Indian Journal of Ecology (2022) 49(2): 629-635
DOI: https://doi.org/10.55362/IJE/2022/3571

Manuscript Number: 3571
NAAS Rating: 5.79

Energy Use Pattern and its Efficiency in Paddy Cultivation in Indian Punjab

S. Ranguwal and J. Singh

Department of Economics and Sociology
Punjab Agricultural University, Ludhiana-141 004, India
E-mail: sangeet@pau.edu

Abstract: Efficient use of energy resources in agriculture is one of the pre-requisites for sustainable agricultural production. Energy intensive paddy cultivation is blamed for several ecological problems of the Indian Punjab. In this backdrop, the present study was carried out to measure the energy use pattern in paddy cultivation across different farm categories along with identification of wasteful uses and calculation of energy use efficiency (EUE) in Punjab during 2018-19. The total energy expended in paddy cultivation was 47014.69 MJ/ha and the average energy use showed an inverse relationship with the farm size. Among different energy sources, chemical fertilizers were the dominant ones (42%) followed by electricity consumption for irrigation (36.05%), machine energy (18%), diesel fuel (17%), human labour (1.36%) and FYM (1.11%).The use of chemical, mechanical and electrical energy varied positively with the farm size while it varied negatively for human and animal labour, seed and FYM. Net energy gain was estimated at 0.175 million MJ/ha. High EI of 6.77 MJ/Kg with a low energy productivity index of 0.148 kg/MJ indicated that there is room for improving energy productivity. The EUE for small farmers (4.98) was the highest. Very high use of NRE and commercial energy was observed which could be harmful to the environment and ecology in the long run.

Keywords: Energy use efficiency, Farm category, Inputs, Paddy, Renewable

Energy is an integral part to overall human development process. It has turned out to be the most valuable input in agriculture in its various forms. Agriculture, basically an energy conversion industry, requires energy as an essential input to production, enhancing food security, adding value and contributing to rural economic development. Efficient use of energy resources in agriculture is one of the principal requirements for sustainable agricultural production as it not only provides financial savings and fossil resources preservation but also reduces air pollution. In India, agriculture has transformed into a commercial entity, largely due to technological innovations which call for large scale use of energy making it imperative to carry out analysis of energy use in crop production systems. Thus, right source and appropriate mix of energy input into crop production is very important from the economic as well as environment point of view. The steady decline in the energy-use efficiency in the present agriculture is also a matter of great concern and calls for optimal and proper utilization of energy inputs involved in various farm operations (Kumar et al 2020, Praveen et al 2021). For farms operating at lower levels of efficiency, sufficient potential exists for improving the productivity by proper management and allocation of the existing resources and technology (Samarpitha et al 2016). Therefore, there is need to access the energy trends in agriculture and to know how far can farms increase their output simply by efficiently utilizing the available resources.

In India, rice is the staple food crop for more than 70 per cent people and accounts for 40-45 per cent of the total area covered by cereal crops. Punjab state with 3.1 million hectares of land under rice contributes about 21 per cent of rice to the national pool. However, energy intensive paddy cultivation is blamed for several ecological problems of the state. Besides depleting the ground water, the consumption of energy in pumping underground water for paddy cultivation is increasing overtime. Electricity being free for agriculture sector, the financial burden on state exchequer has been increased enormously. Therefore, present study was carried out to measure the energy use pattern in paddy cultivation across different farm categories along with identification of wasteful uses and calculation of energy use efficiency (EUE) in Punjab.

MATERIAL AND METHODS

The present study was carried out in the Punjab state. The cross-section data pertaining to the agricultural year 2018-19 were taken from the data collected under centrally sponsored 'Comprehensive scheme to study the cost of cultivation of principal crops in Punjab' operating in the Department of Economics and Sociology, Punjab Agricultural University, Ludhiana for the present study. The data were collected from a sample of 300 farm households in 30 tehsils spread across the three agro-climatic zones of the Punjab state. From each zone, farmers were selected using three-stage stratified sampling technique, with tehsil as stage one, a village/cluster of villages as stage two and operational holdings within the clusters as stage three. From each village/cluster, a sample of ten operational holdings i.e. small (< 1 -2 ha), Medium (2-6 ha) and large (≥6 ha) were selected randomly. Requisite information relevant to various inputs used in paddy cultivation such seed, diesel fuel, fertilizers (N, P_2O5 and K_2O), chemicals, crop yield (economical yield), total working hours of labors as well as draught power used for different farm operations along with total working hours of agri-machinery and equipment etc. were recorded. Data on crop grain yield was used for the estimation of straw yield using crop to residue ratio method (Chauhan 2012).

Estimation of input energy expenditure: The data on inputs and output was converted to energy units using embodied energy equivalents for each input and output energy type, and expressed in Mega Joules (MJ) using specific energy coefficients (Table 1). The energy requirement of electricity consumed for lifting groundwater for irrigation purpose was calculated using capacity of the electric motor/submersible pump-set and duration of pump-set run as following:

Electricity consumption (KWh) =

Capacity of the electric motor/submersible pump-set (HP)×duration of pump-set run× 0.746

Table 1. Energy coefficients used in energy calculation for paddy cultivation

Energy source	Energy coefficient (MJ unit^{-1})
Human labour (h)	
Adult man	1.96
Adult woman	1.57
Animal labour (h)	14.05
Fertilizer(kg)	
N	60.6
P_2O_5	11.1
K_2O	6.7
Farmyard manure (FYM)	0.3
Chemicals (kg)	
Granular chemicals (Kg)	120*
Liquid chemicals (l)	102**
Machinery (h)	62.7
Diesel (l)	56.31
Seed/Grain (kg)	14.57
Straw (kg)	12.5
Electricity (kWh)	11.93

Source: Singh and Singh, 2002; *Canakciet al2005, **Gopalanet al1978

Average annual fuel consumption for a specific make and model tractor was approximated as follows (Grisso et al 2004):

Average diesel fuel consumption (Litre/h) = 0.305 × Ppto

Where *Ppto* = maximum power take-off power, KW

The input energy used in engaging agri-machinery was computed from the total weight, useful life, energy coefficient and time of operation. The conversion coefficients used to compute energy values for different agri-machinery were 87.63 MJ/kg for combine harvester,93.61MJ/kg for tractor and 62.7 MJ/kg for other agri-machinery i.e. cultivator, disk harrow, planker (Canakciet al 2005). Economic life of agri-machinery stated in the American Society of Agricultural and Biological Engineers (ASABE) standards were used in the estimation of agri-machinery energy expenditures. Data regarding average weights of different agri-machinery was collected and used to compute energy inputs from agri-machinery as explained in the following equation:

$$ME = \frac{W}{L \times A} \times C \times T$$

where,

ME is agri-machinery energy (MJ/ ha),C is conversion factor for the machinery (MJ/Kg)

W is weight of machinery (kg), L is the useful life of the machinery (h),T is the working time (h) and A is the area under paddy (ha).

Further, each agricultural input was categorized as direct and indirect energy source. Direct energy sources (DE) are those which bring out the intended energy directly viz. diesel fuel, human labour, animal labour, electricity and irrigation, while the indirect energy sources (IDE) comprised energy sources i.e. seed, agri-machinery, fertilizers and chemicals used in paddy cultivation. Renewable energy (RE) includes seed, labour and irrigation, while NRE comprises diesel fuel, agri-machinery, electricity, chemicals and fertilizers.

Energy indices: Agriculture is not only a consumer of energy but also producer of energy in the form of energy output. To compare how efficiently paddy crop converts input energy into output energy following ratios were carried out.

Net energy (MJ/ha) = Output energy (MJ/ ha) - Input energy (MJ/ ha)

Specific energy or Energy Intensity (MJ/kg) = Input energy (MJ) /Crop yield (Kg)

Energy use efficiency (EUE) = Output energy (MJ / ha)/Input energy (MJ / ha)

Energy productivity (kg/MJ) = Economic output (Kg/ha) /Input energy (MJ/ha)

RESULTS AND DISCUSSION

Input energy use in paddy cultivation : The farmers were using energy from nine different sources for paddy cultivation i.e. human, draught animals, machines, diesel fuel, seeds, fertilizers, farm yard manure (FYM), chemicalsand electricity (Table 2, Fig. 1). The total energy expended for producing paddy was 47014.69 MJ/ha.

Among the different energy sources, chemical fertilizers were the dominant source of energy contributing 19907.92 MJ/ha which accounted for about 42 per cent of the total energy and among fertilizers, the share of nitrogenous fertiliser was highest (41.8 %). Two reasons can be attributed to explain this pattern, lack of knowledge among farmers about the recommended package of practices and nutrient based subsidies on chemical fertilizers especially nitrogen fertilizer. Further, electricity consumption for irrigation use also consumed a noteworthy share of 36.05 per cent in the total energy consumption. The pumping of irrigation water from deeper layers of underground water through submersible electric pumps and electric motors had led to the high electricity consumption in the state. Further, on account of free of cost supply of electric power to agricultural sector in Punjab state, farmers had no incentive in saving electricity. Different studies highlighted the indiscriminate use of nitrogen fertilizers and irrigation water in the transplanted paddy (Chaudhary et al 2017, Basavalingaiah et al 2020).

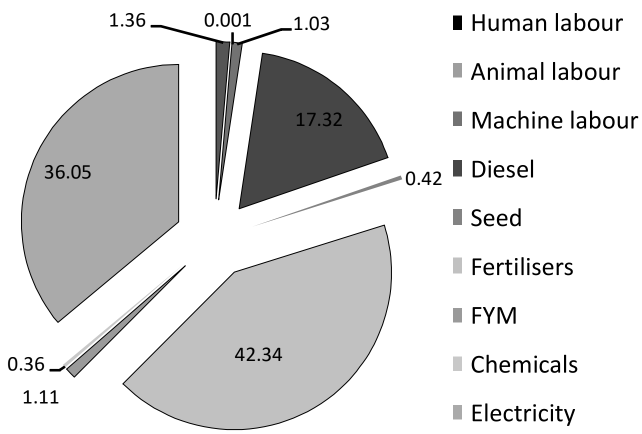

Fig. 1. Different inputs used in paddy cultivation (% share in input energy)

Further, diesel fuel used in prime movers and oil engines/generators for running pumps formed about 17 per cent of the total input energy. Another 485.71 MJ/ha of agri-machinery energy was used for various cultural operations of paddy cultivation. Thus, machine energy collectively accounted for about 18 per cent share while the draught (animal) power had negligible share in the input energy. Further, human labour accounted for another 1.36 per cent followed by FYM (1.11%) whereas all other inputs formed less than one per cent share in the input energy. Seed energy constituted only 0.42 per cent share and different chemicals used for plant protection consumed only 0.36 per cent share in total energy expended in paddy cultivation.

Energy use pattern in paddy cultivation by sources and farm sizes: The results regarding level of energy use for paddy cultivation across different farm size categories in the state showed a direct relationship with farm size (Table 3).

Large farmers used the highest input energy of 48193.01 MJ/ha while on medium and small farmers was

Table 2. Energy input-output pattern in paddy cultivation in Punjab

Input/output (unit)	Qty used unit area^{-1} (ha)	Total energy equivalent (MJ ha^{-1})	% share
Human labour (h)	325.37	637.72	1.36
Animal labour (h)	0.13	0.26	0.001
Machine labour (h)	13.79	485.71	1.03
Diesel (l)	20.13	8143.59	17.32
Seed (Kg)	13.47	198.45	0.42
Fertilisers (Kg)	349.82	19007.92	42.34
N (Kg)	324.29	19652.06	41.80
P (Kg)	19.27	213.89	0.45
K (Kg)	6.26	41.97	0.09
FYM (Kg)	1747.19	524.16	1.11
Chemicals (Kg)	1.40	167.17	0.36
Electricity (KWh)	198.04	16949.71	36.05
Total energy input (MJ ha^{-1})		47014.69	100.00
Energy output (MJ ha^{-1})			
Grain (Kg)	6939.5	102010.8	46.37
Straw (Kg)	9437.7	117971.7	53.63
Total energy output (MJ ha^{-1})	16377.25	219982.55	100.00

47267.32 and 44088.49 MJ/ha respectively. Similar results were obtained for paddy cultivation in Karnataka in an earlier study (Kumar et al 2019) though they were in contrast to that for Bihar (Kumar et al 2014). Source-wise analysis indicated that in all size groups of farmers, fertilizer was dominant source of energy consuming more than 41 per cent of the input energy and they were using excess fertilizer energy in the form of nitrogen, phosphorous and potash respectively, as compared to the recommendations of package of practices and this was mainly due to major share of nitrogenous fertilisers used by them which are comparatively cheaper than fertilisers having P and K contents. Farmers' reliance on energy derived from electricity used for irrigation also increased with farm size and varied from 15220.52 on small to 17783.56 MJ/ha for large farmers. The large farmers were also using relatively higher mechanical energy in total input energy i.e. 8728.95 MJ/ha accounting for 18.11 per cent of total energy input. These farmers were more reliant on agri-machinery as they derived 222.07 MJ/ha from machine use (0.46%) which consumed 8506.88 MJ/ha (17.65%) of diesel fuel. The use of human labour for carrying out different farm activities in paddy cultivation was the least for the large farmers i.e. 1.24 per cent in comparison to small ones with1.63 per cent. Further, the large farmers were deriving highest share of energy from chemicals for plant protection (0.41%) as compared to medium and small farmers (0.29% each). The small farmers appeared to be more inclined towards ecology and environment though use of this energy was guided by lack of economic power to buy costly inputs and farm machinery. The energy utilized from biological (renewable) sources was highest for small farmers which could be attributed to the use of family labor and farm based inputs in larger quantities rather than commercial sources of energy. The use of chemical, mechanical and electrical energy varied positively with the farm size, while the use of human labour, animal labour, seed and FYM showed a negative relationship with the farm size. This is mainly due to huge investment capacity of the large farmers and lack of knowledge among the farmers about the recommended practices.

Productivity, input-output energy and EUE in paddy across sources and farm size: Average grain and straw yield of paddy obtained by sample farmers was 6939.51 Kg/ha and 9437.73 Kg/ha respectively. The total energy output from both main- and by-product varied from 217631.19 MJ/ha on medium to222664.59 MJ/ha on large farm category (Table 4). Energy output for small farms was higher than medium due to higher grain and straw yield. The net energy gain of 0.173 million MJ/Ha indicated that paddy cultivation is energy efficient in the area. On account of paddy

Table 3. Farm-category wise energy input pattern in paddy cultivation

	Energy source/Farm category	Small	Medium	Large	Overall
A	Human Labour	720.06 (1.63)	654.01 (1.38)	599.49 (1.24)	637.72 (1.36)
B	Animal Labour	5.68 (0.01)	1.75 (0.004)	0.940 (0.002)	0.26 (0.001)
C	Machine labour	7220.99 (16.38)	8613.45 (18.22)	8728.95 (18.11)	8629.30 (18.35)
D	Machine use	25.12 (0.06)	106.70 (0.23)	222.07 (0.46)	485.71 (1.03)
E	Diesel	7195.87 (16.32)	8506.75 (18.00)	8506.88 (17.65)	8143.59 (17.32)
F	Seed	211.31 (0.48)	189.26 (0.40)	183.75 (0.38)	198.45 (0.42)
G	Fertilisers	19840.74 (45.00)	19512.25 (41.28)	20357.32 (42.24)	19907.92 (42.34)
	N	19500.63 (44.23)	19364.42 (40.97)	20035.46 (41.57)	19652.06 (41.80)
	P	309.21 (0.70)	119.99 (0.25)	264.03 (0.55)	213.89 (0.45)
	K	30.90 (0.07)	27.84 (0.06)	57.83 (0.12)	41.97 (0.09)
H	FYM	742.79 (1.68)	652.97 (1.38)	340.71 (0.71)	524.16 (1.11)
I	Chemicals	126.39 (0.29)	136.83 (0.29)	198.29 (0.41)	167.17 (0.36)
J	Electricity	15220.52 (34.52)	17506.80 (37.04)	17783.56 (36.90)	16949.71 (36.05)
	Total energy input (MJ ha^{-1})	44088.49	47267.32	48193.01	47014.69

Note: Figures in parenthesis are percentages to the respective total energy input yield differences, the energy gain was observed to be relatively low on medium farms as compared to that on the small and large farms.

With output energy of 219982.5 MJ/ha and input energy of 47014.69 MJ/ha, EUE of 4.68 was obtained in paddy cultivation. The EUE for small farmers (4.98) was higher than medium (4.60) and large farmers (4.62). In a study for South-Western Punjab, EUE of 5.0 was found for transplanted paddy cultivation (Singh et al 2019).In another study for Bihar, again the EUE was found to decline with farm size (Kumar et al 2014). Energy identity (in terms of EUE and energy productivity) and energy input were found to be directly related to farm size for paddy cultivation in Punjab except for small farmers. High energy intensity of 6.77 MJ/Kg was found with a low energy productivity index of 0.148 kg/MJ indicating that there is room for improving energy productivity of rice crop in transplanting cultivation methods. Since chemical fertilisers were easily available in the study area, farmers were overusing these especially small ones. However, over and indiscriminate usage of fertilizer results in significant reduction in crop yield over a period of time and increases the pollution problems. In a study for Karnataka, higher EUE under DSR compared to transplanted paddy was mainly attributed to the significant decrease in energy inputs and scope for saving energy by 6 per cent existed in transplanting method (Basavalingaiah et al 2020). Yuan and Peng (2017) reported that adoption of simplified and reduced input practices resulted in increased EUE and energy productivity by about 19 and 25 per cent, respectively than the farmers' practice in China. Thus, there is need to take suitable steps to increase EUE in paddy cultivation either by minimizing input use or by using them judiciously.

Direct and indirect energy use: Direct and indirect sources of energy use in paddy cultivation comprised about 55(25731.28 MJ/ha) and 45 per cent (21283.41 MJ/ha) of the total energy input respectively (Table 4 and Fig. 2). In all the farm categories, the share of direct energy in was more than 52 per cent and it was the highest for medium category farmers i.e. 56.42 per cent as they were having higher share of machine use as well as diesel fuel in input energy than other farm categories. Maximum energy in indirect form on small farms (47.51%)was on account of relatively higher share of indirect forms of energy like labour, FYM and seeds.

Electricity used for irrigation formed the major share i.e. 65.87 per cent and almost same pattern was observed for all the farm categories as more than 65 per cent of direct energy was obtained from electric power only (Fig. 3a). Diesel formed about 32 per cent share in the direct energy whereas human labour contributed only 2.48 per cent. Animal labour share in direct energy was negligible.

Among indirect sources of energy, major share of about 94 per cent was from fertilisers only with maximum (95.56%) being for large farmers Figure 3b. FYM had share of only 2.46 per cent with maximum being for small farmers i.e. 3.55 per cent. In terms of chemicals about 0.79 per cent indirect energy was used and maximum was in large farmers i.e. 0.93 per cent. Machine use indirectly contributed 2.46 per cent of IDE and large farmers were the leaders in this category with 2.28 per cent share of mechanical energy while for rest it was less than or equal to one per cent only. Thus, electricity as DE and fertilisers in form of IDE were major energy sinks for paddy cultivation in Punjab.

Table 4. Farm-category wise energy pattern in paddy cultivation

Item (Unit)/farm category	Small	Medium	Large	Overall
Total energy input (MJ ha^{-1})	44088.49	47267.32	48193.01	47014.69
Total energy output (MJ ha^{-1})	219457.80	217631.19	222664.59	219982.55
Grain	101767.50	100920.46	103254.56	102010.83
Straw	117690.30	116710.73	119410.03	117971.72
Net energy (Million MJ ha^{-1})	0.175	0.170	0.175	0.173
Energy Intensity (MJ Kg^{-1})	6.37	6.88	6.86	6.77
Energy use efficiency (EUE)	4.98	4.60	4.62	4.68
Energy Productivity (Kg MJ^{-1})	0.157	0.145	0.146	0.148
Direct energy (MJ ha^{-1})	23142.13 (52.49)	26669.30 (56.42)	26890.87 (55.80)	25731.28 (54.73)
Indirect energy (MJ ha^{-1})	20946.36 (47.51)	20598.02 (43.58)	21302.14 (44.20)	21283.41 (45.27)
Renewable energy (MJ ha^{-1})	1679.84 (3.81)	1497.99 (3.17)	1124.89 (2.33)	1360.59 (2.89)
Non-renewable energy (MJ ha^{-1})	42408.64 (96.19)	45769.33 (96.83)	47068.12 (97.67)	45654.10 (97.11)

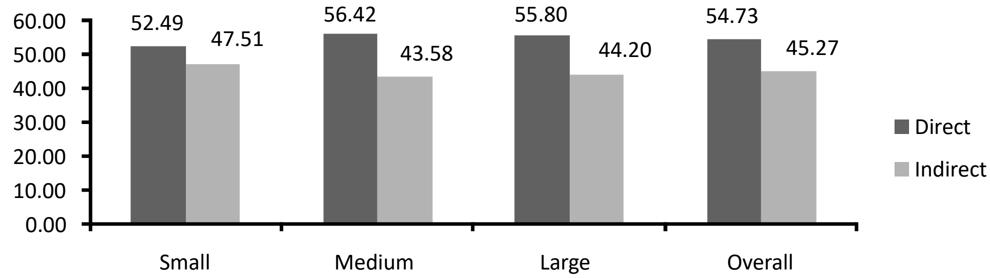

Fig. 2. Farm category wise sources of input energy- Direct and Indirect (% share in input energy)

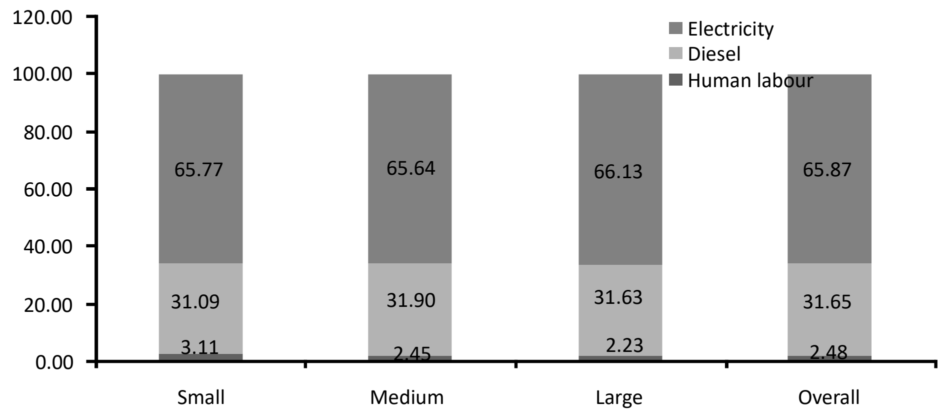

Fig. 3a. Farm category wise sources of direct energy (% share in direct energy)

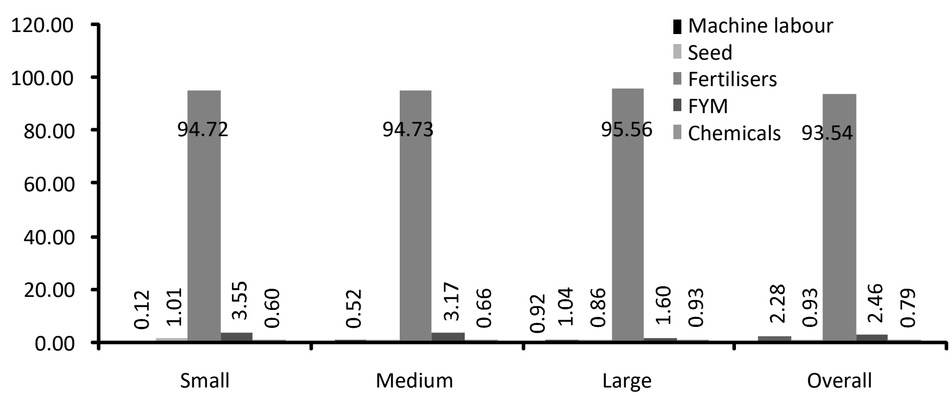

Fig. 3b. Farm category wise sources of indirect energy (% share in indirect energy)

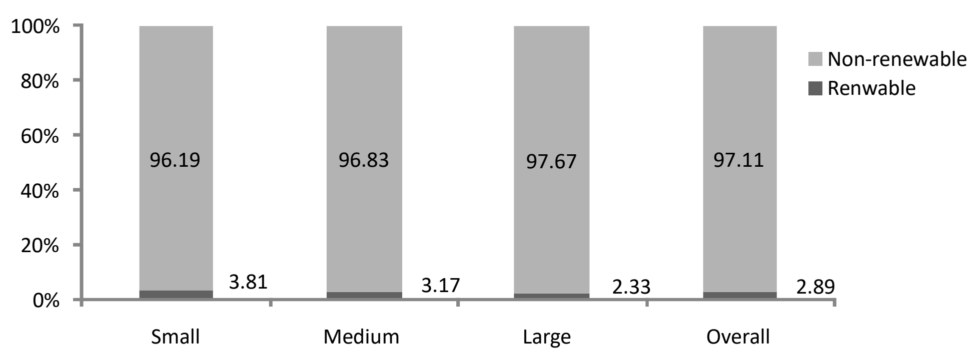

Fig. 4. Farm category wise sources of renewable and non-renewable energy (% share in input energy)

Renewable (RE) and non-renewable energy (NRE) use: Very high use of NRE i.e. 45654.1 MJ/ha (97.11 %) as compared to RE i.e. 1360.59 MJ/ha (2.89%) was observed (Table 4). Several researchers have found similar results that the share of NRE was much higher than that of renewable energy consumption indicating paddy production being mostly depending on fossil energy sources (Kazemi et al 2015, Nassir et al 2021). The selected farmers had used more of NRE sources due to subsidized price but this could be harmful to the environment and ecology in the long run. Therefore, paddy farmers need to switch over to renewable energy sources in paddy production. However, many external factors come in the way of adoption of environmentally benign energy sources in agriculture such as dwindling availability of FYM and increasing labour scarcity.

Energy utilized from biological (renewable) sources was highest among small farmers (3.81%) followed by medium than large farmers (Fig. 4). This could be attributed to the use of family labour and farm based inputs in relatively larger quantities by small and medium farmers as compared to that by the large farmers thus, indicating relatively better management of biological sources of energy by smaller farmers. Similar results were obtained in study for paddy in Karnataka (Kumar et al 2019). Non-commercial energy from labour and FYM constituted only 2.47 per cent share in the total energy with rest being sourced from commercial sources. In a similar study, per hectare use of both commercial and non-commercial energy was more in paddy crop in comparison to wheat crop (Kumar et al 2020).

CONCLUSIONS

With net energy gain, paddy cultivation is energy efficient in Punjab but over-whelming consumption of electric and chemical fertiliser energy underpin the opportunities for energy saving. Paddy cultivation is mostly dependent on commercial, non-renewable and indirect energy forms which do not augur well for sustainability of paddy production and soil ecology of agricultural lands in the state. Energy management at the farm level needs serious attention both for efficient and economical use of energy as well as for the safe guard of agro-ecosystem. Lack of knowledge of scientific recommendations, improper use of modern means of energy, subsidization of commercial energy and prevailing myth and mind-set of the farmers are the most likely obstacles in efficient energy utilization which need to be addressed. Strengthening of extension services can help in encouraging the judicious use of energy intensive inputs by replacing these with alternative organic sources as well by through adoption of recommended farming practices. Farm level adoption of environment friendly technology of paddy cultivation viz. direct seeded technology (DSR) may also help in energy saving without compromising the level of output.

Received 12 December, 2021; Accepted 02 April, 2022

REFERENCES

Basavalingaiah K, Ramesha YM, Venkatesh P, Rajanna G A, Shankar LJ, Shiva DM, Kumar A, Girisha HC, Yogesh GS, Raveesha S, Roopa TK, Shashidhar KS, Kumar B, Ansary DOE and Elansary HO 2020. Energy budgeting, data envelopment analysis and greenhouse gas emission from rice production system: A case study from puddled transplanted rice and direct-seeded rice system of Karnataka, India. *Sustainability* **12**: 6439-6458.

Canakci M, Topakci M, Akinci I and Ozmerzi A 2005. Energy use pattern of some field crops and vegetable production: Case study for Antalya region, Turkey 2005. *Energy Conversion and Management* **46**(4): 655-666.

Chaudhary VP, Singh KK, Pratibha G, Bhattacharyya R, Shamim M, Srinivas I and Patel A 2017 Energy conservation and greenhouse gas mitigation under different production systems in rice cultivation. *Energy* **130**: 307-317.

Chauhan S 2012. District wise agriculture biomass resource assessment for power generation: A case Study from an Indian state, Punjab. *Biomass and Bioenergy* **37**: 205-212.

Gopalan C, Sastri BVR and Balasubramaniam SC 1978. *Nutritive Value of Indian Foods.* National Institute of Nutrition, ICMR, Hyderabad.

Grisso RD, Kocher MF and Vaughan DH 2004. Pedicting tractor fuel consumption. *Applied Engineering in Agriculture* **20**(5): 553-561

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

Kumar A, Kumar J and Rani M 2014. Input Output Analysis of Paddy Cultivation of Bihar. *International Research Journal of Commerce Arts and Science* **5**(3): 10-17.

Kumar H, Kaur A and PKS Bhangu 2020. Analysis of energy use efficiency in Punjab agriculture. *Economic Affairs* **65**(1): 97-105.

Kumar PPS, Reddy C, Umesh KB and PSR Kumar 2019. Energy consumption and sensitivity analysis of paddy production under different farm sizes in southern dry zone of Karnataka, India *Economic Affairs* **64**(1): 259-270.

Kumar R, Mishra JS, Rao KK, Mondal S, Hazra KK, Choudhary JS, Hans H and Bhatt BP 2020 Crop rotation and tillage management options for sustainable intensification of rice-fallow agro-ecosystem in eastern India. *Scientific Reports* **10**(1):1-15.

Nassir AJ, Ramadhan MN and Alwan AAM 2021. Energy input-output analysis in wheat, barley and oat production. *Indian Journal of Ecology* **48**(1): 304-307.

Praveen KV, Jha GK and Adity KS 2021. Discerning sustainable interaction between agriculture and energy in India. *Current Science* **120**(12): 1833-1839.

Samarpitha A, Vasudev N and Suhasini K 2016. Technical, economic and allocative efficiencies of rice farms in Nalgonda district of Telangana state. *Economic Affairs* **61**(3): 365-374.

Singh P, Singh G and Sodhi GPS 2019. Energy auditing and optimization approach for improving energy efficiency of rice cultivation in south-western Punjab, India. *Energy* **174**: 269-279.

Singh S and Singh J 2002. *Research digest on energy requirement in agriculture sector, Department of Farm Power and Machinery*, Punjab Agricultural University, Ludhiana (2002): 1- 263.

Yuan S and Peng S 2017. Input-output energy analysis of rice production in different crop management practices in central China. *Energy* **141**: 1124-1132.