Energy productivity and efficiency of the 'gher' (prawn-fish-rice) farming system in Bangladesh

Rahman, S. ORCID: https://orcid.org/0000-0002-0391-6191 and Barmon, B. K. (2012) Energy productivity and efficiency of the 'gher' (prawn-fish-rice) farming system in Bangladesh. Energy, 43 (1). pp. 293-300. ISSN 0360-5442 doi: https://doi.org/10.1016/j.energy.2012.04.027 Available at https://centaur.reading.ac.uk/105914/

To link to this article DOI: http://dx.doi.org/10.1016/j.energy.2012.04.027

Publisher: Elsevier

EGY-D-11-02372.R1

(Revised version incorporating all comments of the referees)

Energy productivity and efficiency of the '*gher*' (prawn-fish-rice) farming system in Bangladesh

Sanzidur Rahman

School of Geography, Earth and Environmental Sciences, University of Plymouth, UK

Basanta K. Barmon

Department of Economics, East West University, Dhaka, Bangladesh

Address for correspondence

Dr. Sanzidur Rahman

Associate Professor in Rural Development

School of Geography, Earth and Environmental Sciences

Plymouth University

8-11 Kirkby Place,

Drake Circus

Plymouth, PL4 8AA

United Kingdom

Phone: +44-1752-585911

Fax: +44-1752-585998

E-mail: srahman@plymouth.ac.uk

February 2012

Energy productivity and efficiency of the ‘G*her*’ (prawn-fish-rice) farming system in Bangladesh

ABSTRACT

‘Gher’ farming is a unique system that incorporates the joint operation of three enterprises: freshwater prawn, fish and HYV rice, and is expanding rapidly in the coastal regions of Bangladesh because of its proven high income earning potential. In this paper, the sustainability of this system is evaluated by analysing its performance in terms of energy use by applying a stochastic distance function approach which revealed interesting and unexpected results. The prawn enterprise which is the key income earning component is found to be technically inefficient while the rice enterprise is found to be efficient. The net energy balance and the energy use efficiency of the ‘gher’ farming system is estimated at 18,510 MJ ha^{-1} *and 1.72 respectively. The ‘gher’ farmers are operating at a very high level of technical (energy) efficiency (92%). Diversification amongst enterprises is associated with technical (energy) inefficiency. However, larger operation size enhances efficiency. The key policy implication is that the ‘gher’ farming system can be sustained in the long run provided that productivity from the rice enterprise remains high. Also, policies to support the expansion of ‘gher’ farm sizes will improve efficiency.*

JEL classification: O33; Q18; C21

Key Words: Energy productivity, energy efficiency, ‘gher’ farming system, Bangladesh

1. Introduction

Energy serves as the major player for development in Bangladesh as elsewhere in the world. It is also one of the most critical as well as deficient resources in Bangladesh affecting all spheres of life including agricultural development. For the past four decades, since the birth of Bangladesh, lopsided development efforts without proper concerns for the environment as well as declining productivity levels of the resource bases have led to unprecedented crises in various sectors of the economy. The energy sector also faces a severe crisis in meeting the increasing demands for domestic, industrial, transportation, agricultural and other uses [1]. In the agricultural industry, efficient use of available energy resources is crucial to becoming competitive in the world market, increase productivity of the sector as well as aggregate production of crops [2]. Energy is one of the most important elements in agricultural production as it is used in various forms, e.g., farm machinery, human power, draft animal power, electricity and diesel, inorganic fertilizers and pesticides.

Systematic in-depth information on energy use in the agricultural sector of Bangladesh is highly limited. The World Resources Institute reveals that the share of commercial energy use in agriculture constituted only 3.2% (0.467 mmtoe) of total energy produced (14.793 mmtoe) in 1999 [3]. Bain [4] noted that the energy intensity (i.e., commercial energy/GDP ratio) in Bangladesh agriculture has increased steadily from 0.36 in 1977 to 1.87 in 2000. However, Khosruzzaman et al. [5] noted that the energy intensity in the agricultural sector has increased from only 1.78 in 2000 to a high of 11.31 in 2008, revealing that the sector is becoming energy intensive, thereby, adding further a crisis to the existing problem of acute energy deficiency in the economy. The surge in the level of energy use in agriculture has increased manifold largely due to the widespread diffusion of the rice-based ‘Green Revolution’ technology which is highly energy intensive as the technology is characterized by the use of inorganic fertilizers, pesticides, supplementary irrigation (using diesel or electricity operated shallow and/or deep tube wells) and increased use of power tillers in recent years.

Although the economy of Bangladesh is dominated by agriculture, aquaculture is gaining in importance in recent years. Bangladesh is considered as one of the most suitable countries in the world for freshwater prawn (*Macrobrachium rosenbergii*) farming, because of its favourable resources and agro-climatic conditions. A sub-tropical climate and a vast area of shallow water bodies provide a unique opportunity for freshwater prawn production [6]. Within the overall agro-based economy in Bangladesh, *M. rosenbergii* farming is currently one of the most important sectors. During the last three decades, its development has attracted considerable attention due to its export potential. Almost all of the freshwater prawns produced are exported, particularly to the USA, Europe and Japan [7]. In 2007-08, Bangladesh exported 49,317 tons of prawns and shrimps[1] valued at US$415 million, of which 30% was contributed by prawns [8]. Prawn marketing potentially provides high economic returns and social benefits to thousands of rural poor and is seen as a major new vehicle to raise the standard of living of the farming population, particularly those residing in the coastal regions of Bangladesh. In fact, over the past three decades, the productivity of prawn/shrimp farming has improved significantly, currently estimated at 398 kg/ha/year and 452 kg/ha/year in the Chittagong and Khulna regions, respectively [9]. These two regions cover approximately 750 km of coastline in Bangladesh and contribute 97% of the total prawn/shrimp production [9].

A unique feature of the 'gher' farming system is use of a wide variety of inputs, particularly diverse feed ingredients, some of which are naturally sourced. Although there is no dispute about the financial superiority of this farming technology, there is no literature that has explored performance of this system with respect to energy use, more specifically energy productivity and efficiency. A system can be deemed sustainable over the long term if the level of energy output it produces surpasses its energy input levels.

Based on the aforementioned background of the study, the long-term sustainability of this system is evaluated in terms of energy use. More specifically, the present study sets out to estimate: (a) the energy productivity of the 'gher' farming system; (b) technical (energy) efficiency of the system; and (c) the determinants of technical (energy) inefficiency.

---

[1] The term 'shrimp' is used for species in the family *penaeidae*.

The paper proceeds as follows: section 2 briefly describes the ‘gher’ farming system; section 3 describes the analytical framework, study area and the data; section 4 presents the results; and section 5 concludes and draws policy implications.

2. The ‘gher’ farming system

The term ‘gher’ refers to the modification of a rice field to enable the operation of three enterprises: prawn (principal enterprise), fish, and High Yielding Variety (HYV) rice. The middle of the ‘gher’ is surrounded by high and wide dikes with canals dug at the inner periphery of the dikes. The whole area of the ‘gher’ is filled with rain-water during the monsoon season, specifically from June to December, and closely resembles a typical pond. The ‘gher’ becomes dry naturally from January to April except for the canals (see Figure 1).

A typical ‘gher’ cycle begins in June when farmers release freshwater prawn (*M. rosenbergii*) postlarvae into the ‘gher’. Farmers use lime during ‘gher’ preparation to reduce soil acidity. During the growing period, farmers provide supplementary feed to the prawns. Traditionally, snail meat was used as prawn feed, but nowadays farmers use a wide range of homemade and commercially available supplementary feeds to increase production. The fish fingerlings are also released into the ‘gher’ during May-June and are cultured for nine months. Usually, no specific supplementary feed is provided for the fish. Fishes share the feed supplied to the prawns. Between January to April, farmers grow HYV *Boro* rice (dry winter season) on the land inside the ‘gher’, which is irrigated by water from the inside canals using either traditional methods (swing basket) and/or pumps.

3. Methodology

3.1 Data and the study area

This study is based on farm-level cross sectional data for the crop year 2006 collected from Bilpabla[2] located in southern Bangladesh. Bilpabla is one of the typical villages in the Dumuria sub-district of the Khulna District and is located 310 km south of the capital Dhaka.. The village is divided by a small river and the households are located on both sides of the river. The demographic characteristics of the village are very similar to other villages where 'gher' farming is practiced. A total of 90 'gher' farmers were randomly selected. The survey was conducted for a period of six months from November 2006 to April 2007. The survey questionnaire was pretested prior to the interviews with the 'gher' farmers.

3.2 Analytical framework

The analytical framework consists of two approaches: (a) an accounting approach that provides some basic measures of energy productivity, energy use efficiency, and net energy balance seen commonly in the energy literature [2, 10, 11, 12, 13, 14]; and (b) an econometric estimation of the productivity and technical (energy) efficiency of the system. The details are as follows.

3.2.1 The energy accounting approach

Standard energy input output analysis [10, 11, 12, 13] is used to estimate some basic measures of this unique system. These are: energy use efficiency, energy productivity, specific energy and net energy (i.e., energy balance). These are defined as [12]:

$$\text{Energy use efficiency} = \text{Energy output MJ ha}^{-1}/\text{Energy input MJ ha}^{-1} \qquad (1)$$

$$\text{Energy productivity} = \text{Output kg ha}^{-1}/\text{Energy input MJ ha}^{-1} \qquad (2)$$

$$\text{Specific energy} = \text{Energy input MJ ha}^{-1}/\text{Output t ha}^{-1} \qquad (3)$$

$$\text{Net energy} = \text{Energy output MJ ha}^{-1} - \text{Energy Input MJ ha}^{-1} \qquad (4)$$

---

[2] Bilpabla village was selected purposively because the farmers have long years of experience of the 'gher' farming system.

We have applied an ex-post analysis to the level of energy inputs and outputs derived from this farming system, as we have a detailed breakdown of all the quantities of inputs used and outputs produced. We have used the standard energy coefficients from the existing published literature [2, 10, 11, 12, 13, 14] for conversion. For some inputs and outputs whose energy equivalents are not available we have computed using our best possible judgement and in consultation with the academics of the Faculty of Agricultural Engineering, Bangladesh Agricultural University, Mymensingh.

Specifically, the production energy for power tiller and shallow tube wells were calculated as follows [13]:

$$M_{pe} = (GM_p)/(TW) \quad (5)$$

where M_{pe} is the energy of the machine per unit area, MJ ha^{-1}; G is the mass of machine, kg; M_p is the production energy of machine, MJ kg^{-1}; T is the economic life, h; and W is the effective field capacity, ha h^{-1}.

The diesel energy requirement was determined on the basis of fuel consumption, l h^{-1}. The data were converted into energy units and expressed in MJ ha^{-1}. The following equation was used in the calculation of fuel consumption [12]

$$FC = P_m.R.SFC \qquad (6)$$

where FC is the fuel consumption, l h^{-1}; P_m is the machine power, kW; R is the loading ratio, decimal; and SFC is the specific fuel consumption (0.25 l kWh^{-1}).

Table 1 presents the energy coefficients used in this study including literature sources.

3.2.2 The econometric approach: the stochastic input distance function model

Since ‘gher’ farming is an integrated system, a multi-output, multi-input production technology specification is required as opposed to the commonly used single-output, multi-input production technology. The use of a distance function approach (either output-orientated or input-orientated) circumvents this problem and can be analyzed using either parametric or non-parametric methods. Also, the main advantage of a distance function approach is that the production frontier can be estimated without assuming separability of inputs and outputs [15]. We have selected the use of an input-orientated stochastic distance function to address these research questions. This is because, in an economy like Bangladesh, on the one hand, inputs are highly scarce, and on the other hand, farmers are often constrained by cash/credit [16]. Therefore, it is logical to assume that economizing in the use of inputs is the prime concern.

We begin by defining the production technology of 'gher' farm using the input set, L(y), which represents the set of all input vectors, $x \in R_+^K$, which can produce the output vector $y \in R_+^M$. That is,

$$L(y) = \{x \in R_+^K : x\, can\, produce\, y\} \qquad (7)$$

The input-distance function is then defined on the input set, L(y), as

$$D_I(x, y) = \max\{\rho : (x/\rho) \in L(y)\} \qquad (8)$$

$D_I(x,y)$ is non-decreasing, positively linearly homogenous and concave in *x*, and increasing in *y*. The distance function, $D_I(x,y)$, takes a value which is greater than or equal to one if the input vector, *x*, is an element of the feasible input set, *L(y)* [$D_I(x,y) \geq 1$ if $x \in L(y)$]. Furthermore, the distance function is unity if *x* is located on the inner boundary of the input set. Thus, the input distance function can be interpreted as the multi-input input-requirement function allowing for deviations (distance) from the frontier, which are interpreted in terms of technical efficiency [17].

3.2.3 The empirical model

The empirical model is specified using a translog stochastic input distance function allowing for interactions. However, in order to preserve the degrees of freedom, we have allowed all input interactions and output interactions but did not allow interactions between inputs and outputs[3]. All the variables were mean-corrected prior to estimation, so that the coefficients of the first-order terms can be directly interpreted as elasticities or marginal effects. The (partial) translog stochastic input distance function, dropping the j^{th} subscript for individual farms, is specified as:

$$\ln d = \alpha_0 + \sum_{i=1}^{4} \alpha_i \ln X_i + \frac{1}{2}\sum_{i=1}^{4}\sum_{j=1}^{4} \alpha_{ij} \ln X_i \ln X_j + \sum_{k=1}^{3} \beta_k \ln Y_k + \frac{1}{2}\sum_{k=1}^{3}\sum_{l=1}^{3} \beta_{kl} \ln Y_k \ln Y_l \qquad (9)$$

where Xs are inputs and Ys are outputs all presented in energy units. The four inputs used in the analyses are: X_1 = energy from all machinery (i.e., power tiller for land preparation and shallow tube wells for irrigation), X_2 = energy from male and female human labour input (family supplied + hired), X_3 = energy from all feeds, seeds, and fingerlings, and X_4 = energy from chemicals (fertilizers and pesticides). The three outputs are: Y_1 = energy produced by prawn, Y_2 = energy produced by fish, and Y_3 = energy produced by HYV rice and straw.

Following Coelli and Perelman [18], we set $-\ln d = v - u$, and impose the restriction required for homogeneity of degree +1 in inputs $(\sum_{i=1}^{4} \alpha_i = 1)$ to obtain the estimating form of the stochastic input distance function (i.e., normalizing the input vectors by any one of the inputs, specifically the land input X_1):

$$\begin{aligned} -\ln X_1 = \alpha_0 &+ \sum_{i=2}^{4} \alpha_i \ln\left(\frac{X_i}{X_1}\right) + \frac{1}{2}\sum_{i=2}^{4}\sum_{j=2}^{4} \alpha_{ij} \ln\left(\frac{X_i}{X_1}\right)\ln\left(\frac{X_j}{X_1}\right) + \sum_{k=1}^{3} \beta_k \ln Y \\ &+ \frac{1}{2}\sum_{k=1}^{3}\sum_{l=1}^{3} \beta_{kl} \ln Y_k \ln Y_l + v - u \end{aligned} \qquad (10)$$

where the *v*s are assumed to be independently and identically distributed with mean zero and variance, σ_u^2; and the *u*s are technical efficiency effects that are assumed to be identically

---

[3] Coelli and Fleming [19] applied a more restrictive translog specification allowing for only output interactions (presumably to preserve degrees of freedom) and called it a (partial) translog model.

distributed such that u is defined by the truncation at zero of the normal distribution with unknown variance, σ_u^2, and unknown mean, μ, defined by:

$$\mu = \delta_0 + \sum_{d=1}^{6} \delta_d Z_d \qquad (11)$$

where Z_1 = Ogive index of output concentration (number); Z_2 = age of the farmer; Z_3 = education of farmer (years of completed schooling), Z_4 = amount of 'gher' area (ha), Z_5 = dependency ratio (proportion); and Z_6 = share of female labour input (proportion).

Justification of including these Z variables to identify the significant determinants of technical (energy) efficiency of the 'gher' farming system is as follows. We have selected the Ogive (pointed arch) index, which provides a measure of concentration of output shares of the enterprises, to see whether diversification amongst enterprises has an effect on technical efficiency.

The Ogive index is defined as:

$$Ogive = \sum_{n=1}^{N} \frac{(Y_n - (1/N))^2}{1/N} \qquad (12)$$

where N is the total number of production enterprises under consideration and Y is the share of the *n*th enterprise to total energy output. An Ogive value of 1/N indicates perfect diversification of output among enterprises.

In Bangladesh, land ownership serves as a surrogate for a number of factors as it is a major source of wealth and influences crop production [20]. The size-productivity relationship in Bangladesh varies across regions depending on the level of technological development and environmental opportunities. The relationship is positive in technologically advanced regions, whereas the classic inverse relationship still exists in backward areas [21]. We included the 'amount of 'gher' area operated' to test whether size of operation in this farming system influences technical efficiency. This is because Islam et al. [22] reported that ‘gher’ size has an influence on total production with smaller ‘ghers’ managing to yield higher production.

Use of the education level of farmer as a technical efficiency shifter is fairly common [16, 23, 24]. The education variable is also used as a surrogate for a number of factors. At the technical level, access to information as well as capacity to understand the technical aspects related to production is expected to improve with education, thereby, influencing technical efficiency. Age of the farmer is used as the proxy for experience in farming which is also common in the literature [19, 25].

According to the Chayanovian theory of the peasant economy, higher subsistence pressure increases the tendency to adopt new technology and this has been found to be the case in Bangladesh [20]. The subsistence pressure variable (defined as the dependency ratio = family size per household/number of working members) was incorporated to test whether it influences technical efficiency as well [24].

A commonly held view on women's involvement in agricultural production in Bangladesh is that they are involved only in the post-harvest processing of crops, thereby, underestimating their contribution to national economy [26]. However, in the ‘gher’ farming system, female labour use is evident (see Table 2). An argument often used against women farmers is that they are less efficient as compared to their male counterparts [27]. Whether women are more or less efficient than men in farming is a hotly debated issue and results vary [28]. Rahman [26] found significant influence of female labour input share on technical efficiency in crop farming in Bangladesh. In this study, following Rahman [26] we have used the share of female labour input in total labour as the technical efficiency shifter.

3.2.4 Performance measures from the input distance function

A number of performance measures can be developed from an input distance function. The combined first-order input elasticities represent scale economies showing the extent to which productivity increases with input growth. The second-order elasticities reflect production complementarities that reflect economic impacts from output jointness [17]. Specifically, for the input distance function, the **X-Y** scale economy relationship is represented by the sum of individual input elasticities and reflects how much overall input use must increase to support a 1% increase in all outputs. Formally, the individual input elasticity summarizing the input expansion required for a 1% increase in Y_k is $\varepsilon_{D,Yk} = \partial \ln D / \partial \ln Y_k = -\partial \ln X_1 / \partial \ln Y_k = -\varepsilon_{Yk}$. Such a measure can be thought of as an "input share" of Y_k (relative to X_1). In combination, these elasticties represent scale economies: $\varepsilon_{D,Y} = \sum_k \partial \ln D / \partial \ln Y_k = -\sum_y \partial \ln X_1 / \partial \ln Y_m = -\sum_y \varepsilon_{Y_m} = -\varepsilon_Y$. The extent of scale economies (for proportional changes in all inputs) is implied by the short-fall of ε_Y from [17].

The first-order elasticities ε_{Yk} *and* ε_Y can also be decomposed into second-order effects reflecting output compositions as scale expands. This information is implied by technological bias measures indicating how the Y_k input elasticity or share (ε_{Yk}) reflects a change in another output. Such measures provide insights about the output jointness of the production system. Specifically, $\varepsilon_{Yk,Yl} = \partial \varepsilon_{Yk} / \partial \ln Y_l$ represents the increase in the Y_m input share as Y_l increases. If $\varepsilon_{Yk,Yl} > 0$, output jointness or complementarity is implied; that is, input use does not have to increase as much to expand Y_k if the Y_l level is greater. This elasticity is represented by the cross-output coefficient estimate $\beta_{kl} : \varepsilon_{Yk,Yl} = \beta_{kl} = \varepsilon_{Yl,Yk}$ [17].

We follow Battese and Corra [29] in replacing the variance parameters, σ_v^2 and σ_u^2, with $\gamma = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2)}$ and $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$ in the estimating model. The input distances are predicted as [18]: $d = E[\exp(u) \mid e]$, where $e = v - u$. The inverse of these input distances *(d)* are the technical efficiency scores of each individual farm, which have a feasible range from zero to unity, with unity being fully efficient [19]. Estimates of the parameters of the model were obtained using maximum likelihood procedures, detailed by Coelli and Perelman [18]. STATA Software Version 8 was used for the analyses [30].

4. Results

4.1 Energy equivalents of inputs and outputs of the 'gher' farming system

Table 2 presents the energy equivalents of inputs used and outputs produced per hectare of the 'gher' farming system. It is clear from Table 2 that the prawn enterprise is the most energy intensive enterprise of the system. The highest level of energy use is due to the use of a large variety of feed ingredients. Also, it is a highly labour intensive enterprise as compared to the rice enterprise (see lower panel of Table 2). The energy produced from the prawn and fish outputs is very low as compared to the level of energy used as inputs, which is an unexpected but interesting result. Energy use level in the rice enterprise is dominated by the use of irrigation and fertilizers, as expected. However, the energy output produced from the rice enterprise is substantially higher than the energy consumed as inputs.

Table 3 presents the results of the accounting approach used to determine the energy performance of the individual enterprises as well as the overall 'gher' farming system. It is clear from Table 3 that the prawn-fish enterprise uses a substantially high level of energy as inputs and produces very little energy as outputs, which has a serious negative implication for its sustainability in the long run. Specific energy use is substantially high, estimated at 49.86 MJ kg^{-1}. On the other hand, the rice enterprise performs very well in this system with a large positive energy balance (80,819.54 MJ ha^{-1}) and very low specific energy use (1.78 MJ kg^{-1}). This is because the inputs used for HYV Boro rice farming within a 'gher' system are significantly lower than the conventional HYV Boro rice production. This is because the unused feed supplied to the 'gher' for the prawns and fishes serves as fertilizers; and irrigation is provided from the water retained in the canals which is a substantial saving. Barmon et al. [31] noted that the costs of labour, fertilizer and irrigation for conventional

HYV Boro rice production system are respectively 35%, 319% and 218% higher than the HYV Boro rice produced within the ‘gher’ farming system. In fact, the specific energy use of HYV Boro rice in ‘gher’ system is far lower than those reported for other cereals, such as maize and wheat [11, 14, 32].

When the overall ‘gher’ farming as a system is considered, the evaluation passes the test of sustainability. The net energy balance is estimated at 18,510 MJ ha^{-1} and the energy use efficiency is estimated at 1.72. This was made possible because of high energy savings in the rice enterprise which has completely offset the negative energy balance of the financially rewarding prawn-fish enterprise.

4.2 Energy productivity of the ‘gher’ farming system

The results of the maximum likelihood estimation (MLE) of the stochastic input distance function model are presented in Table 4. Two sets of hypotheses were tested using Likelihood Ratio tests. First, we tested for the presence of inefficiencies in the model. The parameter γ is the ratio of error variances from Eq. (10). Thus, γ is defined as being between zero and one, where if $\gamma = 0$, technical inefficiency is not present, and where $\gamma = 1$, there is no random noise. The test of significance of the inefficiencies in the model ($H_0: \gamma = \mu = 0$) was rejected at the 5% level of significance, indicating that the MLE is a significant improvement over an Ordinary Least Squares (OLS) specification and inefficiencies are present in the model. The calculated value of the test statistic is 10.63, which is greater than the critical value obtained from Table 1 of Kodde and Palm [33] with three restrictions. Second, we tested the joint significance of all the variables and the null hypothesis ($H_0: \delta_m = 0$ for all m) was rejected at the 10% level of significance. The calculated value of the test statistic is 11.18, which is greater than the critical value of χ^2 with 6 restrictions, implying that the inclusion of these variables to explain inefficiency is justified.

Fifty percent of the estimated coefficients are significantly different from zero at the 10% level at least. The signs of the coefficients on the first order terms of the input and output variables are consistent with theory. For example, a positive coefficient on any input variable implies substitutability of that input with machinery. On the other hand, a negative coefficient on any output variable implies that a reduction in machinery is positively associated with a reduction in that output. The coefficients on a number of interaction variables (second order terms) are also significantly different from zero, thereby, confirming non-linearities in the production process, and hence, justify the use of flexible translog specification. It should be noted that in a flexible translog function model with a large number of inputs and outputs, violation of the regularity condition in some inputs and outputs is unavoidable. Table 4 shows that the energy output from rice enterprise violates the expected regularity conditions but is not significantly different from zero and may not be a true relationship. Another point to note is that the results presented in Table 4 are true at the point of approximation of the translog function.

The individual output contribution underlying the scale elasticity is also presented in Table 4. These elasticities with respect to output in a distance function also represent the cost elasticity of that particular output [34]. Table 4 shows that output elasticities of prawn and fish enterprises are significantly different from zero, implying that increasing the production of any of these outputs will increase energy use substantially (as seen in Tables 2 and 3). The estimate also shows that the energy elasticity of prawn output is 0.22. This means that a 1% increase in prawn output will increase energy use by 0.22%.

Similarly, the elasticities of the distance function with respect to input quantities are equal to the input energy shares and, therefore, reflect the relative importance of inputs in the production process. Table 4 reveals that all the three input elasticities are positive, as expected, and significantly different from zero. The elasticity with respect to human labour is the largest with a value of 0.59, implying that the energy from human labour represents 59% of total energy use at the sample mean for the overall 'gher' farming system.

To further evaluate the implications of our estimates of output complementarities and their contribution to scale economies, we focus on the (second order) cross-effects. These estimates are represented by the cross-parameters of the estimated functions (β_{kl}), reproduced in the mid-panel of Table 4. We see that the prawn and rice enterprise combination is positive and is significantly different from zero at the 5% level, implying complementarities and/or output jointness in the 'gher' farming system [17]. The prawn and fish enterprises also show positive jointness but the coefficient is not significantly different from zero. Overall, these results suggest that significant scope economies exist in Bangladeshi 'gher' farming, which perhaps explains its rapid expansion in coastal areas.

4.5 Technical (energy) efficiencies

The technical (energy) efficiency scores range from 67% to 99%, with a mean score of a high 92% (Table 5). The implication is that 'gher' farmers are already operating at a very high level of technical (energy) efficiency and only 9% of the potential output can be recovered by eliminating technical inefficiency. Since there is no comparable literature on energy efficiency of the 'gher' farming system, we are unable to provide any comparisons. However, our estimate of technical (energy) efficiency is similar to technical (energy) efficiency of rice production in India [14] and canola production in Iran [35]. The distribution of the efficiency score is skewed towards the higher level of efficiency spectrum (Figure 2). About 71% of the farmers are producing at an efficiency level of 90% or higher which is encouraging.

The lower panel of Table 4 provides the results of the inefficiency effects model. The negative coefficient on the Ogive index indicates that technical inefficiency is negatively associated with specialization, which implies that specialization, therefore, significantly improves technical efficiency. This result is at contrast with Rahman et al. [9] but not surprising. This is because we are evaluating the ‘gher’ farming system in terms of its energy use and not on technical/financial merit as was done in Rahman et al. [9]. As seen from Tables 2 and 3, the prawn enterprise is seriously energy inefficient whereas the rice enterprise is highly energy efficient. Therefore, the implication is that a specialization in rice production will be more efficient when energy use is the evaluation criteria. However, it is encouraging to see that an increase in ‘gher’ area improves technical (energy) efficiency, implying that larger operation size will improve efficiency which is at contrast with Islam et al. [22]. This is again because we are evaluating the energy use performance of the system.

5. Conclusions and policy implications

The principal aim of this study was to examine whether the ‘gher’ farming system in Bangladesh, that has experienced remarkable growth over the past two decades, can be sustained in the future. In this study, the ‘gher’ farming technology is evaluated in terms of energy use and it is found that the prawn-fish enterprise is highly inefficient in energy use while the HYV rice enterprise is highly energy efficient. Overall, the net energy balance of the ‘gher’ farming system is estimated at 18,510 MJ ha^{-1} and energy use efficiency at 1.72, implying that the system can be sustained in the long run provided that the energy productivity of the HYV rice enterprise remains high. The ‘gher’ farmers are operating at a very high level of technical (energy) efficiency estimated at 92%, implying that there is little scope to increase output energy substantially by eliminating technical inefficiency in input use. Diversification economy exists between the prawn and rice enterprises as expected, although the diversification of enterprises is negatively associated with technical efficiency. This is because of the overriding influence of a very high level of energy use inefficiency of the prawn-fish enterprise. However, it is encouraging to note that larger operation size significantly improves technical (energy) efficiency.

A key policy implication that emerges from the results of this study is that the ‘gher’ farming system is a sustainable system when evaluated in terms of energy use. Although the prawn-fish enterprise, which is the most financially rewarding component of the system, happens to be highly energy inefficient, the HYV rice enterprise offsets this by being a very high energy efficient component. However, the system will suffer if the physical productivity of the HYV rice enterprise falls or its input use levels increase. Therefore, serious attention must be paid to keep HYV rice productivity high. This can be accomplished by using new strains of HYV rice seed released from the research stations (i.e., Bangladesh Rice Research Institute) which are highly productive as well as disease and weather resistant. Also, attention must be paid to alter the feeding pattern of the prawns since energy used up from the feed ingredients (which are renewable energy sources) constitutes 70% of the total energy used. In addition, measures to enhance ‘gher’ operation size will significantly improve technical (energy) efficiency. Hopefully, the effective implementation of these measures will enable Bangladeshi freshwater prawn industry to be sustained in the long run and raise the welfare of the farming population as well.

References

[1] Government of Bangladesh. *Report of the Task Forces on Bangladesh Development Strategies for the 1990s: Environment Policy*. Volume IV. University Press Limited. Dhaka, Bangladesh. 1991.

[2] Ozkan B, Ceylan RF, Kizilay H. Energy inputs and crop yield relationships in greenhouse winter crop tomato production. *Renewable Energy*, 2011; 36: 3217-3221.

[3] World Resources Institute. Energy and resources Bangladesh, country profile. http://earthtrends.wri.org/pdf_library/country_profiles/ene_cou_050.pdf (accessed on 24/12/2011).

[4] Bain SK. Indicators of energy use and efficiency in Bangladesh. Bangladesh University, Mimeo. 2001. http://bdeconassoc.org/userfiles/pdf/39%20Energy%20------%20Perspectives%20Paper_Subrata%20K%20B.pdf (accessed on 24/12/2011).

[5] Khosruzzaman S, Asgar M, Rehman KMR, Akbar S. Energy intensity and productivity in relation to agriculture: Bangladesh perspective. *Journal of Bangladesh Academy of Sciences*. 2010; 34: 59-70.

[6] Ahmed N, Demaine H, Muir JF. Freshwater prawn farming in Bangladesh: History, present status and future prospects. *Aquaculture Research*, 2008: 39: 806-819.

[7] Ahmed N, Lecouffe C, Allison EH, Muir JF. The sustainable livelihoods approach to the development of freshwater prawn marketing systems in southwest Bangladesh. *Aquaculture Economics and Management*, 2009; 13: 246-269.

[8] Khondaker HR. Prawn hatchery development in Bangladesh: problems and potentials. In: M.A. Wahab and M.A.R. Hossain (eds.), Abstracts – National workshop on Freshwater Prawn Farming in Bangladesh: Technologies for Sustainable Production and Quality Control, 9 July 2009, Dhaka, Bangladesh, p. 11.

[9] Rahman S, Barmon BK, Ahmed N. Diversification economies and efficiencies in a 'Blue-Green Revolution' combination: a case study of prawn-fish-rice farming in the ‘gher’ system in Bangladesh. *Aquaculture International*, 2011; 19:665-682.

[10] Unakitan G, Hurma H, Yilmaz F. An analysis of energy use efficiency in canola production in Turkey. *Energy*, 2010: 35: 3623-3627

[11] Banaeian N, Zangeneh M. Study on energy efficiency in corn production of Iran, *Energy*, 2011; 36: 5394-5402

[12] Mohammadi A, Tabatabaeefar A, Shahin S, Rafiee S, Keyhani A. Energy use and economical analysis of potato production in Iran a case study: Ardabil province. *Energy Conversion and Management*, 2008; 49: 3566-3570.

[13] Canakci M, Topakci M, Akinci I, Ozmerzi A. Energy use pattern of some field crops and vegetable production: Case study for Antalya Region, Turkey. *Energy Conversion and Management*, 2005; 46: 655-666.

[14] Chauhan NS, Mohapatra PKJ, Panday KP. Improving energy productivity in rice production through benchmarking—An application of data envelopment analysis. *Energy Conversion and Management*, 2006; 46: 1063-1085.

[15] Kumbhakar SS, Orea L, Rodriguez-Alvarez A, Tsonias EG. Do we estimate an input or an output distance function? An application of the mixed approach to European railways. *Journal of Productivity Analysis*, 2007; 27: 87–100.

[16] Rahman S. Whether crop diversification is a desired strategy for agricultural growth in Bangladesh. *Food Policy*, 2009; 34: 340-349.

[17] Morrison-Paul CJ, Nehring R. Product diversification, production systems, and economic performance in U.S. agricultural production. *Journal of Econometrics*, 2005; 126, 525-548.

[18] Coelli TJ, Perelman S. A comparison of parametric and non-parametric distance functions: with application to European railways. *European Journal of Operational Research*, 1999; 117: 326-339.

[19] Coelli TJ, Fleming E. Diversification economies and specialization efficiencies in a mixed food and coffee smallholder farming system in Papua New Guinea. *Agricultural Economics*, 2004; 31: 229-239.

[20] Hossain M, Quasem MA, Akash, MM, Jabber, MA, Differential impact of modern rice technology: the Bangladesh case. 1990. Bangladesh Institute of Development Studies, Dhaka.

[21] Toufique KA. Structural constraint to agricultural growth: an explanation of the farm size productivity relationship in Bangladesh. Working Paper. 2001. Bangladesh Institute of Development Studies, Dhaka.

[22] Islam MS, Milstein A, Wahab MA, Kamal AHM, Dewan S. Production and economic return of shrimp aquaculture in coastal ponds of different sizes and with different management regimes. *Aquaculture International*, 2005; 13: 489-500.

[23] Asadullah MN, Rahman S. Farm productivity and efficiency in rural Bangladesh: the role of education revisited. *Applied Economics*. 2009; 41: 17-33.

[24] Wang J, Cramer GL, Wailes EJ. Production efficiency of Chinese agriculture: evidence from Rural Household Survey data. *Agricultural Economics*, 1996; 15: 17–28.

[25] Llewelyn RV, Williams JR. Nonparametric analysis of technical, pure technical, and scale efficiencies for food crop production in East java, Indonesia. *Agricultural Economics*, 1996 15: 113-126.

[26] Rahman S. Women's labour contribution to productivity and efficiency: empirical evidence from Bangladesh. *Journal of Agricultural Economics*, 2010; 61: 318-342.

[27] Food and Agricultural Organization. 1985. *Women in developing country agriculture*. 1985. Rome.

[28] Adesina AA, Djato KK. Relative efficiency of women as farm managers: profit function analysis in Cote d'Ivoire. *Agricultural Economics*, 1997; 16: 47-53.

[29] Battese GE, Corra GS. Estimation of a production frontier model: with application to the pastoral zone of Eastern Australia. *Australian Journal of Agricultural Economics*, 1977; 21: 161-179.

[30] STATA Corp. *Stata Statistical Software: Release 8.0.* Stata Corporation, 2003. College Station, Texas.

[31] Barmon BK, Kondo T, Osanami F. Water productivity of HYV variety of rice production: rice-prawn and year-round rice farming systems in Bangladesh. *Asia-Pacific Journal of Rural Development*, 2008; 18: 99-118.

[32] Mani I, Kumar P, Panwar JS, Kant K. Variation in energy consumption in production of wheat–maize with varying altitudes in hilly regions of Himachal Pradesh, India, *Energy*, 2007; 32: 2336–2339

[33] Kodde D, Palm F. Wald criteria for jointly testing equality and inequality restrictions, *Econometrica*, 1986; 54: 1243-1248.

[34] Irz X, Thirtle C. Dual Technological Development in Botswana Agriculture: A Stochastic Input Distance Function Approach. *Journal of Agricultural Economics*, 2004; 55, 455-478.

[35] Mousavi-Avval SH, Rafiee S, Jafari A, Mohammadi A. Improving energy use efficiency of canola production using data envelopment analysis (DEA) approach. *Energy*, 2011; 36: 2765-2772.

[36] Calorie count website http://caloriecount.about.com/calories-prawns-i76955 (accessed on 01/09/2011).

[37] International Food Policy Research Institute, Food Consumption and Nutrition Division, www.ifpri.org (personal communication)

Appendix

Nomenclature

Boro rice = rice grown in dry winter season (Nov–March) with supplementary irrigation

Dikes = raised boundaries of the ‘gher’ farm (see Figure 1)

‘Gher’ farming = refers to integrated rice-fish-prawn culture.

HYV = high yielding variety

Ogive index = an measure of output concentration from various enterprises

Output jointness = joint production of two or more outputs using same set of inputs

Scale economy = the reduction in cost as plant/operation size expands

Translog function = Transcendental Logarithmic function

Table 1. Energy coefficients for inputs and outputs of the 'gher' farming system

Particulars	Unit	Energy equivalent (MJ unit^{-1})	References
Inputs			
A. Prawn and fish enterprise			
Prawn fingerling	kg	4.40	[36] + calculated
Fish fingerling	kg	4.52	[37]
Egg	kg	6.20	[37]
Vermicelli	kg	5.59	[37]
Fish meal	kg	12.14	[37] + calculated
Meat of snail	kg	3.37	[36]
Oilcake	kg	14.40	[37] + calculated
Broken rice	kg	15.28	[37]
Wheat bran	kg	9.02	[13] + calculated
Flattened rice	kg	14.40	[37]
Pulses	kg	14.11	[37]
Male labour	hour	1.96	[13]
Female labour	hour	1.57	[13]
Output			
Prawn	kg	4.40	[36]
Fish	kg	4.61	[37]
B. HYV rice enterprise:			
Inputs			
Rice seed	kg	15.28	[37]
Power tiller (land preparation)	litre	62.20	Calculated
Irrigation (diesel)	litre	56.31	[12]
Pesticides	litre	120.00	[12]
Nitrogen (N)	kg	66.14	[12]
P_2O_5	kg	12.44	[12]
K_2O	kg	11.15	[12]
Sulphur (S)	kg	1.12	[12]
Output			
Rice	kg	15.28	[37]
Rice Bran	kg	13.23	[37]
Straw	kg	2.25	[37] + computed

Note: IFPRI refers to standard conversion used by the Food Consumption and Nutrition Division of IFPRI to compute calorific and dietary requirements for Bangladesh (personal communication).

Table 2. Energy equivalences of inputs and outputs

Energy source	Mean (MJ ha^{-1})	Standard Deviation
Prawn and Fish enterprise:		
Inputs		
Prawn fingerling	0.90	0.78
Fish fingerling	169.67	266.90
Egg	10.81	23.67
Vermicelli	91.15	94.53
Fish meal	26353.93	43043.37
Meat of snail	5761.79	15238.48
Oilcake	1584.25	4889.02
Broken rice	7930.04	15913.42
Wheat bran	4887.8	6894.20
Flattened rice	1617.45	2660.82
Pulses	7248.91	12667.39
Male labour	12144.57	6226.39
Female labour	1060.3	1099.83
Output		
Prawn	5252.7	4754.34
Fish	1298.83	1045.02
HYV rice enterprise:		
Inputs		
Seed rice	707.06	106.32
Power tiller (land preparation)	900.98	304.32
Irrigation (diesel)	2851.59	1070.78
Pesticides	325.97	52.98
Nitrogen (N)	2509.00	1677.21
P_2O_5	349.64	308.80
K_2O	24.30	73.95
Sulphur (S)	0.48	1.98
Male labour	707.33	204.42
Female labour	114.73	124.60
Output		
HYV rice	59751.51	3726.99
Rice bran	17556.83	1095.82
Straw	12812.75	7062.35

Table 3. Energy input-output ratios in prawn, fish, and HYV rice production

Enterprises	Unit	Mean
Prawn and fish enterprise:		
Energy input	MJ ha^{-1}	68861.56
Energy output	MJ ha^{-1}	6551.54
Yield	kg ha^{-1}	1476.86
Specific energy	MJ kg^{-1}	49.86
Energy use efficiency	-	0.11
Energy productivity	kg MJ^{-1}	0.23
Net energy	MJ ha^{-1}	-62310.03
HYV rice enterprise:		
Energy input	MJ ha^{-1}	9301.55
Energy output	MJ ha^{-1}	90121.09
Yield	kg ha^{-1}	5236.57
Specific energy	MJ kg^{-1}	1.78
Energy use efficiency	-	10.19
Energy productivity	kg MJ^{-1}	0.59
Net energy	MJ ha^{-1}	80819.54
‘Gher’ system as a whole		
Energy input	MJ ha^{-1}	78163.11
Energy output	MJ ha^{-1}	96672.62
Yield	kg ha^{-1}	6713.43
Specific energy	MJ kg^{-1}	10.88
Energy use efficiency	-	1.72
Energy productivity	kg MJ^{-1}	0.18
Net energy	MJ ha^{-1}	18509.91

Table 4. Parameter estimates of the stochastic input distance function including inefficiency effects.

Variables	Parameters	Coefficients	t-ratio
Production Variables			
Constant	α_0	-8.2471	-210.98***
ln(Prawn)	β_1	-0.2253	-5.08***
ln(Fish)	β_2	-0.0812	-2.89***
ln(Rice)	β_3	0.4891	1.04
½ ln(Prawn)^2	β_{11}	-0.2794	-2.89***
½ ln(Fish)^2	β_{22}	0.0215	0.33
½ ln(Rice)^2	β_{33}	-1.9674	-1.00
ln(Prawn) x ln(Fish)	β_{12}	0.0333	0.55
ln(Prawn) x ln(Rice)	β_{13}	1.4198	2.09**
ln(Fish) x ln(Rice)	β_{23}	-0.4560	-0.96
ln(Inputs/Machineries)	α_2	0.0459	1.70*
ln(Labour/ Machineries)	α_3	0.5891	12.19***
ln(Chemicals/ Machineries)	α_4	0.0822	3.61***
½ ln(Inputs/ Machineries)^2	α_{22}	0.0548	0.97
½ ln(Labour/ Machineries)^2	α_{33}	0.4391	1.73*
½ ln(Chemicals/ Machineries)^2	α_{44}	0.0223	0.49
Ln(Inputs/ Machineries) x ln(Labour/ Machineries)	α_{23}	0.0155	0.41
ln(Inputs/ Machineries) x ln(Chemicals/Machineries)	α_{24}	-0.1829	-2.01**
ln(Labour/Machineries) x ln(Chemicals/Machineries)	α_{34}	0.0413	0.47
Model diagnostics			
Gamma	γ	0.583**	
Sigma-squared	σ_s^2	0.018**	
Log likelihood		73.99	
$\chi^2_{(18,0.99)}$		554.37***	
Inefficiency effects function			
Constant	δ_0	5.1728	1.72*
Ogive index of output concentration	δ_1	-2.5628	-1.65*
Age of the farmer	δ_2	-0.0016	-0.60
Education of the farmer	δ_3	-0.0271	-1.50
‘gher’ area	δ_4	-1.1040	-1.66*
Dependency ratio	δ_5	0.0907	0.74
Female labour ratio	δ_6	-0.7099	-1.06

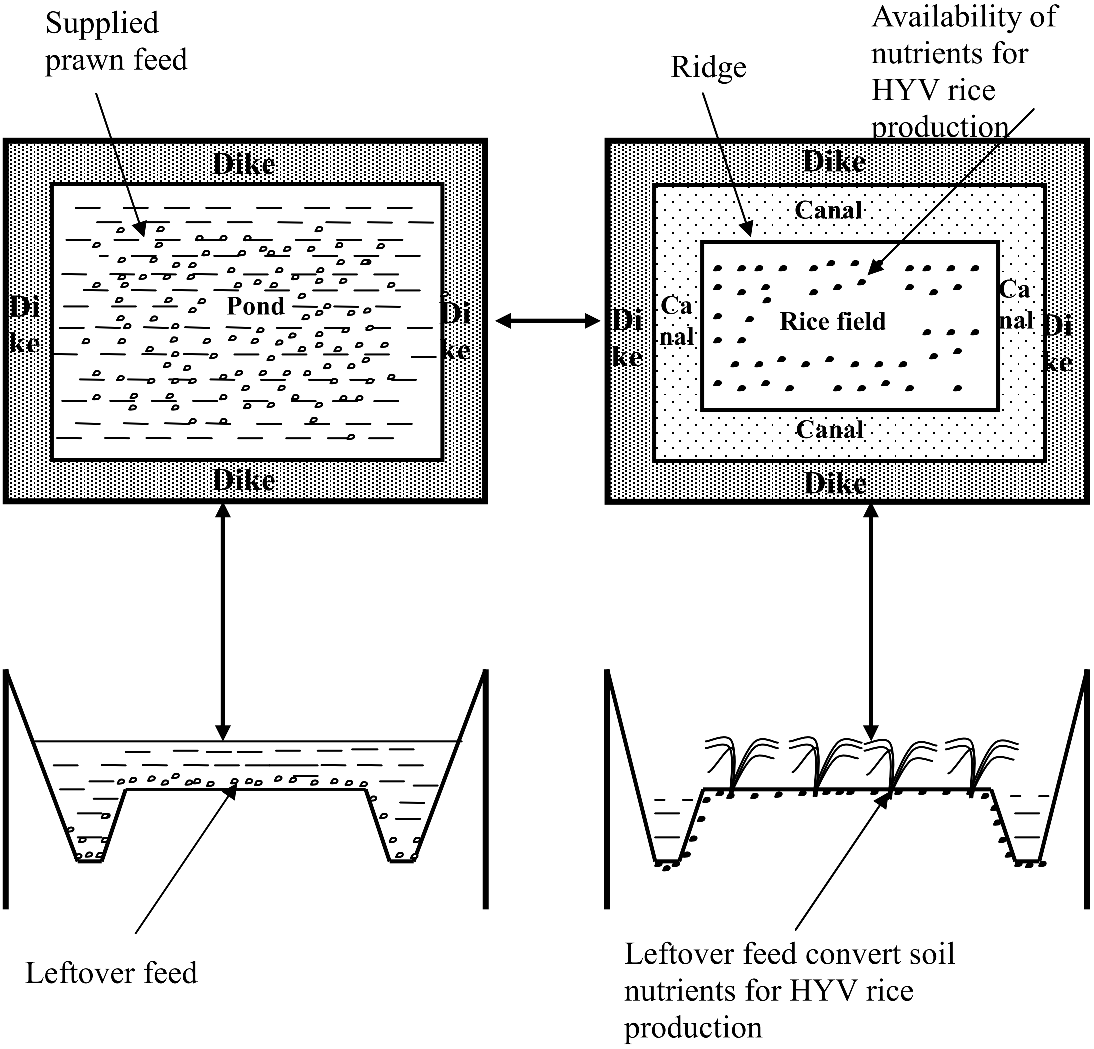
Note: *** = significant at 1% level (p<0.01)

** = significant at 5% level (p<0.05)

* = significant at 10% level (p<0.10)

Table 5. Technical (energy) efficiency scores

Variables	Estimates
Efficiency levels	
upto 70 %	2.2
71 – 80 %	3.3
81 – 90 %	23.3
90 and above	71.2
Mean efficiency level	0.92
Standard deviation	0.07
Minimum	0.67
Maximum	0.99
Number of observations	90



a) ‘gher’ farming in rainy season

b) ‘gher’ farming in winter season

Figure 1. The ‘gher’ farming system
Source: Adopted from Barmon et al. [31]

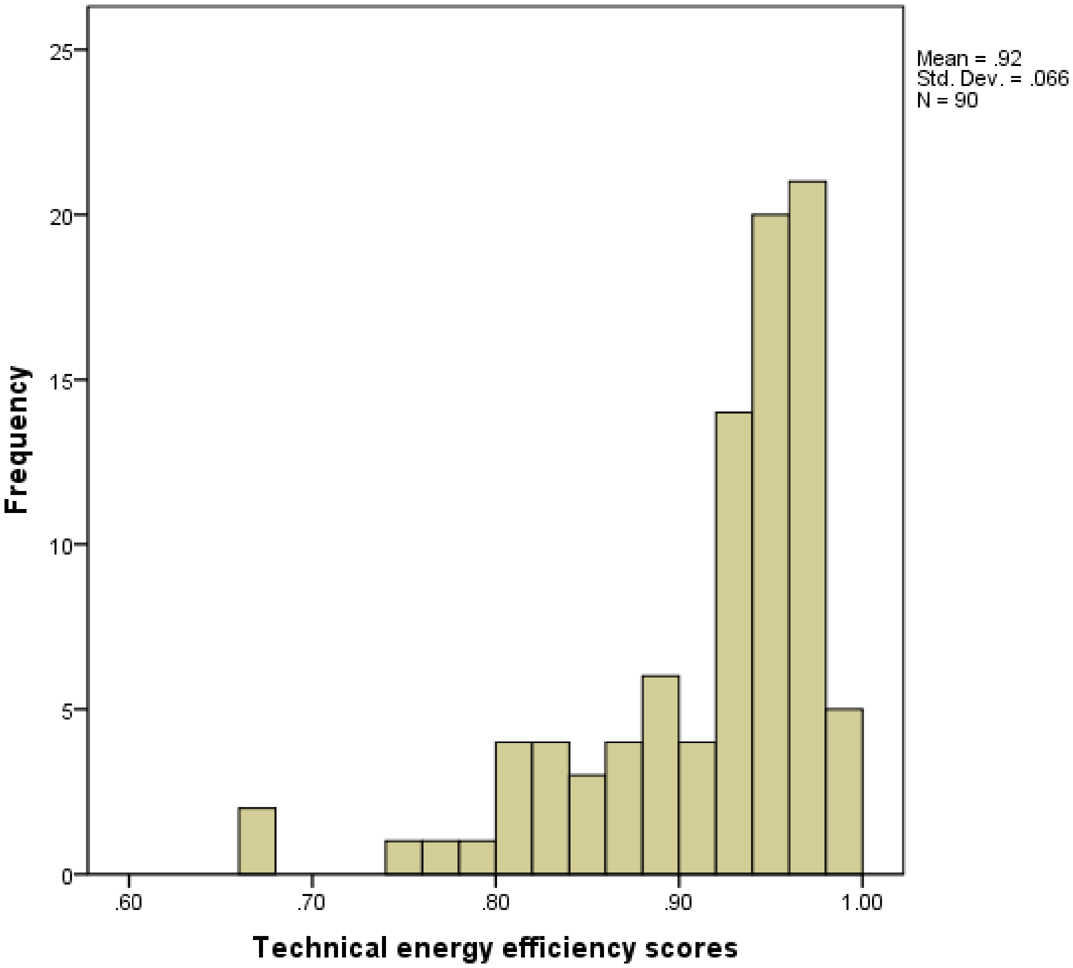


Figure 2. Distribution of technical (energy) efficiency scores of ‘gher’ farmers.