen and Petersen (1993) as mathematically expressed below:

$$[Super\ CCR.I] \qquad \theta^* = Minimize\ \theta_0 \tag{11}$$

$$Subject\ to\ \ \theta x_0 = \textstyle\sum_{j=1, j\neq 0}^{n} \lambda_j x_j + s^- \tag{12}$$

$$\begin{gathered} y_0 = \textstyle\sum_{j=1, j\neq 0}^{n} \lambda_j y_j - s^+ \\ \lambda \geq 0, \qquad s^- \geq 0, \qquad s^+ \geq 0 \end{gathered} \tag{13}$$

The objective function in formulas (11)–(13) is minimization as we argued that in order to reach best frontier the slacks should be minimum. The minimization of slack is our target in objective function. Whereas s^- and s^+ indicates the inputs and outputs slacks, respectively, for efficient DMUs the (y_0, x_0), $\theta*$ is not less than unity and this value represents the super efficiency value. Whereas j shows DMU_j $(j = 1, 2, ..., k)$, $x_j = (1, 2, ..., m)$ and $y_j = (1, 2, ..., n)$ represents the inputs and outputs of DMU_j.

Energy Saving Targets Ratio (ESTR)

ESTR is defined as the ratio of energy-saving targets to actual energy inputs. ESTR is a useful technique to differentiate efficient and inefficient farmers, and energy use inefficiency for each DMU can be specified using ESTR. Mousavi-Avval et al. (2011b) and Abbas et al. (2018b) also used Energy saving targets ratio to suggest energy savings for different crops. ESTR can be calculated by the formula given in formula (14) (Hu & Kao, 2007).

$$ESTR\ (\%) = \frac{(Energy\ Saving\ Target)}{(Actual\ Energy\ Inputs)} \times 100 \quad (14)$$

where the energy-saving target is the total energy that can be saved without compromising the output level. The value of ESTR can lie between zero and hundred, DMU with ESTR value zero implies that DMU is fully efficient and no more energy can be reduced, whereas any value higher than zero indicates inefficient energy usage and indicates that DMU has energy-saving potential keeping output constant.

2. Results and Discussions

2.1 Energy Input-output Analysis for Tobacco Production

The amount of physical inputs, output, energy equivalents, and standard deviations are given in Tab. 3. The average tobacco yield was calculated to be 3,871.23 kilograms per hectare (kg/ha^{-1}). The consumption of inputs, such as human labor, farmyard manure, and the seed, was calculated as 164.27 h/ha^{-1}, 1,459.12 kg/ha^{-1} and 3.16 kg/ha^{-1} respectively. The amount of chemical fertilizers, mainly nitrogen, phosphate, and potassium were 512.66 kg/ha^{-1}, 200.12 kg/ha^{-1}, and 51.18 kg/ha^{-1}. Diesel, insecticide, and pesticide were consumed as given in Tab. 3 were 120.93 liters per hectares l/ha^{-1}, 6.25 l/ha^{-1}, and 3.49 l/ha^{-1}. Water for irrigation was calculated to be 6,724.98 m^3/ha^{-1}, whereas machine hours and energy equivalents for each machine are already given in Tab. 2.

The physical inputs and outputs were converted into energy equivalents MJ/ha^{-1}. The results in Tab. 3 revealed that total energy required in tobacco production was 52,703.58 MJ/ha^{-1}, with the highest share of nitrogen calculated to be 33,908.40 MJ/ha^{-1} followed by irrigation and diesel 6,859.62 MJ/ha^{-1} and 5,780.60 MJ/ha^{-1} respectively. Abbas et al. (2018a) investigated energy use efficiency for corn production in Pakistan and reported that 30,969.47 MJ/ha^{-1} energy input was required in corn production. Furthermore, it was also noted that nitrogen has the highest share with 14,760.27 MJ/ha^{-1} of energy followed by

Tab. 3: Average inputs, the output used for tobacco production and energy equivalents

Inputs & outputs	Quantity (unit/ha^{-1})	Total energy (MJ/ha^{-1})	St. dev.*
Inputs			
1. Human labor (h)	164.27	321.97	35.529
2. Machinery (h)		790.81	
3. Diesel (l)	120.93	5,780.60	629.14
4. Water (m^3)	6,724.98	6,859.62	1,046.90
5. Fertilizers (kg)			
a) Nitrogen (N)	512.66	33,908.40	11,675.15
b) Phosphate (P_2O_5)	200.12	2,489.65	861.00
c) Potassium (K_2O)	51.18	570.72	799.863
d) Farmyard manure	1,459.12	437.74	675.005
6. Chemicals (l)			
a) Insecticides	6.25	632.32	275.69
b) Weedicides	3.49	832.59	394.99
7. Seed (kg)	3.16	79.16	28.49
Outputs			
1. Tobacco yield (kg)	3,871.233	3,097.05	475.39
Total energy output		**52,703.58**	

Source: own

Note: * Standard deviation for energy equivalents of inputs and outputs energy (MJ/ha^{-1}).

Tab. 4: **Tobacco farmers average, maximum and minimum efficiencies**

Particular	Average	Maximum	Minimum	St. dev.
Technical efficiency	0.902	1	0.633	0.081
Pure technical efficiency	0.961	1	0.82	0.048
Scale efficiency	0.938	1	0.724	0.067

Source: own

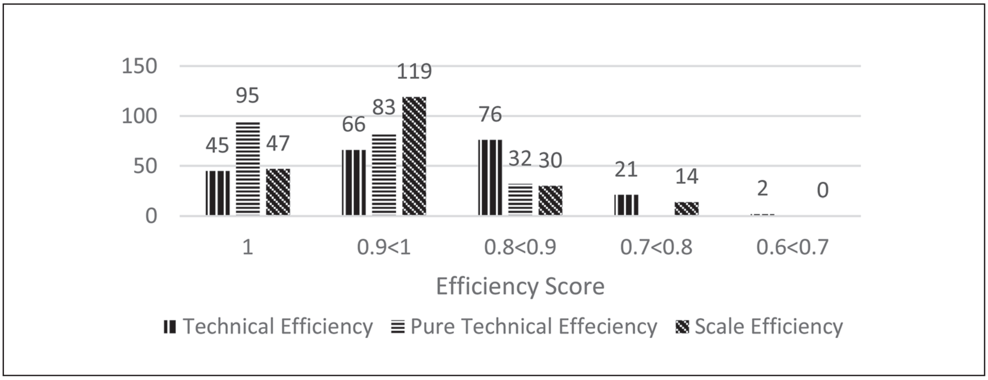
irrigation and diesel with 6,333.87 MJ/ha^{-1} and 5,141.40 MJ/ha^{-1} respectively, implies that nitrogen, irrigation, and diesel were the key energy inputs.

2.2 Efficiency Estimation

Technical, pure technical and scale efficiency of the producer was investigated using DEA – CCR and BCC approach. The results given in Tab. 4 indicate that average technical, pure technical and scale efficiency of the farmers were 0.902, 0.961, and 0.938, respectively. The maximum technical efficiency calculated was 1.00, and the minimum was 0.633, with a standard deviation of 0.081. Pure technical efficiency score remained between 1.00 and 0.82. Whereas for scale efficiency maximum value was calculated as 1.00 and minimum score was 0.724 with a standard deviation of 0.067. A large variation in technical efficiency score of producers implies that producers have technical inefficiency, for instance, the farmers were not applying the optimum amount of inputs at the right time and in proper way (Mohammadi et al., 2011).

Efficiency scores obtained from DEA-CCR and BCC for all three efficiencies are presented in Fig. 1. The results indicate that the majority of the farmers are working at an optimal level or near it. The results revealed that 45.24% of farmers, i.e., 95 out of total 210, have a pure efficiency score of 1.00. Whereas technical efficiency of 45 farmers was calculated to be 1.00, that indicates that 21.42% of farmers are said to be globally efficient farmers. However, the remaining 40 farmers are said to be locally efficient due to some reasons or the other such as scale size. The rest of the 47 farmers have scale efficiency score of 1.00. On the other hand, the majority of the inefficient farmers are also close to the efficient score, pure technical efficiency score of 83 farmers lies between 0.90 to 0.99, and 32 farmers got a pure technical score between 0.80 to 0.89 ranges. These results are similar to the study conducted by Mohammadi et al. (2011) who applied DEA

Fig. 1: **Efficiency distribution of tobacco farmers**



Source: own

Tab. 5: **Ranking 10 super-efficient tobacco growers**

Ranks	Farmer no.	Score	Ranks	Farmer no.	Score
1	113	1.697	6	112	1.038
2	175	1.049	7	9	1.036
3	96	1.048	8	201	1.026
4	161	1.045	9	8	1.020
5	89	1.040	10	71	1.014

Source: own

model to analyze energy efficiency in kiwi production; calculated technical, pure technical and scale efficiency score to be 0.94, 0.99 and 0.95 respectively. Mousavi-Avval et al. (2011b) reported technical, pure technical and scale efficiency to be 0.85, 0.92 and 0.93 respectively in soybean production in Iran.

2.3 Ranking Farmers by Radial Super-efficiency Approach

Super efficiency, benchmarking, and cross efficiency methods can be used to identify and rank the best performers among the efficient ones. Plenty of studies has already been conducted to rank efficient farmers using different techniques such as; Mousavi-Avval et al. (2011a) and Pahlavan et al. (2012) used benchmarking method to rank the efficient farmers, whereas Mousavi-Avval et al. (2011b) ranked efficient farmers by applying cross efficiency approach. This study identified and ranked 10 most efficient farmers using DEA super efficiency constant return to scale. The results in Tab. 5 indices that DMU 113 is the best farmers in the sample and has a super efficiency score of 1.697.

The farmer with the highest score in the super-efficiency model is considered to be the most efficient, and higher efficiency score makes the farmers more superior among others in the sample. Based on cited literature, no study could be found using DEA super efficiency model in the Pakistan context, especially in agricultural research.

Tab. 6: **Physical inputs and output comparison among efficient and inefficient farmers**

Particulars (units)	(A) Efficient farmers	(B) Inefficient farmers	(%) Difference (B−A) × 100/B
Inputs			
1. Human labor (h)	142	154	7.79
2. Machinery (h)	34	36	5.5
3. Diesel (l)	109	125	12.8
4. Water (m^3)	5,914	6,626	10.47
5. Fertilizers (kg)	911	1,918	52.5
6. Chemicals (l)	4	12	66.5
7. Seed (kg)	3	3	0
Outputs			
1. Tobacco yield (kg)	3,805	2,891	−31.62

Source: own

2.4 Comparing Consumption of Physical Inputs among Efficient and Inefficient Farmers

Efficient and inefficient farmers were identified by using DEA super efficiency model. The results given in Tab. 6 implies the average amount of physical inputs consumed and output gained by 15 most efficient and inefficient farmers. The findings divulged that all efficient farmers not only consumed less amount of physical inputs in the production process but also obtained higher yield than inefficient farmers. It can also be observed in the results given in Tab. 6 that among inefficient farmers, the use of fertilizers and other chemical was the highest 52.5% and 66.5%, followed by diesel and irrigation. Efficient farmers have 31.62% higher output than inefficient farmers. Different studies also reported that inefficient farmers were using a high amount of physical inputs with less obtained outputs (Mobtaker et al., 2012).

2.5 Optimum Energy Required and Saving Targets

The results obtained from the DEA BCC model were used to suggest the optimal amount of energy required and potential energy savings in tobacco production. The results in Tab. 7 indicated that optimal energy required in tobacco production was calculated to be 51,585.89 MJ/ha^{-1} and results also revealed that 7,121.66 MJ/ha^{-1} of energy can be saved if farmers adopt best management practices. It is also evident from the results that the optimum energy requirement for different inputs such as fertilizers, chemicals, diesel, irrigation, machinery, seed, and human labor is 33,968.78, 1,135.97, 5,256.12, 6,859, 996, 71.20 and 298.90 MJ/ha^{-1} respectively.

The optimal energy requirements in the form of fertilizers and chemicals remained highest followed machine and diesel. Energy saving target ratio ESTR is also presented in Tab. 7, which indicated that 18.03% and 11.96% energy could be saved from chemicals and fertilizers in tobacco production. In addition to that, ESTR also shows that in total, 13.83% energy can be saved by adopting best management practices.

Abbas et al. (2018a) suggest that total 17.11% energy could be saved in corn production in Pakistan; energy consumed in the form of chemicals, fertilizers, irrigation, and farm machinery had the highest potential of energy savings. Chauhan et al. (2006) carried out a study to investigate energy efficiency in paddy production in India and suggest that 11.6% energy consumed in the form of inputs could be saved in paddy production.

2.6 Advising Optimal Energy Requirement Level for Inefficient Farmers

Agricultural production follows the principle of diminishing marginal productivity. As in the present study land used by farmers' remains

Tab. 7: Optimum energy requirements and energy savings for tobacco farmer

Particulars (units)	Optimum energy requirement (MJ/ha^{-1})	Energy savings (MJ/ha^{-1})	ESTR (%)
1. Human labor (h)	298.90	23.06	6.62
2. Machinery (h)	996	98	9.11
3. Diesel (l)	5,256.12	524.47	8.56
4. Water (m^3)	6,859	501.68	6.58
5. Fertilizers (kg)	36,968.78	5,640.56	11.96
6. Chemicals (l)	1,135.97	328.94	18.03
7. Seed (kg)	71.20	7.95	7.99
Total	**51,585.89**	**7,121.66**	**13.83**

Source: own

fixed during the production period, therefore, with the continuous increase in other inputs while keeping the land fixed will not increase the output after a certain level. Concluding that for sustainable agriculture production it is very important to optimize the level of inputs instead of maximization of agricultural inputs. Thus, Tab. A2 in the Appendix explains the actual and the optimum energy input required for farmers without affecting the output.

Farmers with pure technical efficiency score less than 1.00 are currently inefficient farmers and applying the undesired amount of energy inputs. So, it is essential to recommend optimal energy requirements to the inefficient farmers. On the bases of the results obtained from the BCC model, 115 farmers were found to be using more inputs than the optimal level. The results given in Tab. A2 indicate the amount of energy inputs being used by inefficient farmers and in next half optimum amount of the inputs is recommended. ESTR for each farmer given in the last column of Tab. A2 indicates the percentage of energy inputs that each inefficient farmer can save respectively. Farmer no. 115 has ESTR 46%, which is considered to be worst among the inefficient farmers and could save 46% of energy by applying the optimal amount of energy inputs in tobacco production.

The results indice that in tobacco production farmers are applying the undesired amount of energy inputs in form for fertilizers, chemicals, irrigation, and diesel due to mismanagement and lack of education, technical training, and knowledge. There is a great potential to reduce production cost and environmental degradation by applying the optimal amount of energy inputs required for crop production. Technical training, extension services, and proper education should be provided to the farmers. In this matter, the government should involve agriculture institutes to deploy agricultural graduates as internee to guide farmers. Furthermore, NGOs and private sector organizations such as (fertilizers, seed, and chemical companies) should provide technical and smart training to the farmers to adopt best management practices. Extension department should launch some awareness program to apply best management practice and apply optimum energy inputs to reduce cost and save the environment. The government should initiate some technical training school at the local level for short courses to train farmers about the application of chemical and fertilizers; and the use of lasts technology such as machines and irrigation techniques.

Conclusion

The current study was conducted to investigate the energy efficiency in tobacco production in Pakistan. Data Envelopment Analysis, CCR, BCC, and super-efficiency models were applied to find the technical, pure technical efficiency and raking the superior farmers, respectively. The results of the study indicated that tobacco crop is energy extensive crop and the huge amount of energy inputs in the form of fertilizers, chemicals, irrigation, and diesel is required. The findings also divulged that chemicals, fertilizers, irrigation, and diesel had the highest potential to save energy. Overall, 13% of the energy could be saved if all tobacco growers in the sample were operating at the full efficient level. Adopting an optimal level of energy inputs can make tobacco farmers more competitive in the region with a reduction in the production cost. Technical training to adopt best management practices and applying the required level of energy inputs can improve energy efficiency. Ending with the note; that DEA super efficiency technique was beneficial to identify and rank the energy inefficiency in tobacco production and to suggest required energy levels in the region.

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Appendix

Tab. A1: List of abbreviations

Sr.	Name	Abbreviation
1	Non-government organizations	NGO
2	Irrigation	IRI
3	Farm yard manure	FYM
4	Phosphate	Ph
5	Potassium	Po
6	Pesticides	PES
7	Weedicide	WED
8	Seed	S
9	Human labor	HL
10	Diesel	D
11	Machine	MACH
12	Nitrogen	N
13	Hectare	ha
14	Hour	h
15	Kilogram	kg
16	Mega joules	MJ
17	Liters	l
18	Slack base measure	SBM

Source: own

Tab. A2: Actual energy consumption and optimal energy requirements MJ/ha^{-1} – Part 1

Actual energy consumption (MJ/ha^{-1})												
DMU	PTE	IRI	FYM	N	Ph	Po	PES	WED	S	HL	D	MACH
001	0.92	6,144	0	49,498	3,118	0	750	1,176	88	302	5,191	1,006
002	0.89	7,370	712	50,011	3,197	0	1,000	588	49	325	5,723	1,110
003	0.88	9,104	3,558	49,684	3,135	0	1,000	588	82	329	6,462	1,253
004	0.92	6,720	1,779	33,177	3,120	0	750	588	93	300	5,866	1,137
010	0.90	9,104	1,779	50,011	3,166	1,378	500	588	93	392	6,162	1,207
012	0.93	8,562	1,334	41,513	3,135	1,378	750	588	77	380	5,808	1,137
016	0.93	7,603	0	41,173	3,086	689	1,000	1,176	62	335	5,321	1,089
021	0.90	7,370	1,779	49,439	1,614	0	1,250	1,176	62	320	5,443	1,114
027	0.88	7,011	0	41,232	3,109	0	500	1,176	88	338	5,256	1,076
029	0.88	7,184	0	49,653	3,133	0	500	588	88	330	5,346	1,094
032	0.90	8,020	1,779	49,848	3,151	689	1,000	588	124	351	7,163	1,137
041	0.90	7,470	342	40,934	3,092	0	750	1,176	95	308	6,356	1,009
049	0.93	7,470	0	49,408	3,109	1,378	500	588	59	329	6,793	1,079
051	0.92	6,156	0	24,842	3,105	0	1,000	588	99	343	5,585	1,010
055	0.87	6,729	0	41,143	3,119	1,378	500	1,176	81	314	6,041	1,092
058	0.86	7,630	0	33,177	3,120	0	750	1,176	93	358	5,677	1,026
063	0.92	7,002	0	41,186	3,105	0	750	588	46	319	5,946	1,075
067	0.89	6,153	0	41,079	3,098	0	1,000	1,470	83	353	5,967	1,079
068	0.84	9,321	0	41,513	3,135	1,378	500	1,176	93	397	6,675	1,207
072	0.86	7,197	0	49,684	3,135	689	500	588	93	371	5,558	1,096
076	0.84	8,004	0	49,785	3,145	0	1,250	1,176	119	383	5,525	1,089
077	0.87	7,197	890	41,186	3,105	0	750	1,176	93	326	5,558	1,096
079	0.91	7,088	356	49,439	3,112	1,378	500	588	62	328	5,487	1,082
084	0.92	7,011	0	41,326	3,118	0	750	588	53	327	5,457	1,076
097	0.92	7,989	0	49,498	3,118	1,378	750	1,176	88	343	5,777	1,088
099	0.92	7,170	0	49,345	3,086	689	750	1,176	62	332	5,785	1,089
105	0.82	7,556	0	49,498	3,118	1,378	750	882	88	342	5,777	1,088
106	0.92	6,144	0	49,498	3,118	0	750	1,176	88	302	5,345	1,006
107	0.89	7,370	712	50,011	3,197	0	500	588	49	325	5,893	1,110
108	0.87	9,104	3,558	49,684	3,135	0	750	1,470	82	329	6,654	1,253
118	0.93	8,844	0	33,079	3,123	1,378	750	941	74	382	5,135	1,040
121	0.92	7,603	0	41,173	3,086	689	750	1,176	62	335	5,377	1,089
123	0.87	6,590	1,067	41,513	3,135	0	1,000	1,764	86	383	5,203	1,054
124	0.89	8,064	890	49,357	3,120	1,378	750	1,176	93	371	7,087	1,096
125	0.91	6,142	0	32,778	3,081	2,755	500	588	103	307	6,509	1,006
126	0.88	7,370	1,779	49,439	1,614	0	750	1,176	62	320	6,240	1,114
132	0.83	7,011	0	41,232	3,109	0	750	1,176	88	338	6,025	1,076
134	0.84	7,184	0	49,653	3,133	0	500	1,176	88	330	6,129	1,094
137	0.90	8,020	1,779	49,848	3,151	689	750	588	124	351	6,369	1,137
138	0.90	8,237	1,779	49,575	3,125	689	750	1,176	185	336	6,499	1,160
140	0.91	6,503	890	33,232	3,125	1,378	750	1,176	103	308	5,851	1,045
146	0.91	7,470	342	40,934	3,092	0	1,000	882	166	308	5,652	1,009
154	0.93	7,470	0	49,408	3,109	1,378	750	1,176	59	329	6,426	1,079
156	0.93	6,156	0	24,842	3,105	0	500	588	99	343	6,015	1,010
160	0.87	6,729	0	41,143	3,119	1,378	875	882	81	314	6,506	1,092
163	0.86	7,630	0	33,177	3,120	0	750	1,176	93	358	6,114	1,026

Tab. A2: Actual energy consumption and optimal energy requirements MJ/ha^{-1} – Part 2

Optimal energy requirements (MJ/ha^{-1})											ESTR%
IRI	FYM	N	Ph	Po	PES	WED	S	HL	D	MACH	
5,647	0	28,515	1,613	0	461	963	81	278	4,771	922	35.71
6,460	252	36,227	1,166	0	362	347	44	290	5,101	989	26.89
6,953	0	42,221	905	0	470	517	64	289	5,234	1,034	23.28
6,160	32	30,412	1,805	0	533	539	84	275	5,120	988	14.17
6,970	315	42,155	837	1,205	395	527	83	320	5,523	1,082	20.13
7,035	181	38,490	1,466	472	594	545	72	308	5,385	1,055	14.01
6,385	0	33,014	1,542	641	437	372	57	292	4,952	977	20.91
6,157	239	34,363	1,271	0	383	391	55	284	4,885	956	29.59
5,479	0	25,819	1,584	0	439	708	78	278	4,616	893	33.27
5,971	0	26,113	1,264	0	441	519	78	286	4,714	922	40.65
6,858	394	35,372	2,141	618	660	528	76	315	5,356	1,021	27.77
5,593	0	28,209	1,609	0	300	1,059	83	276	4,849	913	30.30
6,880	0	37,052	829	0	367	332	55	291	5,152	1,001	26.52
5,689	0	22,959	1,690	0	538	544	77	281	4,637	899	12.67
5,879	0	27,464	1,580	0	437	693	70	274	5,030	954	31.17
5,419	0	25,006	1,575	0	500	588	77	277	4,508	883	26.74
6,408	0	30,490	1,247	0	459	491	43	295	5,238	993	23.92
5,476	0	26,505	1,584	0	500	588	74	279	4,619	899	32.78
6,603	0	34,698	1,582	0	418	983	77	288	5,281	1,009	22.11
6,118	0	26,162	1,174	0	428	503	79	289	4,757	931	41.31
5,593	0	28,209	1,609	0	541	869	83	276	4,629	913	39.38
6,046	0	32,828	1,439	0	524	949	81	279	4,854	957	21.86
6,431	25	33,779	1,497	605	426	364	56	292	4,978	981	28.79
6,146	0	28,781	1,332	0	461	495	49	293	5,047	963	27.03
6,530	0	35,336	1,694	0	388	1,086	81	288	5,227	1,004	27.49
6,617	0	29,397	2,375	141	369	897	57	301	5,254	1,005	33.20
5,527	0	24,050	1,576	0	464	588	72	280	4,606	893	46.00
5,647	0	28,515	1,613	0	311	1,081	81	278	4,908	922	35.70
6,437	350	35,288	1,671	0	445	524	44	290	5,246	988	26.48
6,728	3	38,665	1,108	0	86	1,157	71	286	5,512	1,014	28.14
6,083	0	25,331	1,918	0	456	602	69	287	4,780	940	26.09
6,397	0	33,072	1,534	636	437	371	57	292	4,962	978	20.55
5,479	19	25,766	1,551	0	491	572	75	277	4,539	889	35.82
6,234	235	35,651	1,946	281	671	1,052	83	293	5,017	980	28.53
5,600	0	25,476	1,778	183	456	536	79	280	4,740	918	25.52
6,472	202	35,702	1,417	0	494	625	54	281	5,076	978	26.57
5,519	0	25,526	1,542	0	495	575	73	279	4,583	894	35.06
5,721	0	27,949	1,592	0	420	925	74	277	4,880	920	38.29
6,858	394	35,372	2,141	618	660	528	76	315	5,356	1,021	26.74
6,620	86	36,741	1,342	617	244	963	93	301	5,415	1,040	27.27
5,779	0	30,122	1,661	180	680	1,066	90	278	4,697	947	16.30
5,616	0	27,998	1,631	0	602	799	83	277	4,588	914	30.15
6,880	0	37,052	829	0	367	332	55	291	5,152	1,001	27.01
5,755	0	23,225	1,674	0	468	550	68	286	4,757	914	11.63
5,849	0	26,971	1,572	0	511	615	70	273	4,899	949	32.86
5,419	0	25,006	1,575	0	500	588	77	277	4,508	883	27.34

Source: own