Study and determination of energy consumption to produce conventional rice of the Guilan province

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Abstract

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The aim of this study was to determine the energy efficiency indices in the agro-ecosystems of the Guilan province in 2010. One hundred and twenty-seven farmers were interviewed using a particularly designed questionnaire. The inputs in the calculation of energy use in agro-ecosystems embraced labour, machinery, electricity, diesel oil, fertilizers, seeds, while rice and straw yield were included in the output. The results depicted that total input and output energy into these agro-ecosystems were about 47,604 and 90,680.04 MJ/ha, respectively. The highest energy input was related to water (38.84%), electricity (27.87%) and nitrogen fertilizer (17.5%). Energy efficiency and energy productivity in these agro-ecosystems was 2.19 and 0.064 kg/MJ, respectively, and water productivity was 0.11 kg/m^3. The results also showed that due to application of flood irrigation in these agro-ecosystems and also water elicited from subterranean sources by electrical pump, the inputs had the largest portion among the energy inputs to agro-ecosystems that this matter increased energy use in the unit area and also reduced energy efficiency and productivity.

Keywords: energy input; energy output; energy efficiency; energy productivity

Energy is the basic driving force in human development. The history of civilization is largely a story of man's progress in harnessing energy, i.e. to convert energy to a more useful form. In agriculture, energy is important in terms of crop production and agro-processing for value adding (Ozkan et al. 2004). In the evolution from traditional to modern farming, the commercial energy use was increased sharply (Iqbal 2007). This trend led to ecstatic impacts of environmental immensity e.g. degradation and erosion of the soil structure, and environmental pollution brought about carbon dioxide emissions, loss of quality food and risk of their toxicity and high energy costs created. As a result, these systems reduced energy efficiency more than traditional systems making instability of these systems (Zoghipour, Torkamani 2005).

Since efficient use of the energy resources is vital in terms of increasing production, productivity, competitiveness of agriculture as well as sustainability of rural living, energy auditing is one of the most common approaches to examining energy efficiency and environmental impact of the production system. It enables researchers to calculate output-input ratio, relevant indicators, and energy use patterns in an agricultural activity (Adem Hatirli et al. 2006). Also, the energy audit provides sufficient data to establish functional forms to investigate the relationship between energy inputs and outputs. Estimating these functional forms is very useful for determining elasticity of inputs on yield and production (Adem Hatirli et al. 2006).

Energy requirements in agriculture are divided into two groups – direct and indirect. Direct energy is required to perform various tasks related to crop production processes such as land preparation, irrigation, inter culture, threshing, harvesting and transportation of agricultural inputs and farm produce (Singh 2000). Indirect energy, on the other hand, consists of the energy used in the manufacture, packaging and transport of fertilizers, pesticides and farm machinery (CAEEDAC 2000; Kennedy 2000). As the term addresses, indirect energy is not directly used on the farm. Major items for indirect energy are fertilizers, seeds, machinery production and pesticides. Calculating energy input in agricultural production is more difficult in comparison to the industry sector due to the high number of factors affecting agricultural production (Yaldiz et al. 1993).

When a natural system capable of producing a certain amount of energy containing biomass is converted into an agroecological system, the natural capability limit is often exceeded by adding energy inputs. The greater the input of external energy, the more the natural capability of the system can be exceeded, and the less sustainable the system becomes. Because of this relationship, an analysis of agro-ecosystem's input/output energy balance can be a comprehensive indicator of its sustainability (Farshad, Zinck 2001). In this regard, efficient use of energy by the agriculture sector seems as one of the conditions for sustainable agriculture because it allows financial savings, fossil resources preservation and air pollution decrease (Pervanchon et al. 2002).

Many researchers studied energy analysis to determine the energy efficiency of plant production, such as potato in India (Yadav et al. 1991), sugarcane in Morocco (Mrini et al. 2001) and Louisiana (Ricaud 1980), rice in Malaysia (Bockari-Gevao et al. 2005), vegetables in Turkey (Canakci et al. 2005), cotton in Greece (Tsatsarelis 1991). Pathak and Bining (1985) pointed out that the energy consumption in paddy production is much higher than that of wheat production, primarily due to the high irrigation requirements of rice. Najim (2010) reported that energy productivity of irrigation water of rice in the main season at Tanjong Karang was 0.29 kg/m^3. Baruah and Dutta (2007) reported that the energy productivity (kg/MJ) of some states of India, in this report which energy intensive farming were considered, the energy for Uttar Pradesh, Tamil Nadu and Punjab were as 0.29, 0.186 and 0.187, respectively.

The aim of this study was to determine energy flow in rice production farms of Northern Province of Iran, Guilan. In addition to these, it was also an aim to calculate energy efficiency, energy productivity, and specific energy used in paddy production.

MATERIAL AND METHODS

The data were collected from 127 paddy farmers in 13 zones by interviewing the farmers using a specially designed and pre-tested questionnaire for 1 year in 2010. These zones are located in the Guilan province of Iran, where rice cultivation is the main source of income for farmers (Fig. 1). The questionnaire included all kinds of inputs e.g. fertilizers, chemicals and farmyard manure, power sources (human and prime movers) and agricul-

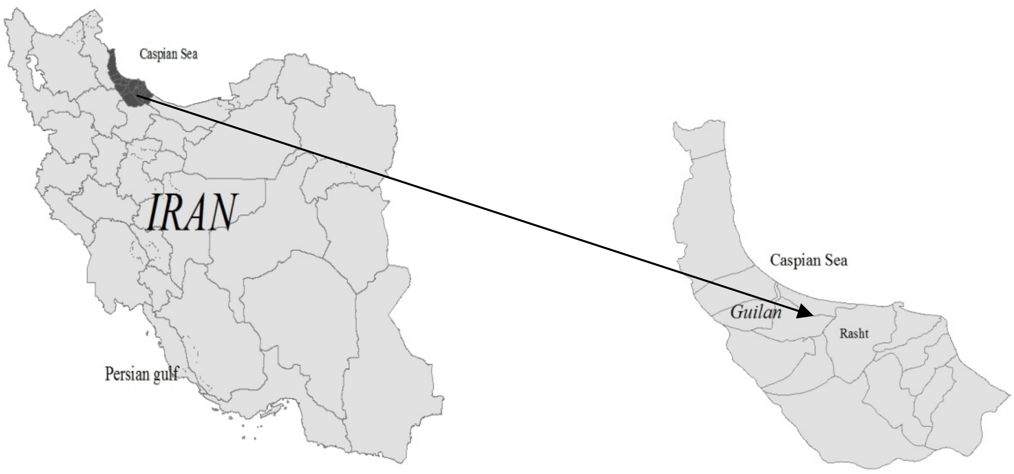

Fig. 1. Site of study

Table 1. Energy coefficient used in energy calculation

Energy source	Energy coefficient (MJ/unit)	Reference
Human labour (h)	1.96 MJ/h	Gundogmus (2006)
Fertilizer (kg)		
N	60.60 MJ/kg	
P	11.10 MJ/kg	Gundogmus (2006)
K	6.70 MJ/kg	
O	0.30 MJ/kg	
Pesticide (kg)		
Insecticide	199 MJ/kg	
Fungicides	92 MJ/kg	Gundogmus (2006)
Herbicide	238 MJ/kg	
Diesel (l)	56.31 MJ/l	Gundogmus (2006)
Paddy (kg)		
Seed	14.57 MJ/kg	Iqbal (2007)
Straw	12.50 MJ/kg	
Machinery (h)	62.70	Gundogmus (2006)
Water (m^3)	0.63	Gundogmus (2006)
Electricity (kWh)	11.93	Gundogmus (2006)

tural machinery (power tiller, weeder, sprayer and thresher) as well as yield of main and by-products. Each agricultural input was divided into as direct and indirect energy source. Direct energy sources were labour energy, tractor and/or other implement/machinery used for the particular operation and electric/diesel motor to run water pump, while indirect energy sources included seed of high yielding varieties, fertilizers and chemicals used in the production process; energy sources were classified into renewable and non-renewable. Renewable energy included human, labour, manure and seed, while non-renewable sources included diesel, electricity, chemicals, fertilizers, machinery. The energy coefficients of these sources are available in the papers (Croke 1979; Khan, Singh 1996; Ozkan et al. 2004; Canakci et al. 2005; Hatirli et al. 2006). The energy coefficients used in this study are given in Table 1. Basic information on energy inputs and rice yields were entered into MS Excel and SPSS v. 18 (IBM Co., New York, USA) spread sheet, data were also inserted in software ESRI ArcMap 9.3 (ESRI, Redlands, USA) as spatial layers and the energy efficiency, energy productivity, water productivity and specific energy maps were produced.

Energy indices

Energy efficiency, specific energy, energy and water productivity. Energy use efficiency (energy ratio), energy productivity, water productivity, specific energy (Khan, Singh 1996; Mandal et al. 2002; Khan et al. 2004; Yilmaz et al. 2005), and net energy were calculated, as they are shown in Eqs 1–5 (Singh et al. 1997; Mandal et al. 2002; Mohammadi, Omid 2010).

$$\text{Energy efficiency} = \frac{\text{Total energy output (MJ/ha)}}{\text{Total energy intput (MJ/ha)}} \quad (1)$$

$$\text{Energy productivity} = \frac{\text{Grain yield (kg/ha)}}{\text{Total energy intput (MJ/ha)}} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Total energy input (MJ/ha)}}{\text{Grain yield (kg/ha)}} \quad (3)$$

$$\text{Water productivity} = \frac{\text{Grain yield (kg/ha)}}{\text{Amount water applied (m}^3\text{/ha)}} \quad (4)$$

$$\text{Net energy} = \text{Energy output (MJ/ha)} - \text{Energy input (MJ/ha)} \quad (5)$$

RESULTS AND DISCUSSION

Analysis of input-output energy use in rice

Amounts of inputs used and output in rice production for each item are illustrated in Table 2; as it can be seen, 137.40 kg nitrogen, 77.1 kg phosphorus, 40.78 kg potassium, 10.63 kg manure of farm fertilizer, 32.73 l diesel fuel, 4.41 kg pesticide,

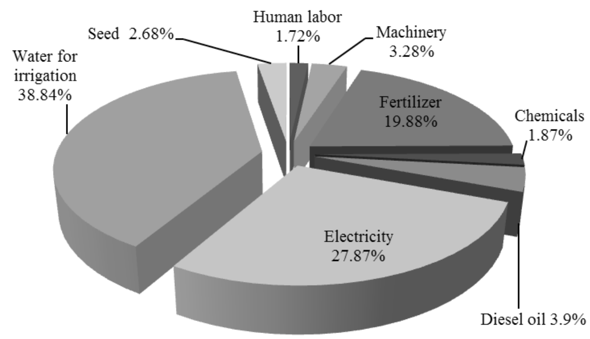

Fig. 2. The anthropogenic energy input ratios in the production of paddy

Table 2. Energy inputs, outputs and output-input ratio in paddy production

Energy source	Quantity used per unit area (ha)	Total energy equivalent (MJ/ha)	(%)
Inputs (unit)			
Human labour (h)	419.65	822.53	1.72
Machinery (h)	24.88	1,559.89	3.28
Fertilizer (kg)	–	9,459.13	19.88
Nitrogen fertilizer (kg)	137.40	8,327.01	17.5
Phosphorus (kg)	77.1	855.66	1.8
Potassium (kg)	40.78	273.27	0.573
Manure (kg)	10.63	3.19	0.007
Chemicals (kg)	–	888.9	1.87
Insecticides (kg)	2.02	403.26	0.847
Fungicides (kg)	0.57	52.37	0.11
Herbicide (kg)	1.82	433.27	0.91
Diesel oil (l)	32.73	1,842.95	3.9
Electricity (kWh)	1,112.1	13,267.17	27.87
Water for irrigation (m^3)	29,345.1	18,487.4	38.84
Seed (kg)	87.57	1,275.85	2.68
Total energy input (MJ/ha)		47,603.82	100
Outputs (unit)			
Seed (kg)	3,033.7	44,201.02	48.75
Straw(kg)	3,574.32	46,479.01	51.25
Total energy output (MJ/ha)	–	90,680.04	100
Net energy (MJ/ha)	–	43,076.22	–
Specific energy (MJ/Kg)	–	15.7	–
Energy efficiency	–	2.19	–
Energy productivity (kg/MJ)	–	0.064	–
Water productivity (kg/m^3)	–	0.11	–

29,345.1 m^3 water, 419.65 h human labour, 24.88 h machinery, 1,112.1 kwh electrical energy per hectare are employed for the production of rice. The average annual yields including seed and straw were found to be 3,033.7, 3,574.32 kg/ha in the enterprises that were analysed.

Total energy used in various farm operations during rice production was 47,603.82 MJ/ha (Table 2) that consists of 1.87% pesticide (the share of insecticides, herbicides and fungicides of total energy were 0.847%, 0.91% and 0.11%, respectively), 1.72% human labour, 3.28% machinery, 19.88% fertilizers, 3.9% fuel (diesel energy was mainly consumed for land preparation, cultural practices, and transportation), 27.87% electricity, 38.84% water and 2.68% seed inputs.

The highest energy inputs are provided by water and electricity. These findings are contradicted with Khan (2010) that asserted the greatest amount of energy input to rice fields related to chemical fertilizers (43%). Irrigation operation consumed the maximum energy on rice farm due to the higher water requirement of rice crop. Rice crop was mostly grown on canal water; Pimentel and Pimentel (1996) reported that irrigation energy requirement for rice production in the United States of America is 8,949.6 MJ/ha (18.1% of the total energy requirement), the electrical energy is mainly utilized by motor pumps to run irrigation pump set.

Based on the energy equivalents of the input and output given in Table 2, the average total energy

Table 3. Total energy input in the form of direct, indirect, renewable and non-renewable energy for paddy

Type of energy	(MJ/ha)	%
Direct energy	15,932.65	33.5
Indirect energy	31,671.17	66.5
Renewable energy	2,101.57	4.41
Non-renewable energy	45,502.76	95.59

consumed per farm per year was determined as 47,603.82 MJ/ha. This is higher than the 23,358.75 MJ/ha that Iqbal (2007) calculated in Bangladesh.

Direct/indirect and renewable/non-renewable energy forms used in rice production are also investigated (Table 3). The results showed that the share of direct input energy was 33.5% in the total energy input compared to 66.5% for the indirect energy. Also, renewable and non-renewable energy contributed to 4.41 and 95.59% of the total energy input, respectively. It is clear that the proportion of indirect and non-renewable input energy use in surveyed farm's rice is very high. The results of this research clearly showed that the rice production is mainly depended on water and electricity in the targeted area.

Net energy

The amount of net energy calculated in the Guilan agro-ecosystems was approximately 43,076.22 MJ/ha (Table 2) which was considerably lower than the net energy of 86,050 MJ/ha reported in Bangladesh (Iqbal 2007). This observation could be argued by the statement that overusing of inputs caused increment in consumed energy and lower yield of rice in this region compared to other areas in the world. Inappropriate management in these agro-ecosystems, application of low yielding indigenous varieties and perhaps decreasing return to scale could clarify low yield of rice in this area as well.

Energy and water productivity. In regard to energy indices, energy productivity index was determined as 0.064 kg/MJ (Table 2). However, in a similar research in Australia, it was 1.48 kg/MJ (Khan 2010) indicating almost ten-fold higher energy productivity in Australia compared to Iran. High energy relevance in agro-ecosystems could justify lower productivity on energy consumption in Iran. Also on rice farms, water productivity (Table 2) here was much lower (0.11 kg/m^3) compared to studies of Australia (0.50 kg/m^3) (Croke 1979) and Pakistan

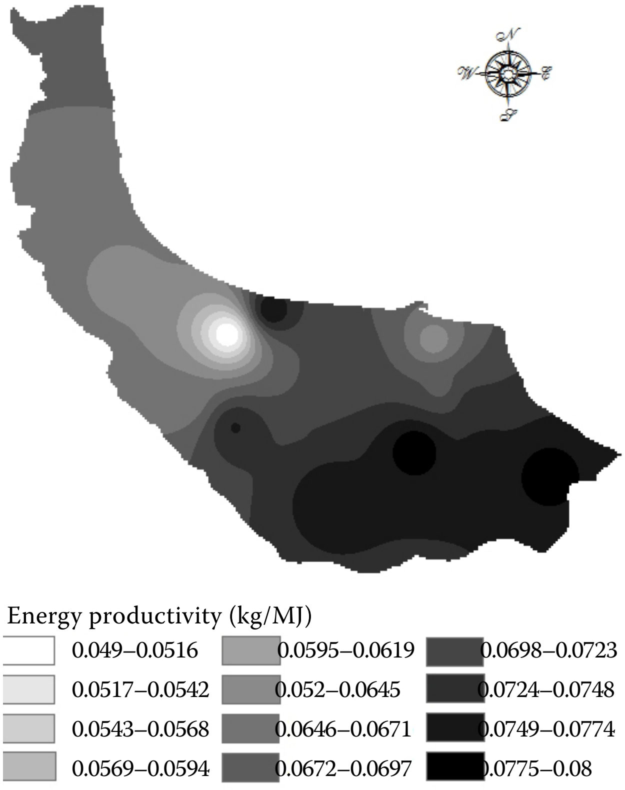

Fig. 3. The anthropogenic energy productivity in the production of paddy

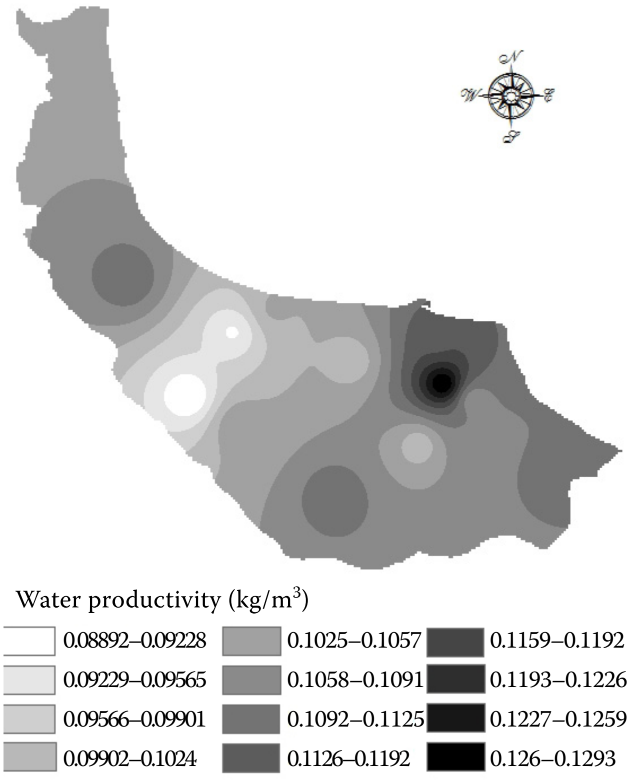

Fig. 4. The anthropogenic water productivity in the production of paddy

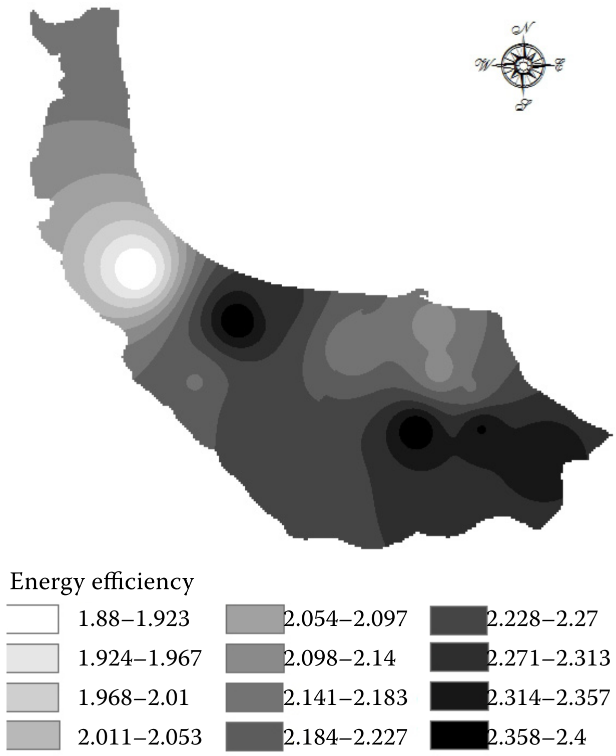

Fig. 5. The anthropogenic energy efficiency in the production of paddy

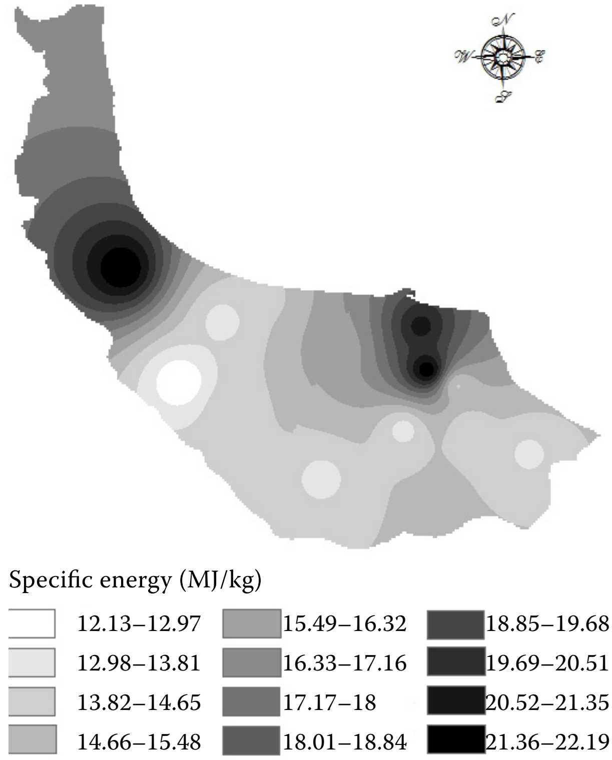

Fig. 6. The anthropogenic specific energy in the production of paddy

(0.33 kg/m^3) for rice crop (Khan et al. 2009). In this study, results obviously illustrated that water productivity in the farms of Guilan is lower, which is apparently because of inefficient irrigation system and defective water management. Furthermore, access to groundwater resource without no governmental supervision particularly during the period of drought, makes it worse. Also low pure energy in rice farms could be in consequence of excessive use of chemical input without appropriate management. Since chemical inputs are inexpensive in Iran, farmers are stimulated to apply them without considering its biological and ecological impacts. On the other hand, lack of awareness about the negative impacts of chemical inputs and utilitarian viewpoint of farmers toward the agriculture, could be another reason for excessive use of chemical inputs.

As to profile of energy and water productivity which is deduced from ESRI ArcMap 9.3 in paddy farms of study area, Fig. 3 illustrates the amount of energy productivity in the eastern province of Guilan which is higher than the other regions so that the lowest amount of energy productivity is completely perceptible in the central energy productivity. Furthermore, Fig. 4 shows the highest amount of water productivity in the central province of Guilan and also the lowest rate in the water productivity is evidence into the eastern part. It is well worthy mentioning here that the differences in the levels of these indicators are not that much significant.

Energy efficiency (Energy ratio). Energy efficiency in agro-ecosystems located in Guilan was 2.19; this index in Australia was calculated 6.7 for agro-ecosystems (Khan 2010). As the modernization and mechanization in agro-ecosystems increased, the energy efficiency in these mankind ecosystems, followed a decreasing trend (Gliessman 2001). As agro-ecosystems in Iran are considerably not as mechanized as in Australia, the only reason of this phenomenon could be overuse of energy only because of low cost and expenses for this unique input in Iran.

As can be seen in Fig. 5, the highest amount of energy efficiency is related to the darkest point of the figure which is located in the eastern and central part of the province and the white point of the figure is suggestive of the lowest amount of energy efficiency. Under such these circumstances the differences in this index are not remarkable.

Specific energy. Specific energy is an index which shows how much energy was used to produce one unit of disposable product. In this study the mentioned index was calculated as 15.7 MJ/kg which demonstrated poor output rather than input in the farm. In the researches done on greenhouse tomato, the index was calculated as 12.4 MJ/kg (Adem 2006).

With regard to specific energy index, deduced data from Fig. 6 denotes the amount of specific energy in the central and southeastern parts of the Guilan district which is much higher than the other regions. Hence, the observed differences are not again notable.

CONCLUSION

This study utilized an energy analysis to evaluate the energy flow in paddy farms of the Guilan province of Iran. The results revealed that the energy inputs of paddy production were 47,603.82 MJ/ha. The energy input related to water and electricity contributed the biggest share of the total energy inputs in production systems. The share of direct energy was 33.5% of the total energy input in conventional systems and the share of non-renewable energy in total energy input was 66.5%. The results indicated that the net energy for conventional paddy production systems had low values. This finding indicated that energy was not used efficiently in systems and portions of energy may be lost.

Results also revealed that the value of the energy and water productivity were low (0.064 kg/MJ and 0.10 kg/m^3, respectively). In addition, energy efficiency and specific energy were in low degree which is definitely due to overusing energy in the rice productions. In the research area, energy use in rice production is not efficient and safe to the environment for the sake of using tremendous inputs. On the other hand, increasing used inputs might cause a disruptive pressure on the ecosystems which this degradation could be excessive use of non-renewable resources.

To sum, we can conclude that the rate of water irrigation, electricity and N fertilizer utilized rice farms of the targeted area is considerably higher than what is really necessary for production process of the crop. Accordingly, the objective is not to lower the use of inputs into ecosystems but also the efficient use of these inputs.

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