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Research article

Energy efficiency measurement of arrowroot production of Vietnam

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Abstract: Energy efficiency along with friendly agricultural production is becoming one of the priority concerns of many countries in the world including Vietnam. The objective of this study was to estimate energy indicators and to determine the number of optimum energy inputs of arrowroot farms in Backan province regarding different regions and farm categories by using data envelopment analysis (DEA) technique. Findings unveiled that arrowroot farms in Nari district had high energy indicators, i.e., energy ratio, energy productivity, net energy, as compared to other farms in Babe district. The technical and pure technical efficiency and the amount of potential GHG emission reduction found to be higher in Babe district than that in Nari district. Farms in Nari district had opportunities to reduce energy input with slightly higher than that in Babe district (54.54% and 53.61%, respectively). Regarding farm sizes, other than specific energy, small arrowroot farms had the highest energy indicators as compared to other farm size groups. Thus, small farms had the quantity of optimum energy input (392.76 MJ acre^{-1}), saving energy (509.70 MJ acre^{-1}) and amount of GHG emission reduction (4.26 kg $CO_{2\text{-eq}}$/acre) which were more than the others. Based on the results of this study, the suggested solutions to improve the energy efficiency and reduce the adverse effects of arrowroot production to the environment should focus on developing the extension activities as well as short technological training courses for farmers addressing on raising awareness of energy conservation when applying chemical fertilizer and other input factors.

Keywords: energy efficiency; optimum energy data envelopment analysis (DEA); arrowroot farms; Vietnam

1. Introduction

Using energy issues in agricultural production is becoming critically important in the world. In Vietnam, due to the rapid population increase and economic growth, food and energy demand are predicted to triple raising in the future [1]. To meet the food demand, optimal solution is maximum the yield of crop per unit of land, implying that used energy inputs are also increased. Thus, the question is that how to use energy resource efficiently in agricultural production, is usually paid attention by the Vietnamese government.

Arrowroot (*Canna edulis* Ker) is one of staple food for people in South America and Asia region. It was found and used as a conventional food in Andean region since 4000 years ago [2]. With a high quantity of starch, arrowroot starch is often used to make cakes and noodles. In addition, arrowroot tuber also contain important nutritional components, e.g., protein content (0.069–0.078%), lipid (0.014–0.019%), and high amylose content (21–28%) [2,3]. Recently, arrowroot is cultivated popularly in many Asian countries such as Thailand, China, Taiwan, and Vietnam. Arrowroot is considered as one of the economic crops contributing to increase incomes for local people in the Northern mountainous provinces of Vietnam such as Quangninh, Caobang, Hoabinh, Backan, etc. Recently, due to the demand of increasing the yield of arrowroot, farmers are often raise the quantity of energy inputs usage, meaning that the energy consumption in arrowroot increase. Previous studies about arrowroot have only focused on analyzing botanical characteristics [4], nutritional value evaluation [5], and quality of starch which is made from arrowroot [6], and economic efficiency [7]. However, the study on the energy efficiency of arrowroot production in Vietnam has been limited while the question is whether arrowroot cultivation can bring energy efficiency need to address. Besides, increasing food consumption in the world leads to the growth of energy consumption as well as natural resources in agricultural sector. Therefore, the issue of using energy effectively and efficiently is becoming one of the most prominent problems of sustainable agricultural production in many countries including Vietnam. According to the Vietnamese national energy efficiency program, in order to meet the standard of energy security and environmental protection during the period of 2019 to 2030, strategic solutions need to focus on enhancing energy use efficiency, improving energy performance in economic sectors to reduce energy loss and greenhouse emission gas. Thus, the evaluation of energy efficiency which aims to provide the suitable solutions to reduce the energy input usage without sacrificing the output plays a crucial role in sustainable agricultural production of Vietnam.

Data envelopment analysis (DEA) is described as a useful tool and more appropriate to evaluate the performance and show the benchmarking of decision making units (DMUs) with multiples inputs and outputs [8–10]. Other than the econometric methods, in DEA, the linear programming tool is used to convert several inputs into outputs with the aim of seeking the best performance of DMUs compared to other DMUs [11–13].

In recent years, employing DEA methodology to measure the efficiency of energy use in agricultural production was conducted for various crops in many countries around the world, e.g., corn [14,15], rice [16,17], canola [18,19], cucumber [20], orange [11,21,22], grape [23,24], and kiwifruit [25].

To the authors' knowledge, the research on measuring the energy efficiency of arrowroot production is limited. Therefore, this research can fill in the gap in the existing literature by exploring the energy efficiency in arrowroot production in Vietnam. Accordingly, the specific objectives of this study included:

- To evaluate energy efficiency of arrowroot farms in the study area;
- To determine optimum energy inputs and the energy-saving quantity in arrowroot production in Backan province;
- To make policy recommendations to improve the energy efficiency of arrowroot production.

This study provided meaningful information about the energy efficiency of arrowroot production in Vietnam. It is the first study addressed on the energy efficiency analysis of arrowroot production. Therefore, the findings of our paper gave evidences to indicate the negative effects of energy loss in arrowroot production on the natural environment. In addition, the results of this paper are considered valuable literature for the future study.

2. Materials and method

2.1. Data source and research area

This study used the data which were gathered from 346 arrowroot farms in Backan province, Vietnam. Backan province is located in the Northern Vietnam, within 21°48' and 22°44' North latitude, and 105°26' and 105°15' East longitude [26]. Backan has 7 districts and 1 city (Figure 1). All of the regions in Backan cultivated arrowroot as a high-value economy crop and contributing to creating livelihood for locals. Moreover, the natural area of Backan is approximate 486 thousand ha, in which 85% of the area are being mountainous and hilly, meaning that arrowroot production is very suitable for this geographical condition. The survey conducted in two districts, including Nari and Babe, because of the fact that these regions are high ranks in the planted area and producing arrowroot in Backan (500 ha and 366 ha, respectively) [28].

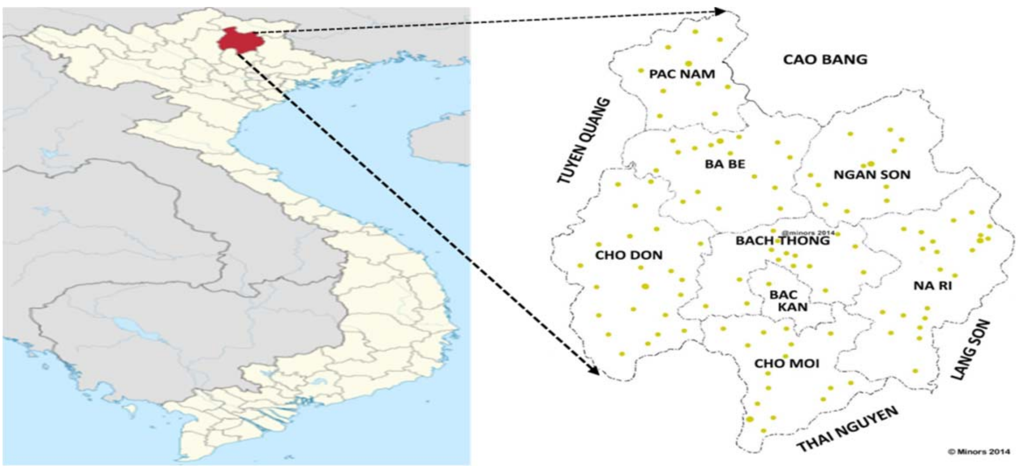

Figure 1. Map of the study location [27].

A direct interview technique was used to conduct survey during the production year of 2017–2018. The data, inputs and output, were converted to energy value equivalent per acre. Input variables used in arrowroot production were human labor, fertilizers, and seed; while the output was the yield of arrowroot. Then, the energy inputs and output were computed by multiplying these inputs and output variables with the coefficient of energy equivalent in Mega Joule (MJ), which was expressed in Table 1.

Table 1. Energy equivalent coefficient of input and output variables.

Variables	Unit	Energy equivalent coefficient (MJ/unit)	Sources
Inputs			
Human labor	h	1.96	[14,16,29]
Fertilizers	kg		[14,19]
Nitrogen		66.14	
Phosphate		12.44	
Seed	kg	4.07	[30]
Output	kg	4.07	[30]
Arrowroot tuber			

2.2. Empirical analysis model

2.2.1. Energy analysis

From the values of energy inputs and output which were computed by using energy equivalent coefficients as indicated in Table 1, the energy ratio in MJ, energy productivity, specific energy and net energy of arrowroot farms under different regions and farm categories were calculated by applying the Eqs as follows from 1 to 4:

$$Energy\ rate = \frac{Output\ energy\ (MJ\ acre^{-1})}{Input\ energy\ (MJ\ acre^{-1})} \tag{1}$$

$$Energy\ productivity = \frac{Arrowroot\ output\ (kg\ acre^{-1})}{Input\ energy\ (MJ\ acre^{-1})} \tag{2}$$

$$Specific\ energy = \frac{Input\ energy\ (MJ\ acre^{-1})}{Arrowroot\ output\ (kg\ acre^{-1})} \tag{3}$$

$$Net\ energy = Output\ energy\ (MJ\ acre^{-1}) - Input\ energy\ (MJ\ acre^{-1}) \tag{4}$$

2.2.2. DEA methodology

In this study, the DEA approach was used to analyze efficiency of the arrowroot farms in Vietnam. In DEA, there are two solutions which can be taken to make an inefficient DMUs to become efficient, namely input-oriented and output-oriented. Input-oriented means refers to that inefficient DMUs can reduce the input usage while the output level is constant. On the other hand, output-oriented means is that inefficient farms can increase the quantity of output holding the input levels intact. In this research, input-oriented based on constant returns to scale (CRS) and variable returns to scale (VRS) models were more suitable to compute technical and pure technical efficiency because only one output was produced while several inputs were used in arrowroot production [11,29]. Moreover, the input-oriented model was used in this research with the aim of minimization input used for the desired output level to be attained. Based on findings of input-oriented, the optimal solution will be implemented to improve the efficiency score.

Based on the CCR (Charnes, Cooper and Rhodes) model which was developed by Cooper [31], the technical efficiency (TE) of arrowroot farms was measured. According to Ali [32] and Mohammadi [9], the TE defines the ability of the farms to use the inputs in optimal proportion to obtain the maximum output. The TE scores range from 0 to 1 where the TE score of 1 indicates that the farm performs the best and locates on the production frontier. In contrast, the TE score is less than one implies that the farmers used input factors inefficiently [33]. The TE can be computed by using the Eq 5 as follow:

$$TE_k = \frac{u_1 y_{1k} + u_2 y_{2k} + \ldots + u_n y_{nk}}{v_1 x_{1k} + v_2 x_{2k} + \ldots + v_m x_{mk}} = \frac{\sum_{r=1}^{n} u_r y_{rk}}{\sum_{s=1}^{m} v_s x_{sk}} \tag{5}$$

where TE^k denotes the TE of the k^{th} of arrowroot farms (k = 1,2,…, n); x and y are the quantity of input and output; u_r and v_s indicate the weight of output and input; s and r are the number of input and output (s = 1,2,…, m; r = 1,2,…, n). Eq 6 reveals a linear programming problem which was investigated by Charnes [34]:

$$\begin{aligned} &Maximize\, \theta = \sum_{r=1}^{n} u_r y_{rk} \\ &Subjected\ to\, (i) \sum_{r=1}^{n} u_r y_{rk} \le \sum_{s=1}^{m} v_s x_{sk} \\ &(ii) \sum_{s=1}^{m} v_s x_{sk} = 1 \\ &(iii)\, u_r\ and\ v_s \ge 0\ for\ all\ r\ and\ s \end{aligned} \tag{6}$$

where θ denotes the technical efficiency. As mentioned by Avkiran [35], the Eq 6 is called the input-oriented CCR model under CRS.

$$\begin{aligned} &Maximize\ z = \sum_{r=1}^{s} u_r y_{r0} - u_0 \\ &Subjected\ to\ (i) \sum_{r=1}^{s} u_r y_{rk} - \sum_{i=1}^{m} v_i x_{ik} - u_0 \le 0, with\, k = 1,2,\ldots,\mathrm{n} \\ &(ii) \sum_{i=1}^{m} v_i x_{i0} = 1 \\ &(iii)\, v \ge 0, u \ge 0, u_0\ free\ in\ sign \end{aligned} \tag{7}$$

According to Banker [36], pure technical efficiency (PTE) is computed by using BCC (Banker, Charnes and Cooper) model under the assumption of VRS. The dual linear program form of BCC

model is expressed as Eq 7 as above follows.
where *z* indicates the scalar and u_0 is the free in sign; *u* and *v* denote the weight of output and inputs, respectively; *x* and *y* denote the input used and output produced, respectively of the k^{th} farm.

2.2.3. Data analysis

Based on empirical models, the DEA Solver Professional version 5.0 software which is designed by SAITECH Inc., USA was applied to calculate the TE and PTE of arrowroot farms. Based on the results of BCC model, optimum energy inputs and the amount of energy saving (MJ/acre) were also computed. To investigate whether there exists difference between districts and farm size categories, this study applied SPSS version 22 software with independent t-test and one-way ANOVA test in order to compare the means between groups.

3. Results and discussion

3.1. Energy efficiency of arrowroot farms in Backan province

Table 2 indicated the average of input used and output produced in two districts of Backan province and their energy equivalent value. The results indicated that the total input and output energy in Nari district were 845.91 MJ acre^{-1} and 5679.79 (MJ acre^{-1}, which were higher than that in Babe district (736.07 and 3954.01 MJ acre^{-1}, respectively). In addition, on average, the seed input made the highest percentage in total energy input in both district with 40.81% and 33.64% for Nari and Babe districts, respectively.

Table 2. Input and output energy used in arrowroot production.

Variables	Nari district (n = 223)		Babe (n = 123)	
	Quantity (Unit/acre)	Energy equivalent (MJ acre^{-1})	Quantity (Unit/acre)	Energy equivalent (MJ acre^{-1})
Inputs				
Human labor (h)	125.18	245.35	88.97	174.39
Chemical Fertilizers (kg)				
Nitrogen	2.91	192.51	3.92	259.42
Phosphate	5.08	63.21	4.39	54.64
Seed (kg)	84.73	344.85	60.84	247.63
Total		845.91		736.07
Output				
Arrowroot tuber (kg)	1395.52	5679.79	971.50	3954.01

By using Eqs 1–4, the energy ratio, energy productivity, specific energy and net energy of arrowroot farms were calculated and the results were revealed in Table 3.

Table 3. The ratio of energy input and energy output in arrowroot production under different regions.

Indicators	Unit	Nari district (n = 223)	Babe district (n = 123)	t-value
Energy input	MJ $acre^{-1}$	845.91	736.07	1.912^{*}
Energy output	MJ $acre^{-1}$	5679.79	3954.01	5.799^{***}
Energy ratio	-	7.39	6.58	2.056^{**}
Energy productivity	kg/MJ	1.82	1.62	2.056^{**}
Specific energy	MJ/kg	0.76	0.81	−0.918
Net energy	MJ $acre^{-1}$	4833.87	3217.94	5.768^{***}

Note: *,**,*** indicate statistical significance at 10%, 5%, 1% level.

The findings showed that there was a significant difference in energy ratio and energy productivity between Nari district and Babe district at 5% level. Arrowroot farms in Nari district had higher energy ratio and energy productivity than farms in Babe district, implying that farms in Nari district used energy inputs more efficiently than other counterparts in Babe district. Moreover, the average energy productivity of arrowroot farms in Nari district was 1.82 kg/MJ compared to 1.62 kg/MJ of Babe district, meaning that arrowroot farms in Nari region can be obtained 1.82 kg tuber by using one unit of energy input, while the output quantity of edible canna tuber by using one unit of energy input of farms in Babe was 1.62 kg.

In addition, the net energy of farms in Nari region was also higher than that of Babe region ($p < 0.01$), implying that, on average, output energy produced by farms in Nari district was higher than that of Babe district. This might be attributed to that the application and allocation of input energy in the arrowroot production in Nari region was more efficient than Babe district.

DEA under both CCR and BCC model were employed to compute the TE and PTE of arrowroot farms in the study area. The results were reported in Table 4.

The findings in Table 4 showed that the TE of arrowroot farms was 0.500 for Nari district and 0.530 for Babe district. This meant that farmers could improve their efficient level by reducing 50% and 47% of energy inputs usage keeping the output constant. Furthermore, the findings illustrated that, on average, arrowroot farms in Backan province had low TE. The number of farms that had technical efficiency less than 0.8 in Nari district was 198 or 88.79% of total farms, and in Babe district was 109 farms or 88.62% of total farms.

Table 4 also revealed that some inefficient arrowroot farms measured in CCR model became efficient under the BCC model. 12.20% of farms in Babe district were become efficient compared to 7.17% of Nari district. However, the percentage of inefficient farms was still high (accounted for 86.99% of total farms). Moreover, the independent t-test results indicated that the inter district comparison of pure technical efficiency between Nari and Babe, was significantly different ($p < 0.05$). On average, Babe district farmers'pure technical efficiency in arrowroot production found to be higher than that of Nari district. The reason may be that farms in Nari district used energy inputs inefficiently or a part of energy inputs lost because the farm size was not appropriate.

Table 4. The frequency distribution of efficiency scores of arrowroot farms (by regions).

Items	TE (CCR model)				
	Nari district (n = 223)	Percentage (%)	Babe district (n = 123)	Percentage (%)	Total
Efficient farms	8	3.59	6	4.88	14
Inefficient farms	215	96.41	117	95.12	332
>0.9	6	2.79	2	1.71	8
0.8–0.9	11	5.12	6	5.13	17
0.7–0.8	10	4.65	13	11.11	23
0.6–0.7	23	10.70	18	15.38	41
0.5–0.6	44	20.46	15	12.82	59
<0.5	121	56.28	63	53.85	184
Mean	*0.500*	-	*0.530*	-	-
	PTE (BCC model)				
Efficient farms	24	10.76	21	17.07	45
Inefficient farms	199	89.24	102	82.93	301
>0.9	8	4.02	8	7.84	16
0.8–0.9	13	6.53	12	11.76	25
0.7–0.8	21	10.55	16	15.69	37
0.6–0.7	29	14.57	11	10.78	40
0.5–0.6	46	23.11	16	15.69	62
<0.5	82	41.21	39	38.23	121
Mean	*0.607***	-	*0.663***	-	-

Note: ** denotes statistical significance at 5% level.

Based on the results of DEA-BCC model, the optimum energy input and the quantity of energy saving were computed and presented in Table 5. The result indicated that average optimal level total energy input for arrowroot farms in Nari found to be higher than that in Babe region, i.e., 384.53 MJ acre^{-1} for Nari district and 341.45 MJ acre^{-1} for Babe district. The difference was statistically significant at 10% level.

Total saving energy of farms in Nari district was found to be 461.39 MJ acre^{-1} (accounted for 54.54% of total energy input) compared to 394.61 MJ acre^{-1} (accounted for 53.61% of total energy input) in Babe district, meaning that farmers need to reduce about 53.61 to 54.54% of energy input respectively in Nari and Bade districts to improve their energy efficiency in arrowroot production. Moreover, the findings were also showed that chemical fertilizer inputs, i.e., nitrogen and phosphate, had the highest contribution to total saving energy with 54.59% and 39.51% in Babe and Nari district, respectively. This revealed that the energy efficiency of arrowroot farms would be improved by reducing the consumption of chemical fertilizers in production. The energy of chemical fertilizer made a major percentage in the total saving energy was also discovered by Chauhan [37], Mohammadi [9] and Nabavi-Pelesaraei [11].

Table 5. The energy input target and saving energy for arrowroot production in Backan province, Vietnam.

Items	Inputs	Nari	Babe	t-value
Optimum energy input (MJ/acre)	Human labor	133.79	98.86	4.369***
	Fertilizer			
	Nitrogen	52.86	77.47	−3.039***
	Phosphate	20.59	21.16	−0.191
	Seed	177.29	143.96	2.996***
	Total	384.53	341.45	1.773*
Saving energy (MJ/acre)	Human labor	111.56	75.53	3.295***
	Fertilizer			
	Nitrogen	139.65	181.94	−1.497
	Phosphate	42.62	33.47	1.530
	Seed	167.56	103.67	2.277**
	Total	461.39	394.61	1.286
Contribute to the total saving energy (%)	Human labor	24.18	19.14	-
	Fertilizer			
	Nitrogen	30.27	46.11	-
	Phosphate	9.24	8.48	-
	Seed	36.31	26.27	-
	Total	100.00	100.00	-

Note: *, **, *** indicate statistical significance at 10%, 5%, 1% level.

3.2. Energy efficiency of arrowroot farms under different farm size

The difference in energy inputs and output of arrowroot farms by farm categories was shown in Table 6. The results indicated that small arrowroot farms in Backan province had the highest energy input (902.45 MJ $acre^{-1}$) compared to 519.19 MJ $acre^{-1}$ for larger farms and 502.07 MJ $acre^{-1}$ for medium farms. Chemical fertilizers and seed accounted for a major energy input in arrowroot production, with 71.52%, 75.37%, and 81.14% for small, medium, and large farm size, respectively. In addition, on average, small farms had the highest energy output equivalent (5794.83 MJ $acre^{-1}$); while the energy output produced by medium and larger farms were 3192.87 MJ $acre^{-1}$ and 2640.94 MJ $acre^{-1}$, respectively.

The results of the analysis of energy indicators of arrowroot farms in Backan province by different farm categories were presented in Table 7. The findings indicated that there was a significant difference in the amount of energy input, output and net energy among arrowroot farm groups at 1% level. On average, small farms had the highest net energy of 4892.37 MJ $acre^{-1}$; while the large farms had the lowest quantity of 2121.75 MJ $acre^{-1}$. This may be attributed to that small arrowroot farms could produce a higher energy output per energy input unit compared to other groups.

Table 6. The amount of energy inputs and output used in arrowroot production (by farm size).

Inputs and output	Small farm size (<9.0 acres; n = 261)		Medium farm size (9.0–15.0 acres; n = 29)		Large farm size (>15.0 acres; n = 56)	
	Quantity (Unit/acre)	Energy equivalent (MJ acre^{-1})	Quantity (Unit/acre)	Energy equivalent (MJ acre^{-1})	Quantity (Unit/acre)	Energy equivalent (MJ acre^{-1})
Inputs						
Human labor (h)	131.16	257.07	63.09	123.66	49.95	97.90
Fertilizer (kg)						
Nitrogen	3.43	227.09	2.04	134.60	3.15	208.29
Phosphate	5.53	68.84	2.62	32.58	2.73	34.00
Seed (kg)	85.86	349.46	51.90	211.24	43.98	179.00
Total	-	902.45	-	502.07	-	519.19
Output						
Arrowroot tuber (kg)	1423.79	5794.83	784.49	3192.87	648.88	2640.94

Furthermore, the ratio of energy was the highest for small groups of 7.27, followed by the medium of 7.19, and 6.25 for the large. This finding was in line with Nassiri and Singh [16]; they pointed out that the energy ratio of small farms was the highest, followed by marginal farms, the semi-medium, the medium and the large. However, the specific energy of small farms, which was the ratio of energy input and output produced, was found to be lowest of 0.77 compared to that of the medium and the large of 0.80 and 0.81, respectively, in this study.

Table 7. The energy indicators of arrowroot farms (by farm size).

Indicators	Unit	Small farm size (<9.0 acres; n = 261)	Medium farm size (9.0–15.0 acres; n = 29)	Large farm size (>15.0 acres; n = 56)
Energy input	MJ acre^{-1}	902.45^{a}	502.07^{c}	519.19^{b}
Energy output	MJ acre^{-1}	5794.83^{a}	3192.87^{b}	2640.94^{c}
Energy ratio	-	7.27^{a}	7.19^{a}	6.25^{a}
Energy productivity	kg/MJ	1.79^{a}	1.77^{a}	1.54^{a}
Specific energy	MJ/kg	0.77^{a}	0.80^{a}	0.81^{a}
Net energy	MJ acre^{-1}	4892.37^{a}	2690.80^{b}	2121.75^{c}

Note: Means followed by the different lower case letters in the same row are significant at 5%.

The frequency distribution of TE and PTE of arrowroot farms under different farm size was presented in Table 8. The results of the DEA-CCR model showed that large farms had the highest TE of 0.714, followed by the medium of 0.540 and the small of 0.500. In other words, to improve the current efficiency, large farms need to reduce 28.6% of energy input usage while the reduction rates for medium and small farms were higher, with 46.0% and 50.0%, respectively. The results of the one-way ANOVA test indicated that the average TE of farm groups was significant difference at 1% level.

In addition, under BCC model, the PTE score of large farms were found to be higher than that of the medium and the small. The PTE scores of the large, the medium and the small were 0.820, 0.785, and 0.603, respectively. The ANOVA test revealed that the difference between PTE scores among groups was significant at 1% level.

Table 8. Frequency distribution of efficiency scores of arrowroot farms (by farm size).

Items	TE (CCR model)			
	Small farm size (<9.0 acres; n = 261)	Medium farm size (9.0–15.0 acres; n = 29)	Larger farm size (>15.0 acres; n = 56)	Total
Efficient farms	9	4	12	25
Inefficient farms	252	25	44	321
>0.9	7	1	5	13
0.8–0.9	12	1	5	18
0.7–0.8	13	1	7	21
0.6–0.7	28	4	8	40
0.5–0.6	52	1	6	59
<0.5	140	17	13	170
Mean	*0.500^{c}*	*0.540^{b}*	*0.714^{a}*	-
	PTE (BCC model)			
Efficient farms	24	7	24	55
Inefficient farms	237	22	32	291
>0.9	15	3	4	22
0.8–0.9	10	4	6	20
0.7–0.8	25	4	6	35
0.6–0.7	35	4	3	42
0.5–0.6	54	6	6	66
<0.5	98	1	7	106
Mean	*0.603^{c}*	*0.785^{b}*	*0.820^{a}*	-

Note: Means followed by the different lower case letters in the same row are significant at 5%.

On the other hand, the results of the input-oriented BCC model in terms of the energy input target and saving energy quantity were presented in Table 9.

The findings revealed that there was a significant difference in the total optimum energy requirement among three farm groups at 1% level. The total optimum energy requirement of small arrowroot farms was the highest of 392.76 MJ acre^{-1}, followed by the large farms group of 350.31 MJ acre^{-1} and the medium group of 297.68 MJ acre^{-1}.

Moreover, the total saving energy of the small farms was found to be 509.70 MJ acre^{-1} (56.48% of total energy input) compared to 204.41 MJ acre^{-1} (40.71% of total energy input) and 168.88 MJ acre^{-1} (32.53% of total energy input) for the medium and the large, respectively. The findings also indicated that the majority quantity of energy-saving of farm categories was from chemical fertilizer inputs, i.e., nitrogen and phosphate. The reason may be that farmers were lack of knowledge of applying optimal amount of chemical fertilizer in arrowroot production. Therefore, training activities aim to increase the awareness of farmers in application of chemical fertilizers may play a vital role in reducing not only the loss of energy input; but also the adverse effects of chemical overuse in arrowroot production to the natural environment. The findings were confirmed by Mohammadi [9] as well.

Table 9. The optimum energy and energy-saving for arrowroot production (by farm size).

Items	Inputs	Small farm size (<9.0 acres; n = 261)	Medium farm size (9.0–15.0 acres; n = 29)	Larger farm size (>15.0 acres; n = 56)
Optimum energy input (MJ/acre)	Human labor	140.41^{a}	86.34^{b}	75.78^{bc}
	Fertilizer			
	Nitrogen	49.60^{bc}	77.51^{b}	126.18^{a}
	Phosphate	20.10^{a}	15.35^{a}	19.57^{a}
	Seed	181.65^{b}	118.48^{c}	128.78^{ac}
	Total	*392.76^{a}*	*297.68^{b}*	*350.31^{a}*
Saving energy (MJ/acre)	Human labor	116.66^{a}	37.32^{b}	22.12^{bc}
	Fertilizer			
	Nitrogen	177.49^{a}	57.09^{b}	82.11^{bc}
	Phosphate	47.74^{a}	17.23^{b}	14.43^{bc}
	Seed	167.81^{a}	92.77^{ab}	50.22^{b}
	Total	*509.70^{a}*	*204.41^{bc}*	*168.88^{c}*
Contribute to the total saving energy (%)	Human labor	22.89	18.26	13.10
	Fertilizer			
	Nitrogen	34.82	27.93	48.62
	Phosphate	9.37	8.43	8.54
	Seed	32.92	45.38	29.74
	Total	*100.00*	*100.00*	*100.00*

Note: Means followed by the different lower case letters in the same row are significant at 5%.

3.3. The potential reduction of greenhouse gases (GHG) emission of arrowroot production in Backan

The evaluation of the quantity of GHG emission aims to investigate the effect of arrowroot production on environment more detail. This study applied GHG emission coefficients which used for agricultural inputs [20] to compute the GHG reduction in arrowroot production. The results of potential GHG emission reduction were expressed in Table 10.

The findings showed that there was a difference in potential reduction of GHG emission between regions and farm size categories. This may be due to the difference in using and management inputs of farms in regions. Regarding to regions, the results revealed that farms in Babe district have more potential reductions in GHG emission than farms in Nari district (4.11 kg $CO_{2\text{-eq}}$/acre and 3.43 kg $CO_{2\text{-eq}}$/acre, respectively). On the other words, farms in Babe and Nari district could improve their energy efficiency in arrowroot cultivation by reducing 4.11 kg $CO_{2\text{-eq}}$/acre and 3.43 kg $CO_{2\text{-eq}}$/acre of GHG emission. By farms size, the results showed that the potential GHG reduction of small farms found to be higher than other farm groups. The reason may be because the unbalance in allocating chemical fertilizer of small farms in production which leads to reduce the energy efficiency level of farms. Therefore, to improve the energy efficiency level in arrowroot production, small farms could reduce the amount of GHG emission by 4.26 kg $CO_{2\text{-eq}}$/acre compared to 1.40 kg $CO_{2\text{-eq}}$/acre and 1.85 kg $CO_{2\text{-eq}}$/acre in other farms.

Table 10. Potential reduction of GHG emission in arrowroot production.

Regions/farm size	N	Current GHG emission (kg $CO_{2\text{-}eq}$/acre)	Target GHG emission (kg $CO_{2\text{-}eq}$/acre)	Potential GHG reduction (kg $CO_{2\text{-}eq}$/acre)
By district				
Nari	223	4.80	1.37	3.43
Babe	123	5.98	1.86	4.11
By farm size				
Small farm size	261	5.57	1.31	4.26
Medium farm size	29	3.17	1.77	1.40
Large farm size	56	4.64	2.79	1.85

4. Conclusions

In this study, the technical efficiency and energy ratio of arrowroot farms in Backan province were evaluated by using the DEA approach. First, regarding regions, the findings explored that there was a significant difference in using energy input of arrowroot farms between Nari and Babe district. The total energy consumption of farmers in Nari district was found to be higher than that in Babe district. However, energy ratio, energy productivity and net energy of farms in Nari district were discovered to be higher than the counterparts in Babe district. The results of DEA under CCR and BCC model indicated that the technical and pure technical efficiency of farms were low for both districts. Therefore, if farms operate efficiently, overall, 461.39 MJ $acre^{-1}$ and 341.45 MJ $acre^{-1}$ will be saved in arrowroot production in Nari and Babe district, respectively.

Second, in terms of farm categories, the results indicated that energy indicators of small farm sizes were found to be higher than other size categories. However, due to the high energy loss rate, technical efficiency and pure technical efficiency of small farms was the lowest as compared to other farm size categories. Therefore, small farms need to reduce a higher amount of GHG emission (4.26 kg CO2-eq/acre) than other groups to improve their energy efficiency.

It can be concluded that energy input consumption in the arrowroot production in Backan province was not efficient. This leads to a damaging impact on the natural environment. Therefore, to improve energy efficiency in arrowroot cultivation, the policy should address on technical assistance and information provision to farm managers to raise awareness of farmers in applying energy inputs efficiently. Furthermore, advanced technology should also be encouraged in arrowroot production to decrease the use of bad inputs while holding the output quantity intact. In other words, the suggestion policies of government should aim at developing the training activities and transfer technology which can help to improve the energy efficiency; along with it, the adverse effects of chemical fertilizer overuse in arrowroot production to the environment can be reduced in Backan province. In addition, expanding farm size should be applied in arrowroot production of Backan province to reduce energy loss rate and improve the efficiency level of farms.

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Conflict of interest

The authors declare no conflict of interest.

Author contributions

Hien Thi Vu, Ke-Chung Peng and Rebecca H. Chung were responsible for research design, building the framework for the study, data analysis, editing and writing this paper. Huong Thi Dao, Trung Quang Ha and Giang Thi Nguyen joined as interviewers in conducting survey in Vietnam.

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