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Energy use efficiency of irrigated rice farming systems: A case study in Ampara district of Sri Lanka during *Maha* season

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Abstract

Energy use efficiency of irrigated rice farming systems of Ampara district in Sri Lanka from 2006/07 to 2016/17 *Maha* season was analyesd with the aim of providing information for farmers and decision makers. Secondary data published by the Socio Economic and Planning Center of the Department of Agriculture from 2007 to 2017 were used to obtain farm input and output components. Data recorded in monetary values were converted to energy values using standard coefficients reported in literature. Rice farming in Ampara was divided into two systems: *Manawari i*n Ampara East and wet seeding in Ampara West. Farm inputs in both systems were recognized as labor, machinery, fuel, agrochemicals, seeds and irrigation water while rice yield and straw were considered as outputs. The total input and output energy into these farming systems were about 30,640 and 144,431 MJ ha^{-1} in Ampara East and 30,984.7 and 130,329.2 MJ ha^{-1} in Ampara West, respectively. The highest energy input was accounted by nitrogen fertilizer, 48.5±1.0% in the East and 50.0±0.8% in the West. The system energy efficiency in the East was 4.8±0.3 and 4.2±0.2 in the West. The overall energy efficiency of two systems was similar (p>0.05); However, a significantly different farm input contributions for the two systems from irrigation water, machinery, human labor and seed paddy were observed (p<0.05). The water productivity in the East was 0.5±0.02 and 0.4±0.02 kg m^{-3} in the West, (p<0.05). The percentage of the nonrenewable energy input was higher than the renewable energy input, whereas 69±0.9% in the East and 69±0.6% in the West and they were not significantly different. Therefore, the energy efficiency analysis is a convenient tool to quantify and compare different rice

farming systems without the influence from monetary escalations across time and regional boundaries.

Keywords: Energy input, Energy output, Energy efficiency, Irrigated rice, Net energy, Renewable energy

Introduction

Agriculture is a process of solar energy conversion into food, feed and fiber through photosynthesis (Stout, 1990). Agriculture also requires many other inputs in addition to solar energy. Energy usage in agriculture has been intensified with increasing human population and limited supply of arable lands. Intensification of the use of additional inputs, which can also be expressed as energy intensification has led to create emerging problems in public health and the environment (Rafiee *et al*., 2010). However, energy intensification to obtain higher yields may not bring maximum profits due to the increase in cost of cultivation (COC). Therefore, appropriate and efficient use of energy resources is one of the basic requirements for sustainable agricultural production with financial savings, minimum environmental pollution while optimizing the yield.

Rice is the staple food for more than half of the world's population, who mainly lives in Asia (FAO, 2014). Rice production in industrialized countries is heavily dependent on intensive use of external inputs originating from fossil fuels such as chemical fertilizers (Barker and Herdt, 1985). The primary objective of commercial agriculture is to maximize the profit; therefore, an economic analysis is used to evaluate and compare agricultural systems in order to make decisions on selecting and starting up an efficient operation. However, the natural environmental inputs to economic production such as land productivity, water, precipitation, solar energy are not considered in most of the conventional economic analysis. As a result, the financial and environmental costs incurred due to degradation and depletion of land, water, and the biological resources remain unknown, thus a need arises to use tools that can comprehensively express the efficiency and sustainability of agricultural systems. A direct financial comparison between input and output of different farming systems remains a difficult task because comparisons based on economic values are incapable of recognizing the contribution from nature.

Energy Systems Theory (EST), a system analysis tool bridging the ecology and the economy was first introduced by H.T. Odum and his colleagues during the 1980's (Lu *et al.*, 2010). Unlike the economic analysis, energy analysis indirectly provides information on both nonrenewable energy usage and climate change weights linked to crop production. It is also not influenced by the artificial changes in the price of inputs (Jones, 1989). Energy analysis can provide information on efficiency of farming systems relevant to energy and it is useful for farmers and decision makers (Pervanchon *et al*., 2002). Therefore, the objective of this research was to evaluate the irrigated rice farming systems in Ampara district based on the energy indices.

Materials and Methods

Study area

Ampara district of the Eastern province of Sri Lanka was selected as the study area which has a high potential for rice production and also has adopted intensive mechanization in rice farming. Moreover, this district has the highest land extent (67,933 ha) under irrigated rice in the country (COC, 2016). Ampara district receives a mean annual rainfall of 1750 mm, mainly during north-east monsoon from November to February (*Maha* season). The mean annual temperature varies between 25-27 °C.

The major Agro Climatic Zone in the district is Low Country Dry Zone (DL) that covers around 80% of the area. The irrigated rice cultivated areas are further divided into two sub regions: Ampara East and Ampara West. Ampara East is located in the eastern part of the district and rice cultivators in this part mainly use the *Manawari* (*Kakulama*) system, which is characterized by dry land preparation and dry seeding. Though the cultivation started with dry land preparation and dry seeding, rest of the management practices are done as irrigated conditions. Ampara West is located in the western part of the district and wet land preparation and broadcasting of pre germinated seeds are prominent methods in this part of the district.

Data sources and energy estimation

The secondary data reported by the Department of Agriculture on rice productivity, farm inputs and COC during the *Maha* season in Ampara district from 2006/07 to 2016/17 were used as the data sources for all analyses. The COC consists of three main cost components; labor, machinery and all other material inputs including agrochemicals. The monetary values of each component were transformed into labor hours, machinery hours and input volumes or masses using standard conversion factors of published data. Then, all inputs and outputs from the cultivation systems quantified in terms of quantities were later transformed into energy units as explained by Alipour *et al.* (2012). The energy equivalents of the inputs and outputs are shown in Table 1.

Table 1. Coefficients used in converting masses to energy values

Energy source	Energy coefficient	Reference
Human labour (h)	1.96 MJ h^{-1}	Gundogmus (2006)
Fertilizer (kg)		
N	60.60 MJ kg^{-1}	Gundogmus (2006)
P	11.10 MJ kg^{-1}	Gundogmus (2006)
K	6.70 MJ kg^{-1}	Gundogmus (2006)
Pesticide (kg)		
Insecticide	199 MJ kg^{-1}	Gundogmus (2006)
Fungicides	92 MJ kg^{-1}	Gundogmus (2006)
Herbicides	238 MJ kg^{-1}	Gundogmus (2006)
Diesel (L)	56.31 MJ L^{-1}	Gundogmus (2006)
Water (m^3)	0.63 MJ m^{-3}	Gundogmus (2006)
Machinery (kg)	62.70 MJ kg^{-1}	Gundogmus (2006)
Self-Propelled Combines (kg)	87.63 MJ kg^{-1}	Hetz (1992)
Tractors (kg)	93.61 MJ kg^{-1}	Hetz (1992)
Paddy (kg)	14.57 MJ kg^{-1}	Iqbal (2007)
Straw (kg)	12.50 MJ kg^{-1}	Iqbal (2007)

Machinery energy was calculated using equation (1) as explained by Alipour *et al.* (2012).

$$ME = \frac{cf \times w}{F_c \times L} \qquad \text{Eq-1}$$

Where, ME is machinery energy (MJ ha^{-1}), cf is energy equivalent (MJ kg^{-1}), w is weight of machinery (kg) and L is useful life of machinery (h). The useful life for the machineries used in the study area was taken from American Society of Agricultural and Biological Engineers (ASABE) as follows: two wheel drive tractor 12,000 h, self-propelled combine harvester 3,000 h, rotary tiller 1,500 h, threshers 3,000 h (ASABE, 2006). Field capacity of the machines and fuel consumptions were obtained from Farm Mechanization Research Centre (FMRC) test reports (unpublished data) and operator manuals of the machines (Table 2). Paddy: straw ratio was taken as 1:1 for output calculations.

Table 2. Machinery data

Machine	Implement used	Field capacity (ha h^{-1})	Fuel consumption (L h^{-1})
Power tiller [a]	Rotovator	0.14	1.83
Two wheel drive tractor [a]	Nine tine tiller	0.38	5.60
Two wheel drive tractor [a]	Rotavator	0.40	6.01
Mini combine harvester [b]		0.09	1.25
Combine harvester [a]		0.30	7.74

[a] *from FMRC unpublished data:* [b] *from operator manual of the machine*

Energy efficiency, net energy, energy productivity, specific energy and water productivity were calculated using Equations (2) to (6) as explained by Alipour *et al.* (2012).

All the statistical analysis were performed using Minitab 19 software.

$$\text{Energy Efficiency} = \frac{\text{Total Energy Output (MJ ha}^{-1})}{\text{Total Energy Input (MJ ha}^{-1})} \qquad \text{Eq-2}$$

$$\text{Net Energy} = \text{Total Energy Output (MJ ha}^{-1}) - \text{Total Energy Input (MJ ha}^{-1}) \qquad \text{Eq-3}$$

$$\text{Energy Productivity} = \frac{\text{Paddy output (kg ha}^{-1})}{\text{Energy Input (MJha}^{-1})} \qquad \text{Eq-4}$$

$$\text{Specific Energy} = \frac{\text{Energy Input (MJ ha}^{-1})}{\text{Paddy output (kg ha}^{-1})} \qquad \text{Eq-5}$$

$$\text{Water Productivity} = \frac{\text{Grain Yield (kg ha}^{-1})}{\text{Water Usage (m}^{3}\text{ ha}^{-1})} \qquad \text{Eq-6}$$

Results and Discussion

Crop establishment and farming practices

In the Ampara district, land preparation process has been done in four steps; pre-weedicide application, general land preparation (land clearing), three or two ploughings and bund plastering. Use of two prominent pre plant herbicides; Paraquat (Gramoxone) and Glyphosate (Roundup), were reported in rice cultivation only up to 2013/14 *Maha* due to unavailability of alternative total killer to replace Paraquat that was banned in 2011 and Glyphosate banned in 2014. Tractors had been used in eastern part of Ampara district for land preparation, but power tillers had also been used in the western part of Ampara district. The selection of implements for land preparation primarily depends on water availability and soil hardness (Hamza and Anderson, 2005). Dry land preparation had been adapted in the Eastern part while wet land preparation had been adapted in the Western parts considering water availability and soil hardness.

In Ampara district, the majority of the farmers practice direct seeding. As described by Akhgari and Kaviani (2011) there are three techniques of direct seeding; dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds on wet puddled soils) and water seeding (seeds sown into standing water). Wet seeding method was used in Ampara west areas and dry seeding method was used in Ampara east area. In the Ampara district, it was found that farmers used more than the recommended rate (100 kg ha^{-1}: DOA, 2019) of seeds which varied from 123.7 kg ha^{-1} in Ampara west to 191.60 kg ha^{-1} in Ampara east during *Maha* season between 2006/07 to 2016/17. As reported by the Department of Agriculture, *Manawari* cultivation system uses a seed rate between 150 to 300 kg ha^{-1} depending on the level of weed infestation (DOA, 2019).

Irrigation, fertilization, weed and pest control were the main cultural practices under the crop management process. The study area was under the major irrigation schemes and thus water for rice production in *Maha* season was available without restrictions. The irrigation water usage of the alluvial soil is taken as 1,128 mm of which 150 mm is used for land preparation (DOA, 2019). It was reported that the majority of the Sri Lankan farmers use direct fertilizers; Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP). In addition, pre and post plant weedicide, insecticide and fungicide applications were also reported during the period of study.

Harvesting process involves cutting, field drying, hauling, staking, threshing, cleaning and bagging (IRRI, 2019). It was reported that manual labor and threshing machines were replaced by combined harvesters in later years. The harvest was transported by tractors for temporary storage.

Average energy input, output and energy indices

The average energy input, output and energy indices are presented in the Table 3.

Table 3. The average energy inputs, outputs and energy indices

	Ampara East (*Manawari*)			**Ampara West (wet seeding)**		
Energy source (units)	**Quantity (ha^{-1})**	**Total energy equivalent (MJ ha^{-1})**	**As a % of the total energy input**	**Quantity (ha^{-1})**	**Total energy equivalent (MJ ha^{-1})**	**As a % of the total energy input**
Input						
Human labour (h)*	251.8	493.5	1.6	315.3	618.0	1.9
Machinery (h)*	9.1	572.5	1.8	7.1	447.5	1.4
N fertilizer (kg)**	245.8	14,893.4	48.5	255.6	15,492.1	50.0
P fertilizer (kg)**	79.8	885.6	2.9	83.7	929.4	3.0
K fertilizer (kg)**	84.9	569.3	1.8	79.0	529.6	1.7
Insecticides and fungicides (kg)**	0.2	33.9	0.1	0.1	30.0	0.1
Herbicides (kg)**	3.9	930.0	3.0	2.5	605.5	1.9
Diesel (L)**	59.7	3,362.0	10.9	60.8	3,424.3	11.0
Irrigation water (m^3)*	9780.0	6,161.4	20.1	11,280.0	7,106.4	22.9
Seeds paddy (kg)*	191.6	2,791.5	9.1	123.7	1,802.1	5.8
Total energy input (MJ ha^{-1})**		30,639.1			30,984.7	
Output						
Seeds (kg)**	5,335.4	77,737.5		4,814.5	70,147.6	
Straw (kg)**	5,335.4	66,693.1		4,814.5	60,181.5	
Energy Indices						
Total energy output (MJ ha^{-1})**		144,430.6			130,329.2	
Net energy (MJ)**		113,737.5			99,344.4	
Specific energy (MJ kg^{-1})**		5.9			6.6	
Energy productivity (kg MJ^{-1})**		0.2			0.2	
Water productivity (kg m^{-3})*		0.5			0.4	
Energy efficiency**		4.8			4.2	

** Significantly different between East and West: ** Not Significantly Different ($p>0.05$)*

Total energy used during various farm operations was 30,693.1±990.1 MJ ha^{-1} in Ampara East and 30,984.7±633.6 MJ ha^{-1} in Ampara West (Table 3). Total energy output was 144,430.6±4,686.7 MJ ha^{-1} in Ampara East and 130,329.2±5,685.6 MJ ha^{-1} in Ampara West. Alipour *et al*. (2012) found that total energy input and output of the conventional rice farming system in Iran was 47,607 and 90,680.04 MJ ha^{-1}, respectively. Iran uses about 4,003.56 MJ ha^{-1} of electricity for water pumping, thus total energy input was much greater than that in Ampara. Out of total energy output 46.2% was from straw and this was not properly managed in the farmer fields, majority of them were burned and wasted. Total energy output of rice production system in Ampara was much higher compared to the south Asian region because the productivity has been recorded as 5.3 t ha^{-1} in Ampara East and 4.8 t ha^{-1} in Ampara West. Nitrogen (N) fertilizer is accounted for the highest single energy input component and that varied from 48.5±1.0% in Ampara East to 50.0±0.8% in Ampara West from the total energy input. These results are in par with the findings of Khan *et al*. (2010) who reported that chemical fertilizer alone accounts for 43% of energy input in Australian rice farming systems. In Bangladesh, fertilizers accounted for 60% of total energy input (Rahman *et al*., 2015). In Iran it was only 17 % of total energy whereas the quantity used was much lower as 137.4 kg ha^{-1} (Alipour *et al*., 2012). Energy equivalent value of the N is much higher than other fertilizers because N fertilizers are manufactured via the Haber-Bosch process. Nitrogen fertilizer is roughly ten times energy intensive than phosphorus and potassium fertilizers (Khan and Hanjra, 2008). Human and machinery energy usage were 493.5±14.7 MJ ha^{-1} and 572.5±8.4 MJ ha^{-1} in Ampara East while it was estimated as 618.0±22.4 MJ ha^{-1} and 447.5±33.6 MJ ha^{-1} in Ampara West, respectively. It was also evident that there is an area demarcation factor for COC, higher machinery energy coupled with lower human energy usage in the eastern region than the west of Ampara. The total energy input was not significantly different between East and West, but human labour, machinery, irrigation water and seeds energy were significantly different ($p<0.05$) during the study period.

Energy indices

Results of the mean comparison revealed that energy indices were not significantly different between East and West, except water productivity ($p>0.05$). Figure 1 shows the variation of energy indices (specific energy (A), energy productivity (B), energy efficiency (C) and water productivity (D)) over the period of study in Ampara district. The average energy efficiency in Ampara East was 4.8±03 and it was 4.2±0.2 in Ampara West. It indicated that the irrigated rice farmers in Ampara East earned nearly five times of energy compared to what they put into the production process. Moreover, during the study period it showed an increasing trend (p<0.05) as shown in Figure 1 C. However, it has reported that the energy efficiency of rice farming systems in Malaysia is about eight (Bockari *et al*., 2005). The reason for decreasing energy efficiency in 2010/11 *Maha* season was due to the low yield resulted due to heavy rains and floods. Power *et al*. (2017) found that water productivity was 0.4 kg m^{-3} in Maharashtra, India. However, that in Ampara was 0.5±0.02 kg m^{-3} in the East and 0.4±0.02 kg m^{-3} in the West which was a similar to that in India. The major difference in the East and the West of the district was the dry land preparation in the Eastern region. This is also reflected by the water productivity and the average specific energy (5.9±0.4 MJ kg^{-1} in the East and 6.6±0.5 MJ kg^{-1} in the West). Average energy productivity in both East and West was 0.2±0.1 kg MJ^{-1} and it shows an increasing trend (p< 0.05) over the period (Figure 1 B).

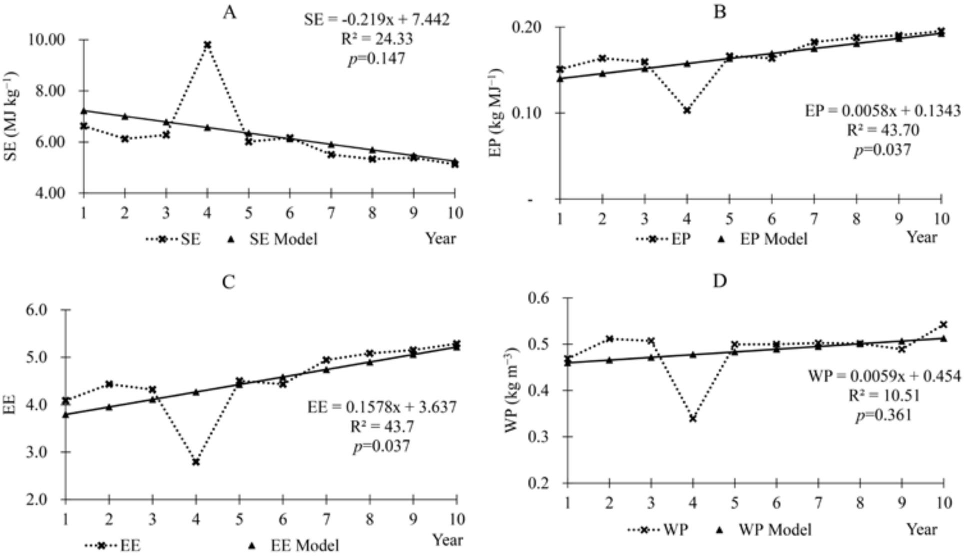

Figure 1. Variation of a) specific energy- SE (MJ kg^{-1}), b) energy productivity- EP (kg MJ^{-1}), c) energy efficiency -EE, and d) water productivity- WP (kg m^{-3}) in Ampara from 2006/07 *Maha* to 2016/17 *Maha*

Net energy

Bertilsson *et al*. (2008) stated that crop production has a highly positive energy balance due to photosynthetic activity where solar radiation is transformed into biomass. Thus, net energy is a good indicator of photosynthetic assimilation. It is assumed that, if the energy efficiency is greater than one, then the production system is gaining energy, otherwise it loses energy (Bockari *et al*., 2005). Net energy in Ampara East and West were 113,737.5±5,252.9 and 99,344.4±5993.8 MJ ha^{-1}, respectively. In comparison, it was only 43,076.2 MJ ha^{-1} (Alipour *et al*., 2012) in Iran and 86,050 MJ ha^{-1} in Bangladesh (Iqbal, 2007). The higher rate of net energy assimilation is governed by the assimilation rate reflected by yield. The higher yield could be due to use of higher yielding varieties and intensive farm mechanization practices implemented in the selected area.

Renewable energy (RE) and nonrenewable energy (NRE)

Energy demand in agriculture can be divided into renewable and nonrenewable energies (Alam *et al*., 2005). Renewable energy consists of human labor, water and seed, whereas NRE includes diesel fuel, fertilizers, chemical, machinery and electricity (Kazemi *et al*., 2015). Results revealed that RE usage in Ampara rice farming systems were 9,446.5±63.7 MJ ha^{-1} (31±0.9%) in the East and 9,526.4±33.0 MJ ha^{-1} (31±0.6%) in the West. The NRE usage was 21,246.6±942.2 MJ ha^{-1} (69±0.9%) in the East and 21,458.3±613.5 MJ ha^{-1} (69±0.6%) in the West. It was clear that the percentage of NRE is higher, hence the rice production system is mostly depending on the NRE was sources such as fossil fuels or their derivatives. Power *et al*. (2017) reported similar results in India that the portion of nonrenewable forms of energy was higher than the renewable forms. Usage of RE and NRE was not significantly different between East and West ($p>0.05$). Figure 2 showed the trend of renewable and nonrenewable energy usage during the period from 2006/07 *Maha* to 2016/17 *Maha*. It was evident from the trend analysis (Figure 2) that variation of RE and NRE usage in Ampara district was having a declining trend ($p<0.05$), though the output from the farming systems increased.

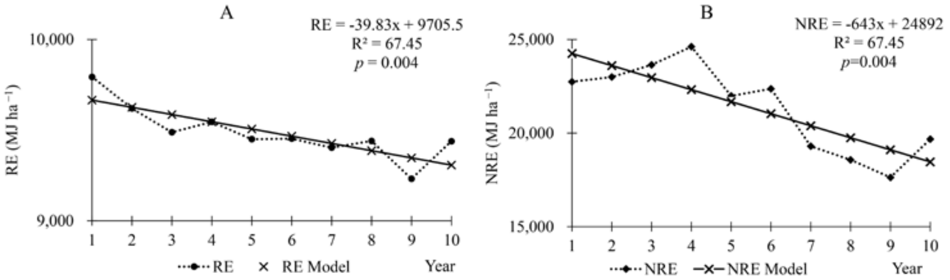

Figure 2. Ten years of variation in renewable (RE) and non-renewable (NRE) energy usage in Ampara district

Conclusion

The net energy of irrigated rice production systems showed comparatively higher values of 113,737.5±5,252.9 MJ ha^{-1} in Ampara East and 99,344.4±5,993.8 MJ ha^{-1} in Amapara West. Moreover, energy efficiency varied from 4.8±0.3 in Ampara East with dry seeding (*Manawari*) to 4.2±0.2 in Ampara West with wet seeding. Nitrogen fertilizer was the largest contributor to the total energy input. Results indicated that the energy productivity of the irrigated rice production system is more sensitive to N fertilizer inputs than any of other farm inputs such as seeds, machinery, labor and other agrochemicals. Proper straw management system should be introduced to utilize 46.2% of the energy wastage in the irrigated rice farming system of Ampara district. The average use of the nonrenewable energy (69±0.9%) was higher than the renewable form in rice farming. In perspective, the energy efficiency analysis is found to be a good indicator to quantify the productivity of rice farming systems across a wider range of ecological and political boundaries as the energy analysis is not influenced by cost escalations.

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References

Akhgari, H. and B. Kaviani. 2011. Assessment of direct seeded and transplanting methods of rice cultivars in the northern part of Iran. African Journal of Agricultural Research 6: 6492-6498.

Alam, M.S., M.R. Alam and K.K. Islam. 2005. Energy flow in agriculture: Bangladesh. American Journal of Environmental Sciences 1: 213- 220.

Alipour, A., H. Veisi, F. Darijani, B.Mirbagheri and A.G. Behbahani. 2012. Study and determination of energy consumption to produce conventional rice of the Guilan province. Resources Agriculture Engineering 58:99–106.

ASABE. 2006. American Society of Agricultural and Biological Engineers, 2950 Niles Road, St. Joseph, USA.

Barker, R. and R.W. Herdt. 1985. The Rice Economy of Asia; Resources for the Future, The John Hopkins University Press, Washington.

Bertilsson, G., H. Kirchmann, and L. Bergstrom. 2008. Energy Analysis of Organic and Conventional Agricultural Systems, Organic Crop Production – Ambitions and Limitations, Eds. H. Kirchmann and, L. Bergström, Pp. 173-188. Springer, Dordrecht, the Netherlands.

Bockari, G.S.M., W.I. Wan, Y. Azmi and C.W. Chan. 2005. Analysis of energy consumption in lowland rice-based cropping system of Malaysia, Songklanakarin Journal of Science and Technology 27: 819-826.

COC, 2016. Cost of cultivation of agricultural crops, Socio Economic and Planning Centre, Department of Agriculture, Peradeniya.

DOA, 2019. Rice Research and Development Institute. https://www.doa.gov.lk/rrdi/index.php?option=com_sppagebuilder&view=page&id=42&lang=en (Accessed on 28. 04. 2019).

FAO, 2014. FAO Statistical Yearbook, Asia and the Pacific. Food and Agriculture; FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Gundogmus, E. 2006. Energy use on organic farming: a comparative analysis on organic versus conventional apricot production on small holdings in Turkey. Energy Conservation Management 47: 3351–3359.

Hamza, M.A. and W.K. Anderson. 2005. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil and Tillage Research 82:121-145.

Hetz, E.J. 1992. Energy utilization in Chilean agriculture. Agriculture Mechanization in Asia, Africa and Latin America 23: 52–56.

Lu, H., Y.U. Bai, H. Ren and D. E. Campbell. 2010. Integrated energy, energy and economic evaluation of rice and vegetable production systems in alluvial paddy fields. Implications for agricultural policy in China. Journal of Environmental Management 91: 2727-2735.

Iqbal T. 2007. Energy input and output for production of Boro rice in Bangladesh. Electronic Journal of Environmental, Agricultural and Food Chemistry 7: 2717–2722.

IRRI, 2019. Rice Knowledge Bank, http://www.knowledgebank.irri.org/step-by-step-production/postharvest (Accessed on 28.4.2019).

Jones, M.R. 1989. Analysis of the use of energy in agriculture approaches and problems. Agricultural Systems 29: 339-355.

Kazemi, H., B. Kamkar, S. Lakzaei, M. Badsar and M. Shahbyki. 2015. Energy flow analysis for rice production in different geographical regions of Iran. Energy 84: 390-396.

Khan, S. and M.A. Hanjra. 2008. Footprints of water and energy inputs in food production – Global perspectives. Food Policy. 34:130-140.

Khan, S., M.A Khan and N. Latif. 2010. Energy requirements and economic analysis of wheat, rice and barley production in Australia. Soil and Environment 29: 61–68.

Pervanchon, F., C. Bockstaller and P. Girardin. 2002. Assessment of energy use in arable farming systems by means of an agro-ecological indicator: the energy indicator. Agricultural Systems 72:149-172.

Power, R.V., P.U. Shahare V.V. Aware and A.A. Deogirikar. 2017. Energy audit of paddy cultivation practices in Kokan region of Maharashtra. International Journal of Agricultural Engineering. 10: 647-654.

Rafiee, S., S. H. M. Avval and A. Mohammadi. 2010. Modeling and sensitivity analysis of energy inputs for apple production in Iran. Energy 35: 3301-3306.

Rahman, M., M. Halder, N. Hassan and F. Haque. 2015. Energy input-output analysis of rice cultivation in the coastal region of Bangladesh. Songklanakarin Journal of Science and Technology 37:455-464.

Stout, B.A. 1990. Handbook of energy for world agriculture. Elsevier Applied Science, London.