Paddy Water Environ (2017) 15:931–941
DOI 10.1007/s10333-017-0603-1

ARTICLE

Comparative energy and economic analyses of conventional and System of Rice Intensification (SRI) methods of rice production in Thai Nguyen Province, Vietnam

Tuyet Thi Anh Truong[1] · John Fry[2] · Phu Van Hoang[1] · Hoang Huy Ha[1]

Received: 13 March 2017 / Revised: 16 June 2017 / Accepted: 21 June 2017 / Published online: 17 July 2017

Abstract The consumption of energy inputs in agricultural production has been increasing rapidly during the past decades. However, given the limitations and costs of non-renewable energy, increasing production while using the least energy possible has become a major concern of most nations. Prompted by this concern, we conducted a face-to-face survey of 90 farming households in Thai Nguyen Province, Vietnam, to find out how energy is being used in agriculture and, specifically, in their rice production. Through analysis of energy input–output balances, combined with economic efficiency analysis, a comparison was made of conventional and SRI methods of rice production. The study found that applying the SRI method can save around 23% of energy inputs, while increasing energy outputs by 11%. Economic benefits per hectare also rise by more than 8 million dong (USD 364) compared to those under the conventional cultivation system. The study also showed conflicts between the energy and economic balances for manual compared with machine ploughing operations. This study contributes to providing an overview of energy consumption in rice cultivation at the household level. Its findings can help stakeholders to assess current policies and make better decisions on the uses of energy in agricultural production. In addition, the comprehensive approach taken here to analysing energy use and efficiency could expand the analysis and comparison of energy uses at sectoral or activity level—still a new field in Vietnam and many other countries.

✉ Tuyet Thi Anh Truong
truongthianhtuyet@tuaf.edu.vn

[1] Thai Nguyen University of Agriculture and Forestry, Thai Nguyen 250000, Vietnam

[2] University College Dublin, Dublin, Ireland

Keywords Rice production · SRI · Economic analysis · Energy efficiency · Energy productivity · Vietnam

Introduction

The expansion of the Vietnamese population from 66.2 million in 1990 to 85.6 million in 2009 (29%) (GSO 2009) was exceeded by rapidly increasing energy consumption, from 32.2 million tons of oil equivalent in 2000 to 50.2 in 2007 (56%) (United Nations Vietnam 2011). If strategies are not instituted for more efficient energy resource management, Vietnam will become a dependent energy-importing country by 2025 (Do and Sharma 2011). Therefore, ways and means for meeting higher demand of energy while sustaining economic development should be taken into consideration.

While agriculture is the most important economic sector in Vietnam, accounting for 21% of the country's gross domestic product in 2009 (GSO 2009), and employing 63% of the total population (IRRI 2010), it is not a major source of energy demand, consuming only 1.6% of the national total. This reflects the fact that most farms are family-run, small-scale enterprises with traditional practices. However, there is increasing reliance on agrochemical inputs which require energy to produce and transport, which builds in a degree of (increasing) energy demand.

The Ministry of Agriculture and Rural Development has been promoting production methods that reduce fertilizer applications and diminish the use of chemical crop protection, through integrated pest management (IPM) and other policies. But pressure from agrochemical producers and a desire to 'modernize' agriculture has been giving momentum to more energy-intensive agriculture in Vietnam.

Any energy savings that can be made in the agricultural sector will diminish the overall growth of demand for energy in the country, and moreover, this will reduce the 'carbon footprint' of its agricultural production. If such reductions could be made without reducing agricultural output—indeed if this can be done with increases in output—this would have desirable economic and social as well as environmental benefits.

Like in many other Asian countries, rice is an indispensable component of household food baskets in Vietnam. Rice plays an important part in Vietnamese life, since the country has been developing from a rice-based agricultural economy with total rice-cultivated land still taking up 66% of cropland (GSO 2010). Conventional rice-growing practices require large energy inputs (particularly for water, chemical fertilizers, pesticides and seeds). This not only contributes to the degradation of soil and water resources, and less directly air resources, but it also reduces economic benefits for farmers and the nation.

In order to boost rice production while reducing the use of inputs such as seeds, water, fertilizer, herbicides and pesticides, the System of Rice Intensification (SRI) practice developed in Madagascar has been introduced and promoted in many countries (http://sri.ciifad.cornell.edu), being also introduced into many provinces of Vietnam with government support since 2007 (Hoang and Vu 2006; Gorman 2008; Castillo et al. 2012).

There have been some studies making economic and environmental comparisons between results of conventional and SRI rice cultivation practices in Vietnam (Uphoff 2006; Hoang and Vu 2006; Gorman 2008). However, studies on energy analysis of agricultural production in general, and of this issue in particular, have not been applied in Vietnam. The current study has undertaken to provide insights into energy use for rice production in Vietnam and to enable comparisons between the conventional and new methods. For this purpose, data were gathered and analysed to compare conventional with SRI practices to find out how much energy and costs can be saved through the SRI practice.

Materials and methods

The study involved a comparison of energy use between conventional and the SRI methods of rice production. All energy inputs and outputs were quantified and compared in a matrix format. To gain a quicker and more precise energy analysis, the study used the *hybrid method* combining *input–output analysis* and *process analysis* (Fluck and Baird 1980). Using this method, process analysis was used to trace back the sequestered energy used in each of the principle production stages for each input item. This embodied energy value for each input was converted to a standardized energy unit (MJ) using conversion factors derived from the published literature. Subsequently, an input–output table for rice production was established, which identified and quantified all the energy inputs to production, as well as output from production (rice). Finally, the sums of energy inputs and outputs were calculated for each production system. The input–output matrix was also used in the economic analysis in the subsequent part of the study by replacing the energy equivalents with monetary values.

To obtain energy consumption data of farms producing rice with both conventional and SRI practices, a 90-farm survey was conducted using face-to-face interviews (Dialsingh 2008) between June and August, 2011 in three districts of Thai Nguyen Province (Phu Luong, Pho Yen and Phu Binh). This province was selected because there was relatively earlier introduction of SRI in this mountainous region of Vietnam and more longitudinal assessment could be done.

Identifying energy inputs and outputs

The energy analysis for rice production was carried out by quantifying the energy inputs and outputs in terms of megajoules (MJ), comparing the ratio between inputs and outputs to assess *energy efficiency*. Properly identifying all inputs and outputs plays a very important role in energy analysis. The energy inputs identified for the study include direct energy (human labour, fossil fuels, electricity and draft animal power but excluded solar energy) and indirect energy (energy to produce machinery, fertilizers, agrochemicals and seed). The principal energy output was in the form of rice. All energy inputs and outputs were calculated per hectare per rice season (spring) and then multiplied with their energy coefficients of energy equivalent (Table 1).

According to Ortiz-Canãvate and Hernanz (1999), the energy of machinery includes the energy used to process raw materials (e.g., steel = 22–60 MJ/kg), the energy consumed in the manufacturing process (87 MJ/kg), of transportation (approximately 8.8 MJ/kg) and, lastly, that used in repairs (0.97 MJ/kg). The *cumulative energy* of a tractor has therefore been calculated as 138 MJ/kg (Ortiz-Canãvate and Hernanz 1999). It is also necessary to know the weight of each machine, its expected useful life and its work capacity per hectare per hour (Ortiz-Canãvate and Hernanz 1999). The following equation is adopted from Fluck (1992) and Bockari-Gevao et al. (2005):

EID = Specific indirect energy for machinery use for a field operation, MJ/ha

$$\mathrm{EID} = \frac{\mathrm{TW} \times \mathrm{CED}}{\mathrm{UL}} \times \mathrm{h} \times \mathrm{RU}$$

Table 1 Energy equivalents of inputs and output in rice production

Items	Unit/ha	Energy equivalent (MJ/ha)	References
Input			
Human labour	H	1.96	Yaldiz et al. (1993), Ozkan et al. (2004), Bockari-Gevao et al. (2005) and Moradi and Azapour 2011
Water buffalo power	H	7.58	Ozkan et al. (2004)
Diesel fuel	L	47.8	Ortiz-Canãvate and Hernanz (1999)
Electricity	kWh	12	Ortiz-Canãvate and Hernanz (1999)
Machinery	kg	138	Ortiz-Canãvate and Hernanz (1999)
Chemical fertilizers			
Nitrogen fertilizer (N)	kg	78.1	Ortiz-Canãvate and Hernanz (1999)
Phosphorus (P_2O_5)	kg	17.4	Ortiz-Canãvate and Hernanz (1999)
Potassium (K_2O)	kg	13.7	Ortiz-Canãvate and Hernanz (1999)
Farmyard manure	kg	0.3	Namdari et al. (2011)
Pesticides	kg		
Insecticides	kg	160	Helsel (1992)
Fungicides	kg	99	Helsel (1992)
Herbicides	kg	85	Helsel (1992)
Seeds	kg	17	Heichel (1980) and Moradi and Azapour (2011)
Output			
Rice	kg	14.7	Ozkan et al. (2004) and Alam et al. 2005

where TW is total weight of the specific machine (kg); CED, cumulative energy demand for machinery (MJ/kg); UL, useful life of machinery (h); *h*, specific working hours per run (h/ha); and RU, runs, number of applications in the considered field operation.

Energy ratio

The energy ratio and energy productivity were calculated using following equations (Cherati et al. 2011)

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy productivity} = \frac{\text{Rice output (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Net energy gain} = \text{Output energy (MJ/ha)} - \text{Input energy (MJ/ha)}$$

$$\textit{Specific energy} = \frac{\text{Energy input (MJ/ha)}}{\text{Rice output (kg/ha)}}.$$

Economic analysis

The current research also used input/output analysis to assess net economic benefits. The process used was similar to that for energy analysis, and the same inputs and outputs per hectare were applied. The monetary value of machinery and water buffalo was calculated by the rent charged for them per hour. For machinery, this rent includes the capital, repair and maintenance, but not the fuel, nor the energy costs of producing the machinery. All prices of input and output were defined by the market prices prevailing in the year 2011. The results of the economic benefits analysis were organized to show both a ratio of physical output to input and a benefit–cost ratio reflecting economic feasibility.

Results and discussion

Energy analysis

The inputs and outputs of rice cultivation are shown in Fig. 1.

Energy inputs

It was seen that total direct energy input was only about one-third of the total indirect energy. Fertilizers account the highest share of the total (64%); next are human labour and diesel fuel (Table 4). SRI methods reduce total direct energy by about 4–5%. In terms of total indirect energy, on the other hand, the SRI method makes a remarkable reduction of almost 28%.

The greatest reduction in direct energy inputs for the SRI method compared to the conventional one is in labour

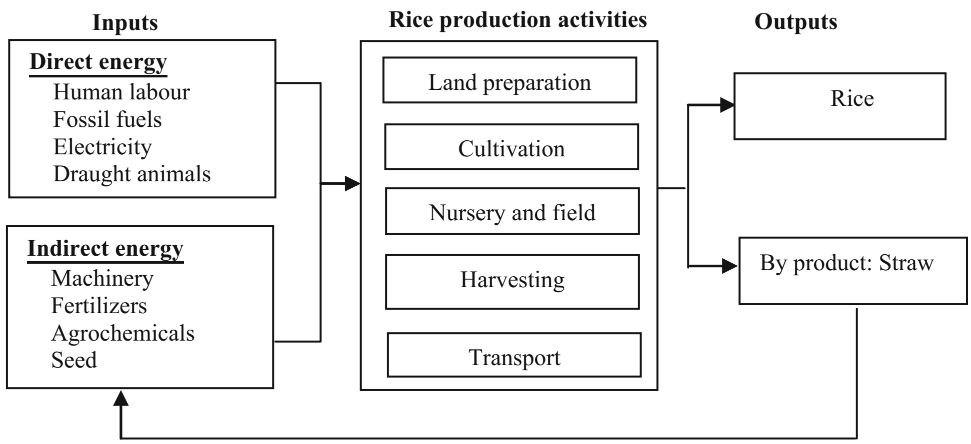

Fig. 1 Flow sheets for energy balance in rice production

(11–12%). In both *manual* and *mechanized ploughing operations*, the most labour reductions are found in cultivating and nursery and field management. By introducing innovation in plant spacing, greatly reducing plant populations (by about 75%) with wider spacing between plants, this new method diminishes the time that farmers must spend in one of their hardest and most time-consuming, which is seedling transfer and transplanting. Differences in labour between *manual and machinery ploughing operations* are also noteworthy. *Mechanized ploughing* with tractors has the effect of releasing human labour from ploughing and transporting. The labour energy consumed for ploughing decreases threefold, from around 780 MJ in manual operations to 220 MJ with machinery operation. Tractors also used as a transporter to carry input materials (fertilizers, chemicals, etc.) to the field and bring harvested paddy back the farmhouse. Hence, the transporting labour in mechanized ploughing also reduces from over 217 to 136 MJ. Total labour energy in mechanized ploughing operations is reduced by about 400 MJ compared to manual ploughing (Tables 2, 3).

In terms of indirect energy, SRI contributes to decreasing the considerable volume of chemical fertilizers and pesticides applied. In detail, the SRI method contributes to a reduction of about 28% in total energy consumed in chemical fertilizers, within which energy consumption for N and P_2O_5 is cut down by over 27 and 36%, respectively. Total chemical fertilizer applications in SRI method decrease by 5905 MJ. SRI method also decreases significantly the amount of energy consumption in applying pesticides. The energy consumed for insecticides declines by about 26%, and there is nearly a 50% reduction in energy use saved in the fungicide application (approximate 68 MJ compared to 138 MJ). More notably, herbicides are totally omitted in the SRI method as manual control, with a mechanical hand weeder or weeding by hand, is undertaken with the supplementary benefit of increasing soil aeration, thereby enhancing root growth and yield (Table 4).

Over 75% reduction in seed requirements is one of the significant innovations of the SRI method. In the conventional method, a hectare of paddy field requires 76 kg of seeds, while the SRI method uses only 19 kg for a hectare of paddy field. Hence, this saves nearly 1000 MJ of energy (Table 4).

Total energy inputs therefore reduce by 7429 and 7415 MJ with machinery and manual ploughing, respectively. This is equivalent to approximately 0.18 tons of oil and 2060 kWh of electric power consumption saved.

Energy consumption is also related to environmental impacts mainly involve the emission of atmospheric pollutants such as SO_2, NO and CO_2—a factor of climate change (Nguyen 1997). According to factsheet of United Nations Vietnam (2007), total CO_2 emissions include energy, industrial processes, agriculture, waste and the sector of land use, land-use change and forestry. Total CO_2 emissions in Vietnam increased five times in the period of 1990–2007 (from 20,000 to 150,000 thousand metric tons of CO2). Therefore, cut-down energy inputs by SRI practice contribute to CO_2 reduction and mitigate climate change. This sparks a new direction for calculating CO_2 emission and reducing impacts of climate change by ecological agricultural production practices such as SRI in future research.

Although mechanized ploughing makes a great contribution to decreasing human labour, its total energy inputs are 22–23% more than manual ploughing due to high use of diesel fuel.

Energy outputs

Low-density transplanting and draining fields after irrigation in the SRI method promote the development of roots, make the plants healthier and induce better tillering than in the conventional method. Therefore, the SRI method produces higher rice productivity than the conventional method, by 555 kg per hectare for the farming operations

Table 2 Energy used in human labour with manual ploughing operations

Types of work	Conventional		SRI		Difference (%)
	Working hours/ha	Energy (MJ/ha)	Working hours/ha	Energy (MJ/ha)	
Tilling the field	295.30	578.79	295.30	578.79	0.00
Cultivating operations	421.98	827.08	301.48	590.90	−28.56
Sowing	60.03	117.66	58.57	114.80	−2.43
Seedling transfer	122.51	240.12	79.14	155.11	−35.40
Transplanting	239.44	469.30	169.24	331.71	−29.32
Nursery and field management	711.81	1395.15	602.16	1180.23	−15.40
Applying fertilizers	441.27	864.89	234.26	459.15	−46.91
Applying pesticides	171.40	335.95	55.56	108.90	−67.59
Weeding	99.14	194.31	312.34	612.19	215.05
Harvesting	525.14	1029.28	527.06	1033.05	0.37
Reaping	268.53	526.32	269.54	528.31	0.38
Threshing	23.06	45.20	23.31	45.69	1.08
Drying	178.07	349.02	178.17	349.21	0.06
Packing	55.48	108.74	56.04	109.84	1.01
Transportation	111.12	217.80	111.12	217.80	0.00
Total	2065.35	4048.09	1837.12	3600.76	−11.05

Table 3 Energy used in human labour with mechanized ploughing operations

Types of work	Conventional		SRI		Difference (%)
	Working hours/ha	Energy (MJ/ha)	Working hours/ha	Energy (MJ/ha)	
Tilling the field	112.51	220.52	112.51	220.52	0.00
Cultivating operations	419.56	822.33	302.87	593.63	−27.81
Sowing	60.00	117.61	58.48	114.62	−2.54
Seedling transfer	119.53	234.28	75.49	147.96	−36.85
Transplanting	240.02	470.44	168.90	331.05	−29.63
Nursery and field management	710.33	1392.26	603.94	1183.72	−14.98
Applying fertilizers	438.09	858.66	235.57	461.73	−46.23
Applying pesticides	174.18	341.39	57.23	112.16	−67.15
Weeding	98.06	192.20	311.14	609.83	217.28
Harvesting	525.14	1029.28	527.06	1033.05	0.37
Reaping	268.53	526.32	269.54	528.31	0.38
Threshing	23.06	45.20	23.31	45.69	1.08
Drying	178.07	349.02	178.17	349.21	0.06
Packing	55.48	108.74	56.04	109.84	1.01
Transportation	69.45	136.12	69.45	136.12	0.00
Total	1836.99	3600.50	1615.83	3167.03	−12.04

studied (5070 kg in conventional method compared to 5626 kg in the SRI method) (Table 4).

Regarding outputs, the effectiveness of SRI in the study area is lower than the average yield increase for the nation as a whole and much lower than other countries (Table 5). According to statistics from Africare et al. (2010), the average yield increase in 13 districts across Vietnam (2007–2008) was 17%—ranked at the bottom of the list compared to other countries, which have a yield increase range from 24 to 105%. In contrast, in the study area the productivity increase in comparisons between the SRI and conventional methods is only approximately 11%. This

Table 4 Energy inputs and outputs in conventional and SRI methods of rice production

Items	Unit/ha	Energy equivalent (MJ/ha)	Conventional		SRI		Difference (%)
			Quantity/ha	Energy (MJ/ha)	Quantity/ha	Energy (MJ/ha)	
Energy inputs							
Direct energy							
Human labour	hr	1.96					
Manual plough			2065.35	4048.09	1837.12	3600.76	−11.05
Machinery plough			1836.99	3600.50	1615.83	3167.03	−12.04
Water buffalo	hr	7.58	362.75	2749.65	362.75	2749.65	0.00
Diesel fuel	l	47.8	78.05	3730.79	78.05	3730.79	0.00
Electricity	kwh	12	21.42	257.04	22.59	271.08	5.46
Indirect energy							
Machinery	kg	138	300.00	17.25	300.00	17.25	0.00
Chemical fertilizers			700.33	21,014.73	506.99	15,109.04	−28.10
Nitrogen fertilizer (N)	kg	78.1	153.07	11,954.77	111.12	8678.47	−27.41
Phosphorus (P_2O_5)	kg	17.4	422.26	7347.32	272.24	4736.98	−35.53
Potassium (K_2O)	kg	13.7	125.01	1712.64	123.62	1693.59	−1.11
Farmyard manure	kg	0.3	8476.23	2542.87	8502.07	2550.62	0.30
Pesticides			2.67	331.91	1.53	201.11	−39.41
Insecticide	kg	160	1.14	182.40	0.83	132.80	−27.19
Fungicide	kg	99	1.39	137.61	0.69	68.31	−50.36
Herbicide	kg	85	0.14	11.90	0.00	0.00	−100.00
Seeds	kg	17	76.40	1298.80	19.45	330.65	−74.54
Total energy inputs							
Manual ploughing				32,243.08		24,813.92	−23.04
Mechanized ploughing				32,793.89		25,378.66	−22.61
Energy outputs							
Rough rice	kg	14.7	5069.85	74,526.80	5625.45	82,694.12	+10.96
Straw	Kg	19.7	6337.31	124,845.01	7031.81	138,526.66	+10.96
Total output				199,371.81		221,220.78	+10.96

lower-than-expected improvement in productivity may be due to inappropriate technical application by the farmers. Farm households are still being affected by memories of the conventional method and do not always apply the correct SRI techniques, such as using denser spacing of plants than recommendations, draining water untimely or applying a large amount of fertilizers and chemicals.

The quantity of straw harvested is 1.25 times the weight of rough rice; therefore, straw contains large amount of energy (124,845 MJ), which is much higher than the 74,526 MJ of rice energy.

Energy indices

Energy output–input ratio (*energy efficiency*) obtained with SRI method was 8.72 with mechanized ploughing and 6.08 with manual ploughing, while for the conventional method. The *energy productivity* indicates per MJ of energy consumed, and there are 0.15–0.16 kg of rice produced in the conventional method and 0.22–0.23 kg in the SRI method, a difference of about 43%. Meanwhile, the results of *specific energy* indicate that the conventional method requires 6.36–6.47 MJ of energy to produce a kilogram of rough rice while with the SRI method, about 4.41–4.51 MJ of energy is consumed to produce 1 kg of rice. This means that each kilogram of rice produced by SRI method will save approximately 2 MJ of energy compared with the conventional method of rice cultivation (Table 6).

Economic analysis

Economic inputs and outputs of rice production with the conventional and SRI methods are shown in Table 5. The study results indicate that SRI reduces total economic inputs by over 4.5 million VND, while it increases outputs considerably, by around 3 million VND per hectare with rough rice and 1 million with by-products (straw). As a result, applying the SRI method significantly increases net

Table 5 Comparison of yield increase from SRI methods in eight countries (*Source* Africare et al. 2010)

Country	(*N*)	Evaluation for/by	Yield increase (%)
Bangladesh (2002–04)	1073[b]	IRRI-BD/BRAC, SAFE, Syngenta BD	24
Cambodia (2004)	500[a]	GTZ	41
(2004)	120[c]	CEDAC	105
China: Sichuan (2004)	82[a]	CAU	29
India: Tamil Nadu (2004)	100[b]	TNAU	28
Andhra Pradesh (2003–04)	1535[b]	ANGRAU	38
West Bengal (2004)	108[b]	IWMI—India	32b
Indonesia (2002–06)	12,112[b]	Nippon Koei	78
Nepal (2006)	412[b]	DADO[e]	82
Sri Lanka (2004)	120[a]	IWMI—SL	44
Vietnam (2007–2008)	[d]	National IPM Program	17 (13–done29)
Total	16,162		47

N number of farmers

[a] Based on random samples

[b] Results are from all cases using SRI methods covered in evaluation, no sampling

[c] Results of NGO study of 120 farmers who had 3 years of experience with SRI methods as of 2004

[d] Results from Farmer Field School trials in 13 districts across Vietnam, with 1274 farmers participating; total number of SRI farmers in these districts in 2008 was 96,544, according to records of the Ministry of Agriculture and Rural Development's National IPM Program

[e] Morang District Agricultural Development Office, Government of Nepal

Table 6 Energy ratio in rice production

	Conventional		SRI	
	Manual ploughing	Mechanized ploughing	Manual ploughing	Mechanized ploughing
Output–input ratio	6.18	6.08	8.92	8.72
Energy productivity (kg/MJ)	0.16	0.15	0.23	0.22
Specific energy (MJ/kg)	6.36	6.47	4.41	4.51
Net energy gain (MJ)	167,128.72	166,577.91	196,406.85	195,842.11

economic benefits for farmers. Averaged, each hectare of rice SRI cultivation increases by 8 million VND of benefits compared to conventional method (Table 7). In contrast to the energy use, mechanized ploughing brings higher economic efficiency than manual ploughing by more than 3 million VND/ha.

Through the case of SRI, we can see that these small changes in agricultural production techniques can create large changes in more efficient energy use and increased income for farmers. Therefore, improvements in agricultural production at the household level are needed and should be further promoted to develop a sustainable agriculture.

Energy efficiency policies in agriculture

Results from the survey show that there is almost no information provided by local government at the household level about energy efficiency use in rice production; it is time that agricultural policy in Vietnam be recast to consider energy efficiency as a criterion and goal.

Tracing the current agricultural energy efficiency policies in Vietnam reveals that there are many issues to be discussed. Energy efficiency and conservation have been considered as *an key item on promoting energy security and protecting environment* by the Vietnamese government (Do and Sharma 2011). The first legal document on energy efficiency and conservation (Decree No. 102/2003/ND-CP on Thrifty and Efficiency Use of Energy) was issued in 2003 (PM 2003). However, this decree was aimed only at raising public awareness. In order to put the decree into life, the National Strategic Program on Energy Savings and Effective Use for the period 2006-2015, Decision No. 79/2006/QD-TTg (PM 2006) was released.

The National Strategic Program was considered to be one of the most crucial and comprehensive energy efficiency legislative provisions enacted to date. It has

Table 7 Comparison of economic inputs and outputs between conventional and SRI rice production methods

	Unit/ha	Value (VND[a])	Conventional		SRI		Difference (VND)
			Quantity per ha	Total value (VND)	Quantity per ha	Total value (VND)	
Inputs							
Human labour							
Manual ploughing	hr	12,500	2065.35	25,816,935	1837.12	22,964,000	−2,852,875
Machinery ploughing	hr	12,500	1836.99	22,962,425	1615.83	20,197,875	−2,764,500
Water buffalo power	hr	10,000	362.75	3,627,500	362.75	3,627,500	0
Diesel fuel	l	21,000	78.05	1,639,083	78.05	1,639,050	0
Electricity	kWh	1300	100.13	130,165	46.34	60,242	−69,927
Machinery	kg	12,000	97.22	1,166,640	97.22	1,166,640	0
Chemical fertilizers			700.33	3,252,205	506.99	2,571,020	−681,210
Nitrogen fertilizer (N)	kg	7000	153.07	1,071,475	111.12	777,840	−293,650
Phosphorus (P_2O_5)	kg	2500	422.26	1,055,640	272.24	680,600	−375,050
Potassium (K_2O)	kg	9000	125.01	1,125,090	123.62	1,112,580	−12,510
Farmyard manure	kg	300	8476.23	2,542,870	8502.07	2,550,621	7,752
Pesticides	kg		2.67	127,119	1.53	77,400	−49,820
Insecticide	kg	60,000	1.14	68,339	0.83	49,800	−18,600
Fungicide	kg	40,000	1.39	55,560	0.69	27,600	−28,000
Herbicide	kg	23,000	0.14	3,220	0.00	0	−3,220
Seeds	kg	18,000	76.395	1,375,110	19.446	350,028	−1,025,082
Total inputs							
Manual ploughing	kg			36,871,973		32,200,811	−4,671,162
Mechanized ploughing				33,195,663		28,612,876	−4,582,787
Outputs							
Rough rice		5,500	5069.85	27,884,175	5625.45	30,939,975.00	3,055,800.00
Straw	kg	1.5	6337.31	9,505,965	7031.81	10,547,715.00	1,041,750.00
Total outputs				37,390,140		41,487,690.00	4,097,550
Economic ratio (output/inputs)							
Manual ploughing				1.01		1.29	
Mechanized ploughing				1.13		1.45	
Economic benefits							
Manual ploughing				518,167		9,286,879	8,768,712
Mechanized ploughing				4,194,477		12,874,814	8,680,337

[a] 1 USD = 22,660 VND

components establishing economic and efficient use of energy in industry, transportation and buildings; raising public awareness about using energy efficiently through propaganda and education; and developing and applying energy-saving applications. Decision No. 79/2006/QD-TTg also proposed a target of saving 3–5% of total national energy consumption over the period 2006–2010 and 5–8% over 2011–2015. However, provisions for energy use in agriculture, as well as sectoral quantitative targets, were not mentioned.

The first law on energy efficiency and conservation No. 50/2010/QH12, dated 17/6/2010, was introduced and has been in force since 1 January 2011 (NA 2010). Articles 22–25, chapter 5, made provisions for efficient use of energy in agriculture for the first time. According to these, solutions for efficient use of energy in agriculture and rural areas included changes in planning and implementation for agricultural production to assure energy-saving uses; reducing energy consumption in households through applying modern technology and research results; removing obsolete equipment in agriculture; and propagating and educating to increase household awareness of the efficient use of energy. Also, the law emphasizes using energy efficiently in irrigation pumps, reducing loss of energy during production and incentivizing the use of renewable energy such as solar, wind energy and energy from by-products.

To bring the law into life, decrees and circulars were issued. Decree No. 21/2011/ND-CP detailing the Law on Economical and Efficient Use of Energy and measures for its implementation up to now is the most comprehensive guide to enact the law on energy efficiency and conservation No. 50/2010/QH12, in which Ministry of Agriculture and Rural Development is responsible for (a) promulgating standards and technical regulations on economical and efficient use of energy in agricultural and/or irrigation production; (b) chairing and collaborating with the Ministry of Industry and Trade in guiding the management of energy utilization for key energy-using units in agricultural production; training and guiding the implementation of measures for economical and efficient energy use in agricultural and irrigation production; (c) organizing courses and workshop to improve knowledge on economical and efficient energy use in agriculture, rural area and irrigation production. In addition, National Action Plan for Green Growth 2014-2020 (Decision No. 403/QD-TTg dated March 20, 2014 of the Prime Minister) built activities for energy saving from 2014 to 2020. Five activities in agriculture were established. Notably, applying organic cultivation approach and improving management skills to reduce GHG emission/technology/innovation were considered in the National Action Plan. This will facilitate for more new cultivation practices which saving energy such as SRI implemented and scale up in large area. However, plans are still general, and no specific legislation related to energy use in agriculture has been released to carry out activities.

Therefore, until now local governments have not responded much to this law and, as a result, the law's effects have not come down to the farm household level. Reviewing current energy efficiency policies in Vietnam, Do and Sharma (2011) commented that government policies on energy efficiency and conservation were based on weak foundations. One of the major reasons is due to no specific policies being issued to promote research and development in energy efficiency. This leads to a lack of comprehensive data and analysis on determining the efficiency of potential energy improvements (AEWG 2009). As a result, strategies and policies remain impractical. In addition, other factors that could impede the promotion of energy efficiency activities are limited to information on advanced technologies and programmes in energy efficiency adopted elsewhere in the world. The lack of authorization for using or changing technologies and equipment leads to the presence of low-quality, highly energy-consuming products on the market (AEWG 2009).

Adoption of SRI

One of the most severe obstacles to adoption of SRI currently is the belief and habits of farmers who are used to the conventional method. Many such farmers do not believe in the new method, perceiving it as risky, and they will not venture to make the changeover. For introducing any new technology or new policies, farmers' perceptions and attitudes are one of the most important factors—and changing these will contribute most to the success of energy efficiency policies in general and to acceptance of the SRI method in particular. In addition, information is another important factor. Currently, information on SRI is provided to households in the study area and training courses about SRI have also taken place. However, this type of information is still limited and has not reached all households—one of the reasons being a lack of support funding from the government. There are also infrastructural problems for applying SRI, such as the irrigation and drainage system in the fields which do not enable farmers and communities to issue smaller but reliable amounts of water to farmers on an agreed schedule. SRI only brings the highest yield when irrigation is well controlled. This aspect should, therefore, receive more financial and technical support from the government. Given the growing scarcity of water for agriculture (due to both reductions in supply and competing demands from other sectors) and the ensuing rising value (cost) of water, investments in water control will give demonstrably higher returns when rice production methods convert to SRI.

Conclusion

With a view to comparing energy and economic efficiency between conventional and new methods of rice production, the study carried out a face-to-face survey of farming households in Thai Nguyen Province, Vietnam. Through analysis of energy input–output balances, combined with economic efficiency analysis, the study shows that the new SRI method is an effective innovation for rice production—in terms of both energy and economic efficiency. A hectare of paddy rice cultivated with SRI practices can save around 23% of energy inputs and generate a more than 7 million VND increase in net farmer income compared to the results with conventional method. By-product such as straw contains a huge source of energy, however, is often lost through feeding animal and burning. How to use this energy source efficiently should be paid more attention.

This efficiency derives from a combination of a remarkable decrease in inputs accompanied by an increase in outputs. Such results imply that a more environmentally friendly method in agricultural production contributes significantly not only to conserving energy which reduce CO_2 emission, mitigate climate change but also to improving income for farmers. Notably, implementing the new method needs only small changes in the perceptions of farmers and in the techniques that they adopt in production. Therefore, the study is meaningful in stimulating new ideas and innovations in agricultural production following the trend of energy saving and economic increase.

The study also showed that either SRI or conventional methods with machinery ploughing are less energy-efficient but more economically advantageous than manual operations due to the remarkable reduction in human labour costs that mechanization accomplishes. Therefore, how to use energy more efficiently in agricultural machinery should be more researched.

However, SRI is a step on the road to improvement, and more changes still need to be made to improve the energy efficiency—such as further reducing inputs from human labour, fertilizers and pesticides. Also, it is also found that the benefits of applying SRI in the case study were still less than in other regions. One of the reasons for this was incorrect application in techniques of farmers, many of whom are still be influenced by the conventional method. Also, the beliefs and habits are the main obstacles preventing farmers from taking part in the application of the mew method.

The study also showed that information on the efficient use of energy at the farm household level is too little. This may derive from weaknesses in the government's energy efficiency and conservation policies, especially in agricultural sector. Some recommendations for energy efficiency policies in agricultural sectors should be considered, including:

- Issuing regulations of quality standards for new agricultural equipment and also establishing regional network for testing efficient use of agricultural machinery.
- Promoting researches and development into technical progress to improve more efficient energy use in agricultural equipment and techniques as well as new methods in agricultural production.
- Undertaking more analysis in energy use and conservation and develop databases to assist programme evaluation and policy formation. Establish an official agency which is responsible for conducting and collecting database in this field is necessary.
- Establishing finical policies such as low-interest loans and direct payments to support for farm households in applying researches in production and new energy-saving equipment in agriculture.
- Enhancing information provision and technical assistance and training to farm level to increase their awareness in use energy efficiently. For examples, set up courses and workshops to introduce appropriated agricultural machinery to farmers, train them operating machines to maximize utilization efficiency of these machines; educating programmes in applying fertilizers, pesticides also should be undertaken. Providing information through mass media also should be promoted.
- Increasing linkage between ministries, sectors in establish policies in energy efficiency and conservation and, in addition, enhancing cooperation of government with non-governmental organizations such as FAO and IRRI to approach new techniques and technologies in production and cooperation with the region (ASEAN) and the world to promote agreements in energy efficiency use, especially in agriculture.

References

Africare, Oxfam America, WWF-ICRISAT Project (2010). More Rice for People, More Water for the Planet. WWF-ICRISAT Project, Hyderabad, India

AEWG (2009) Peer review on energy efficiency in Vietnam. Final Report. In: The 38th APEC Energy Working Group Meeting, Bali, Indonesia

Alam MS, Alam MR, Islam KK (2005) Energy flow in agriculture: Bangladesh. Am J Environ Sci 1(3):213–220

Bockari-Gevao SM, Wan Ishak bin WI, Yahya A, Wan CC (2005) Analysis of energy consumption in lowland rice-based cropping system of Malaysia. Songklanakarin J Sci Technol 27(4):820–826

Castillo GE, Minh NL, Pfeifer K (2012) Learning from the system of rice intensification in North Vietnam. Series on scaling up in agriculture, rural development and nutrition, Brief 15, June. International Food Policy Research Institute, Washington, DC

Cherati FE, Bahrami H, Asakereh A (2011). Energy survey of mechanized and traditional rice production system in Mazandaran Province of Iran. Afr J Agric Res 6 (11):2565–2570. http://www.academicjournals.org/AJAR

Dialsingh I (2008) Face-to-face interviewing. In: Lavrakas P (ed) Encyclopedia of survey research methods. SAGE Publications Inc, Thousand Oaks, pp 260–262. doi:10.4135/9781412963947.n174

Do TM, Sharma D (2011) Viewpoint Vietnam's energy sector: a review of current energy policies and strategies. Energy Policy 39:5770–5777

Dzung NT (2010) SRI Viet Nam: The updated report on the Development of System of Rice Intensification (SRI) in Vietnamto Oxfam America, 2010

Fluck RC (1992) Energy analysis for agricultural systems: energy in farm production. In: Fluck RC (ed) Energy in world agriculture, vol 6. Elsevier, Amsterdam, pp 45–53

Fluck RC, Baird CD (1980) Agricultural energetics. Avi Publishing Company, Westport

Gorman T (2008) SRI in Vietnam: an update. Oxfam, Plant Protection Department/MARD, and the Centre for Sustainable Rural Development, Hanoi

Government of the Socialist Republic of Viet Nam (2011) Decree No. 21/2011/ND-CP detailing the Law on Economical and Efficient Use of Energy and measures for its implementation

GSO (2009) The 2009 Vietnam population and housing census: completed results. General Statistical Office, Statistical Publishing House, Hanoi, Vietnam

GSO (2010) Statistical handbook of Vietnam. General Statistical Office, Statistical Publishing House, Hanoi

Heichel GH (1980) Assessing the fossil energy costs of propagating agricultural crops. In: Pimentel D (ed) Handbook of energy utilization in agriculture. CRC Press. Inc., Boca Raton, pp 27–34

Helsel ZR (1992) Energy and alternatives for fertilizer and pesticide use. In: Fluck RC (ed) Energy in world agriculture, vol 6. Elsevier, Amsterdam, pp 177–201

Hoang VP (2005) Results of study on the System of Rice Intensification (SRI) in Thai Nguyen and Bac Giang Provinces in spring rice crop of year 2005. Sci Technol J Thai Nguyen Univ, vol 35, No.3/2005

Hoang VP (2012) Study on application of the system of rice intensification (SRI) on rainfed land in Vo Nhai District, Thai Nguyen Province. Sci J Agric Rural Dev, Ministry of Agriculture and Rural Development. No.10/2012

Hoang VP, Vu TD (2006) The prospectives of application of system of rice intensification (SRI) in rice production in the Northern Midlands and mountainous areas of Vietnam. In: Proceedings of the national science conference on research and technology development to serve the development of agriculture and rural development of the northern mountainous area, years of 2000–2005, March 2006

IRRI (2010) IRRI World Rice Statistics (WRS). International Rice Research Institute: Philippines. http://beta.irri.org/solutions/index.php?option=com_contentandtask=viewandid=250. Accessed 22 Nov 2011

Khan MA, Khan S, Mushtag S (2009) Energy and economic efficiency analysis of rice and cotton production in China. Sahad J Agric 25(2):291–300

Mishra A, Salokhe VM (2008) Growing more rice with less water in Asia: identifying and exploring opportunities through system of rice intensification. Agricultural Systems and Engineering Asian Institute of Technology, Bangkok, Thailand. [might cite instead their article in EXPERIMENTAL AGRICULTURE]

Moradi M, Azapour E (2011) Study of energy indices for native and breed rice varieties production in Iran. World Appl Sci J 13(1):137–141

NA (2010) Energy efficiency and savings Law No. 50/2010/QH12 approved by the 12th National Assembly on 28/06/2010

Nguyen HN, Hoang VP (2005) The study on the system of rice intensification (SRI) in Thai Nguyen province in spring rice crop of year 2004. Sci J Agric Rural Dev, Ministry of Agriculture and Rural Development, vol. 53, No. 3 + 4/2005

Namdari M, Kangarshahi AA, Amiri NA (2011) Econometric model estimation and sensitivity analysis of inputs for mandarin production in Mazandaran Province of Iran. Res J Appl Sci Eng Technol 3(5):464–470

Nguyen TA (1997) Energy and environmental issues in Vietnam. Nat Resour Forum 21(3):201–207

Ortiz-Canãvate J, Hernanz JL (1999) Energy for biological systems. In: Kitani O (ed) CIGR handbook of agricultural engineering, volume 5—energy and biomass engineering. ASAE Publication, Washington, pp 13–23

Ozkan Burhan, Akcaoz Handan, Fert Cemal (2004) Energy input–output analysis in Turkish agriculture. Renew Energy 29:39–51

PM (2003). Decree No.102/2003/ND-CP on Thrifty and Efficiency Use of Energy. Prime Minister: Hanoi, September, 2003

PM (2006) The National Energy Efficiency Program for the period 2006–2015. Prime Minister's Decision No. 79/2006/QD-TTg: Hanoi, April 2006

PM (2014) Approval of the National Action Plan on Green growth in Vietnam. Prime Minister's Decision No. 403/2014/QD-TTg: Hanoi, March 2014

United Nations Vietnam (2011) Climate change fact sheet: greenhouse gas emissions and options for mitigation in Vietnam, and the UN's responses: version of 11 April, 2011. United Nations, Vietnam

Uphoff N (2006) Report on visit to Vietnam to review SRI progress—January 3–15, 2006. CIIFAD (Cornell International Institute for Food, Agriculture and Development), USA

Yaldiz O, Ozturk HH, Zeren Y, Bascetomcelik A (1993) Energy usage in production of field crops in Turkey. In: 5th international congress on mechanization and energy use in agriculture, 11–14 October, 1993, Kusadasi, Turkey