Analysis of changes in energy use pattern of wheat crop in two decades – A study of central India

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Abstract: For sustainable agriculture a fair balance between different categories of input energy with optimum output need to be established. The main objective of this paper was to investigate the energetics of wheat production for long term (20 years) in central India through a large scale survey which focused on (i) Farmers categories wise energy use pattern (ii) operation wise energy use pattern (iii) source wise energy use pattern. The finding of this research showed that as the farm size increased the input energy per unit was also increased. The input energy was found minimum for marginal farmer's categories and the maximum energy input for large farmers. The minimum and maximum input energy among all the survey period was found in range of 4780 to 7199 MJ ha^{-1} and 8300 to 11638 MJ ha^{-1} for marginal and large farmers. In last survey large farmers were using 17.8% to 38.3% more input energy than marginal farmers. Operation-wise irrigation shows highest input energy followed by seed bed preparation, sowing, transportation and other operations. The use of non-commercial energy sources were reducing over time and transformed to commercial energy sources. Use of renewable source of energy was decreased and use of non-renewable source of energy increased. Similar trend was observed for direct energy and indirect energy sources. Direct energy was decreased and use of indirect source of energy increased. The increase in the productivity of wheat shows that as the use of energy increased the yield was also increased. The yield of wheat was increased in range of 16.88%-33.57%, specific energy requirement reduced in range of 25%-42.24% and the energy use efficiency increase in range of 25.21%-42.15%. Better management of inputs, mechanization, quality seed, plant protection, controlled irrigation resulted into a great positive effect which resulted in higher energy use efficiency.

Keywords: agricultural energy, energy audit, land holding, long term survey, operation-wise energy, source-wise energy, wheat production

Citation: Shrivastava, A. K., P. K. Guru, N. K. Khandelwal, and R. K. Dubey. Analysis of changes in energy use pattern of wheat crop in two decades – A study of central India. Agricultural Engineering International: CIGR Journal, 24(1): 128-144.

1 Introduction

Energy is the basic driving force in human development and 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 agriculture, the commercial energy use was increased sharply (Iqbal, 2007) with the rising cost of production and depleting energy reserves. Both direct energy and indirect energy use have contributed to the major increases in food production (Guru et al., 2018). 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 (Lal et al., 2019,

Received date: 2020-09-03 **Accepted date:** 2021-03-15

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2020; Guru et al., 2019). Indirect energy, on the other hand, consists of the energy used in the manufacture, packaging and transport of fertilizers, pesticides and farm machinery (Patel et al., 2018; Chatterjee et al., 2018).

In present agriculture scenario, dependability on non-renewable energy resources has increased, the productivity and profitability of agriculture depends on energy consumption (Alam et al., 2005; Esengun et al., 2007, Woods et al., 2010). Energy use on farms has increased over years but the average farm sizes are reducing continuously due to land defragmentation (Manjunatha et al., 2013). Therefore energy efficiency has become more so important in Indian agricultural system. Energy consumption and energy efficiency of an cropping system mainly depends on factors such as soil type, machinery, electricity, fossil fuels, chemicals, fertilizers, harvesting, and post harvesting operations (Baishya and Sharma, 1990; Clements et al., 1995; Muazu et al., 2015; Ziaei et al., 2015). Crop management practices can also be helpful and will play important roles in increasing the energy efficiency.

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 (Lal et al., 2020; Patel et al., 2018).

Wheat crop is highly cultivate in central India because it is most suitable for resource-poor farmers and resulted in higher energy use efficiency, energy productivity, and system productivity (Singh et al., 2007; Guru et al., 2015). After harvesting of wheat, dry season crop was also grown with intensive tillage. Apart from higher cost involved in intensive tillage, it is also harmful for soil health as heavy tillage operation increased soil compaction. Therefore, to reduce the manpower requirement and to raise the output, mechanization of crop production is necessary. However, published information on energy use pattern of wheat cultivation is available but for only for crop seasons and also for selected number of farmers (Chaudhary et al., 2006; Singh et al., 2019). Detail study for analyzing the changes in energy use pattern for wheat crop in long run is not available. Nevertheless the increase in the cost of commercial energy and decline in fuel reserves warm the researchers to workout highly productive, profitable and energy efficient operation for tillage, sowing/establishment methods, plant protection and harvesting. Therefore, the present study was undertaken to analyze the energy use in wheat crop and also to see the changes in energy use pattern over two decades. The results of the study are expected to assist policy makers and researchers to understand the changes in energy use pattern operation wise, source wise and among different categories of farmers. The analysis of crop yield as affected by input energy gives better understanding in planning the energy requirement and optimum utilization of energy for the wheat production.

2 Material and methods

2.1 Study area description

Madhya Pradesh is located in the central part of India, extending from 17°48' to 26° 52' north latitudes and from 74°02' to 84°25'east longitudes. The state of Madhya Pradesh was divided in to four major crop zones. 1. rice-wheat zone. 2. sorgham-wheat zone 3. wheat zone. 4. cotton- sorgham zone. Wheat was grown in all the four zones. Therefore, four villages were selected for the study representing different zones. Villages were selected on the basis of multistage stratified sampling method to represent the different agro-climatic area. While selecting a village following parameters were also considered. Population of the village should preferably be more than 1000 with land holding should be well distributed under different category. In this way whole of the state of Madhya Pradesh was covered under study. The four villages selected are Singod (district-Jabalpur, rice-wheat zone); Phanda (district-Bhopal, Wheat zone); Sonsa (district - Gwalior, Sorgham -wheat zone); Kanadia (district-Indore, cotton- Sorgham zone). After selecting the villages data for all the farmers was taken with the help of key persons. The land is classified as per operational holding (Table 1).

Table 1 Land size classes and size groups of operational holdings (Anonymous, 2019)

S. No.	Group	Classes
1	Marginal (MF)	Less than 1.0 ha
2	Small (SF)	1.0 to 2.0 ha
3	Medium (Med)	> 2.0 to 4.0 ha
4	Large (LF)	More than 4.0 ha

2.2 Study details

Four round of detailed study was conducted in four locations namely; Singod, Phanda, Sonsa, and Kanadia. The 1st round of study conducted in year 1992- 93, 2nd round in 1999-2000, 3rd round in 2008-09 and 4th round in 2012-13.

2.3 Collection of data

The information's including the quantity of energy inputs in the form of seed, fertilizers, chemicals, irrigation, human, animal, and prime movers. The output in the form of grain yield and by-product were determined from all the farmers of the villages falling in to different categories, further cropping pattern and hectare age under crop from farm to farm were also recorded. The operation time, fuel consumption, crop yield, and other parameters evaluated in a standardized manner as detailed by Mittal and Dhawan (1988).

The data was collected with the help of pre-designed, pretested questionnaire. The farmers were interviewed twice in *Rabi* season (Wheat growing seson) to collect information. This information include farmer's identifications, land holding, farm power and machinery availability, methods of irrigation, water availability, manpower availability, farm operations (fields operations, manure application and fertilizer application, sowing, irrigation, weeding/intercultural, plant protection, harvesting and threshing) and farm power (fuel consumed per hour by the sources, implements used, hour of use of different implements with power sources, human power in term of hour both viz own and hired labour hour number) and machinery use for different field operations. Similar process of energy auditing was used by Safa and Samarasinghe (2011).

2.4 Energy conversion coefficients

Data for all the farm inputs used and the output (wheat and straw yield) were collected and then converted into equivalent energy values using appropriate conversion coefficients.

Table 2 Energy conversion coefficients (MJ unit^{-1}) for the different inputs and outputs (Mittal and Dhawan, 1988; Patel et al., 2018; Lal et al., 2019; Kitani et al., 1999).

Particulars	Unit	Energy Equivalents (MJ unit^{-1})
Human labour	h	1.96 (1 adult women =0.8 adult man)
Diesel fuel	L	56.31
Petrol	L	48.23
Electricity	kw h	11.93
Bullock (medium size)	pair-h	10.10
Nitrogen (N)	kg	60.60
Phosphorus (P_2O_5)	kg	11.10
Potassium (K_2O)	kg	6.70
Self - propelled machinery	h	62.70
Electric motor	kg	64.80
Tractor	kg	68.40
Farm machinery excluding self-propelled machine	kg	62.70
Seed/Grain (wheat)	kg	14.70
Straw (wheat)	kg	12.50

2.5 Specific mathematical models for calculating energy balance

$$Energy\ Input = Human\ energy + Fuel\ energy + Machine\ energy$$

$$Human\ energy (MJ\ h^{-1}) = Useful\ man\ \text{hour}\ spent\ in\ operation \times man\ energy\ factor$$

$$Fuel\ energy\ (MJ\ l^{-1}) = Fuel\ consumption \times Energy\ factor\ for\ diesel$$

$$Machinery\ energy\ (MJKg^{-1}) = Weight\ of\ \text{the}\ machine \times Self\ propelled\ machine\ energy\ equivalent\ factor \times Useful\ working\ \text{hours} \times Useful\ life\ of\ machine$$

$$Energy\ output = [Total\ grain\ production \times grain\ energy\ equivalent\ factor] + [Total\ straw\ production \times straw\ energy\ equivalent\ factor]$$

$$Specific\ Energy\ (MJkg^{-1}) = \frac{Total\ input\ Energy}{Crop\ yield}$$

$$Energy\ use\ efficiency = \frac{Output\ energy}{Input\ energy}$$

3 Result and discussion

3.1 Farmer's categories wise energy use pattern:

Agricultural energy consumption pattern largely depend on the land holding size and to understand the relation between land holding and energy used for the wheat farming four village data was presented (Figures 1-4). In all the four studies there was direct correlation between the land holding and input energy. As the farm size increased the input energy per unit was also increased. The minimum input energy was found for marginal farmer's categories and the maximum input energy for large farmers. The minimum input energy among all the survey period was found 5666 MJ ha^{-1}, 4780 MJ ha^{-1}, 7199 MJ ha^{-1},and 5444 MJ ha^{-1} for marginal farmers in village Singod, Phanda, Sonsa and Kanadia, respectively. The maximum input energy among all the survey period was found 11121 MJ ha^{-1}, 8300 MJ ha^{-1}, 11638 MJ ha^{-1}, 9631 MJ ha^{-1} in village Singod, Phanda, Sonsa and Kanadia, respectively. For the year 2012-13 large farmers were using 33.3%, 28.6%, 38.3%, and 17.8% more input energy than marginal farmers in village Singod, Phanda, Sonsa and Kanadia, respectively. Sharma et al. (2020) reported higher energy uses associated with higher yield and energy has a positive relationship with crop yield. Kosemani and Bamgboye (2020) reported significant difference among the three farm categories in respect to input energy and agronomical managements in rice production. More input energy requirement was due to the enhanced level of mechanization. Use of high powered machinery enhanced the use of input energy. To ensure the timeliness in farm operations large farmers are using the high capacity machines this will also enhance the input energy requirements. Similar results have been reported in other studies which have concluded that as a consequence of mechanization, the input energy increased significantly (Verma, 2006; Yadav et al., 2013; Shafaei et al., 2019). On the other hand marginal and small farmers were mostly themselves worked on their farms which results in lowing the input energy and also make farming more profitable. There was also a regular increment in energy use pattern over the years. As the results shows that input energy was increasing over the years in all four study locations. This change was due to change in farmers existing practices. In last survey farmers are using mechanical power operated agricultural equipment's basically operated by fossil fuels. Tractors was the most common machines employed for conversion of fuel energy to useful mechanical works. Small and marginal farmers were using tractor for tillage operation while medium and large farmers were moving towards complete mechanization of farms by adopting more powerful machines for quick and timely farm operations.

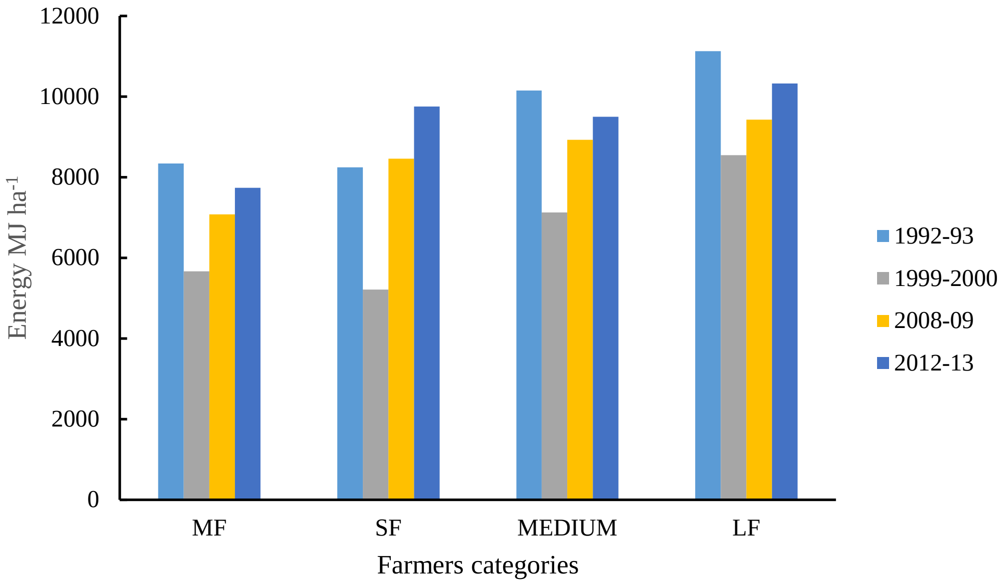


Figure 1 Farmers categories wise energy use pattern in village Singod

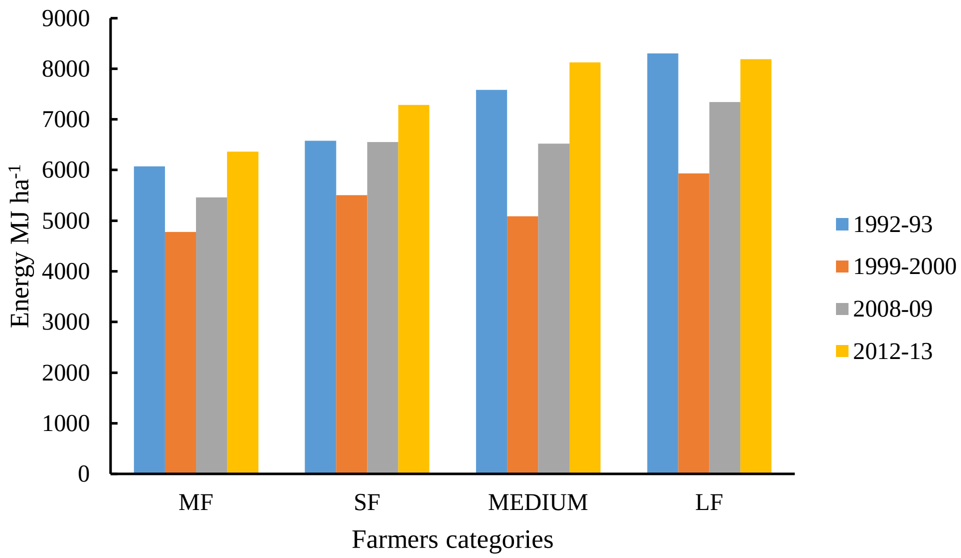


Figure 2 Farmers categories wise energy use pattern in village Phanda

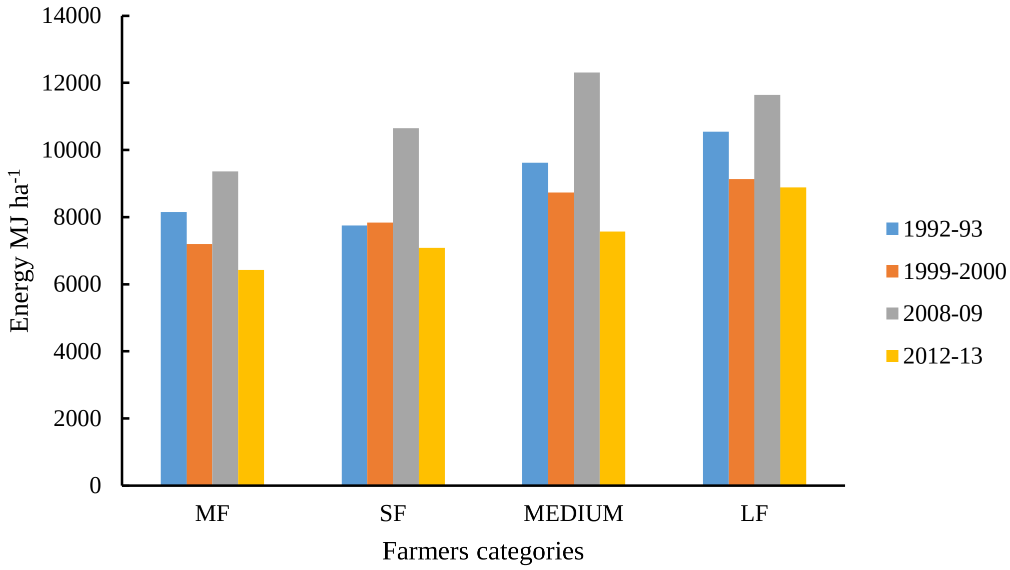


Figure 3 Farmers categories wise energy use pattern in village Sonsa

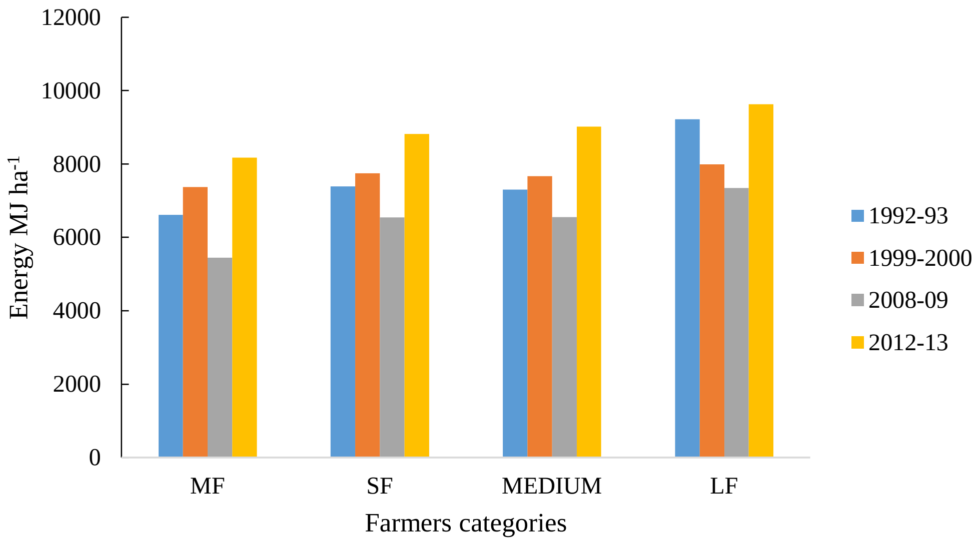
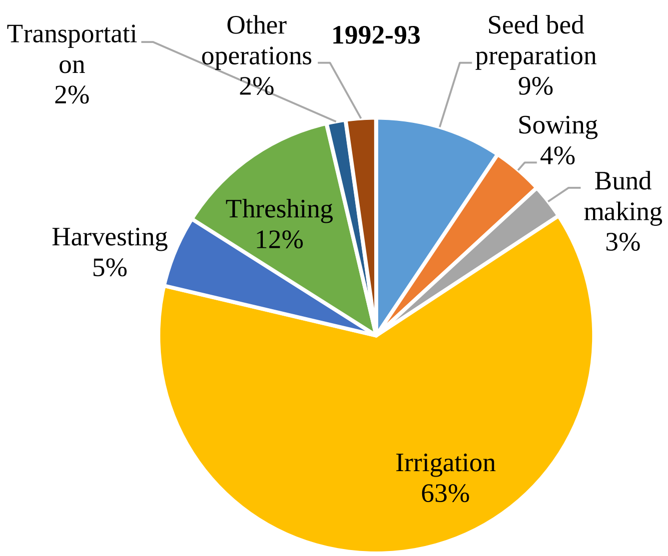


Figure 4 Farmers categories wise energy use pattern in village Kanadia

3.2 Operation wise energy use pattern

In all four survey results irrigation shows highest input energy in all four locations (Figures 5-8). The percentage area under irrigation in different villages increased over different round of surveys. In Singod the average irrigated area were 18.3%, 24.5%, 25% and 31.1% under marginal, small, Medium and large category during 1st, 2nd, 3rd, and 4th, survey respectively. The corresponding values were 70.5%, 48%, 48%, and 53% for Phanda; 44.6%, 48.0%, 49% and 58.7% for Sonsa; and it was 31%, 80%, 79% and 83% for village Kanadia. The main sources of irrigation water were tube well in all the four villages under study. It is very clear that the irrigation facilities increased in all the four villages in recent year as compared to initial year of survey. It is also true that in general large farmers harnessed the underground water more efficiently than other categories of the farmers it may be due to economic status and availability of resources.

In village Singod the initial of study (1992-93) heavy dependency was put on irrigation. However in the later years of survey irrigation is till the major component to energy but there has been significant improvement in seed bed preparation and sowing resulting in the change in energy use pattern. In first survey irrigation required maximum energy (63%) followed by threshing (12%), seed bed preparation (9%), harvesting (5%), sowing (4%), bund making (3%), transportation (2%) and other operation (2%). Other field operations include inter culture, fertilizer application, chemical spraying, winnowing and cleaning. This pattern changes in last survey and the energy required for farm operation irrigation (39%), seed bed preparation (22%), threshing (13%), sowing (11%), transportation (8%), harvesting (5%), bund making (1%) and other operation (1%). Similar trend was observed for other study locations namely Phanda, Sonsa, and Kanadia. The availability of tractor and power tiller for field preparation and sowing operation enhance the input energy of seed bed preparation and sowing. All the farmers irrespective of farming land holding categories were using tractor and power tiller for field preparation and sowing. The medium and large farmers own the machinery and marginal and small farmers were using the machinery for custom hiring basis. Labour shortage and higher wages were also the reason behind increased use of tractors and machinery. Similar trend was also observed in other locations also. Among all the farm operations seed bed preparation, sowing, and transportation shows an increasing trend and required more input energy over the surveyed period. On the other side bund making, harvesting, threshing and other operation showing decreasing trend and required less energy as compared to previous years (Figure 9).



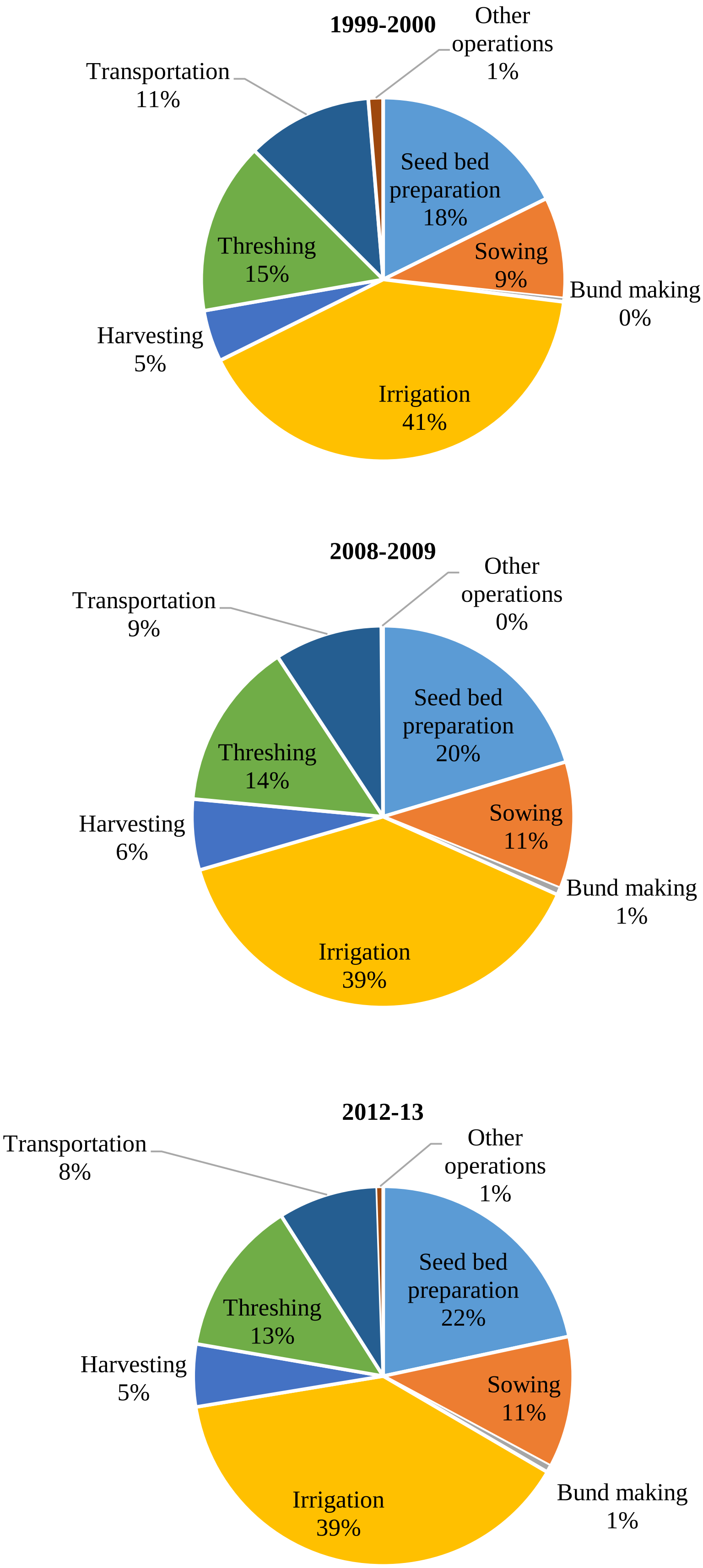
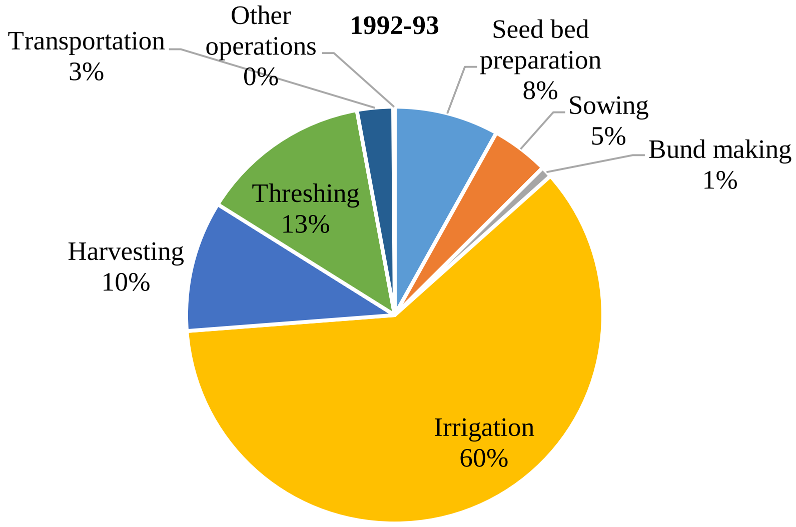
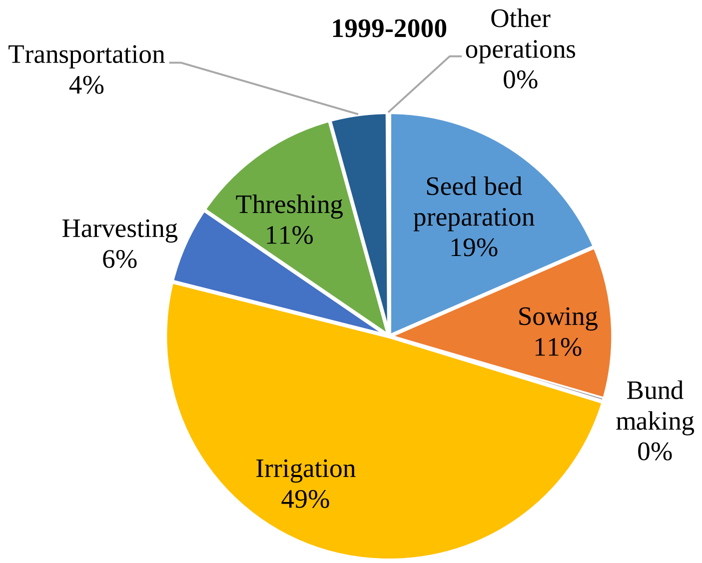
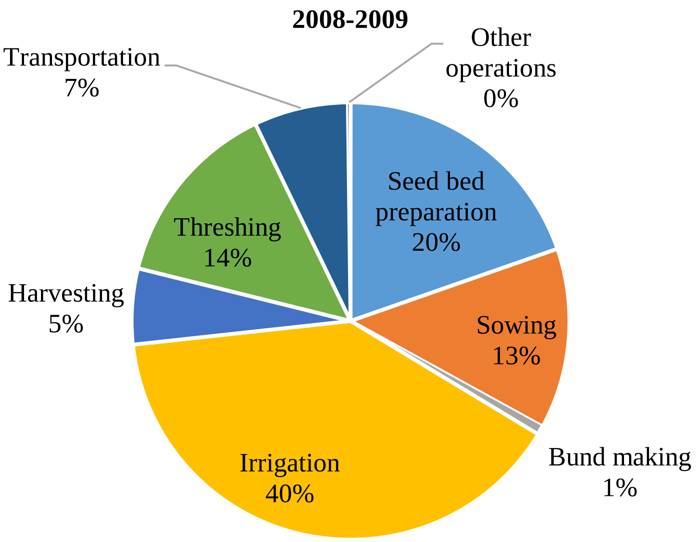


Figure 5 Operation wise energy use pattern in village Singod


1992-93
Transportation
3%
Other
operations
0%
Seed bed
preparation
8%
Sowing
5%
Bund making
1%
Threshing
13%
Harvesting
10%
Irrigation
60%


1999-2000
Transportation
4%
Other
operations
0%
Seed bed
preparation
19%
Threshing
11%
Harvesting
6%
Sowing
11%
Bund
making
0%
Irrigation
49%


2008-2009
Transportation
7%
Other
operations
0%
Seed bed
preparation
20%
Threshing
14%
Harvesting
5%
Sowing
13%
Bund making
1%
Irrigation
40%

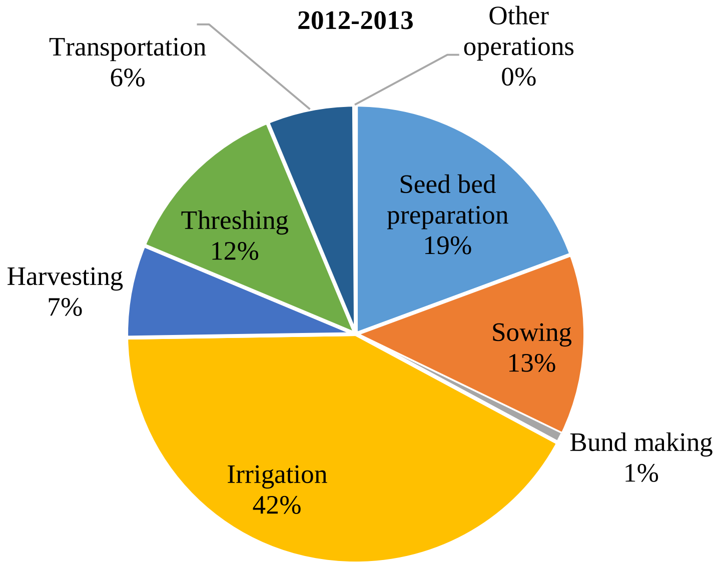
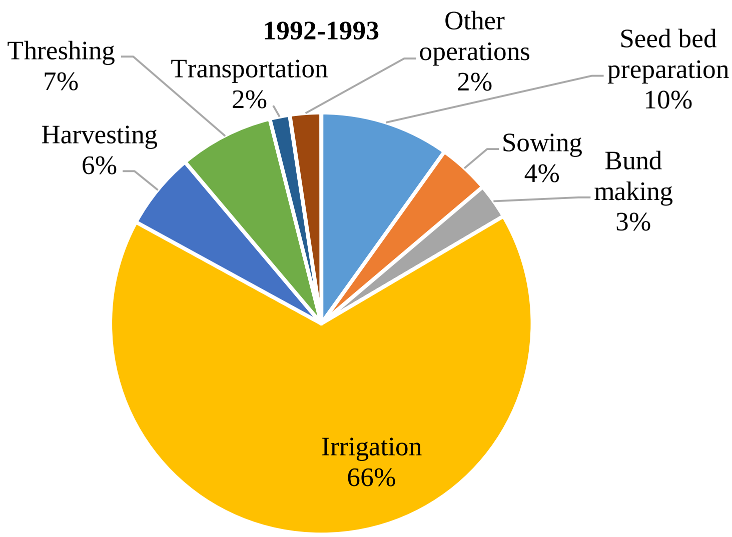
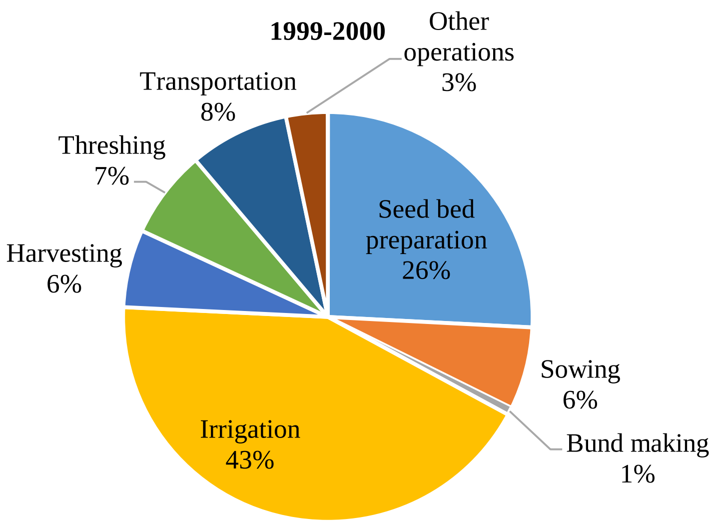
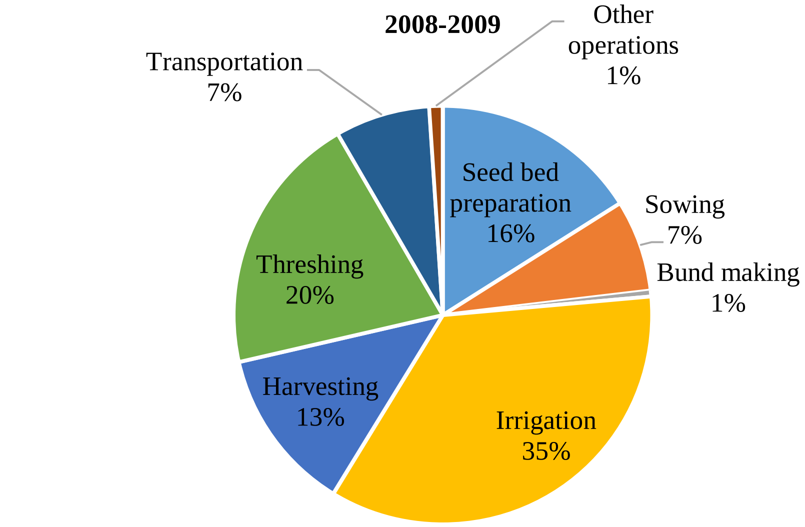


Figure 6 Operation wise energy use pattern in village Phanda







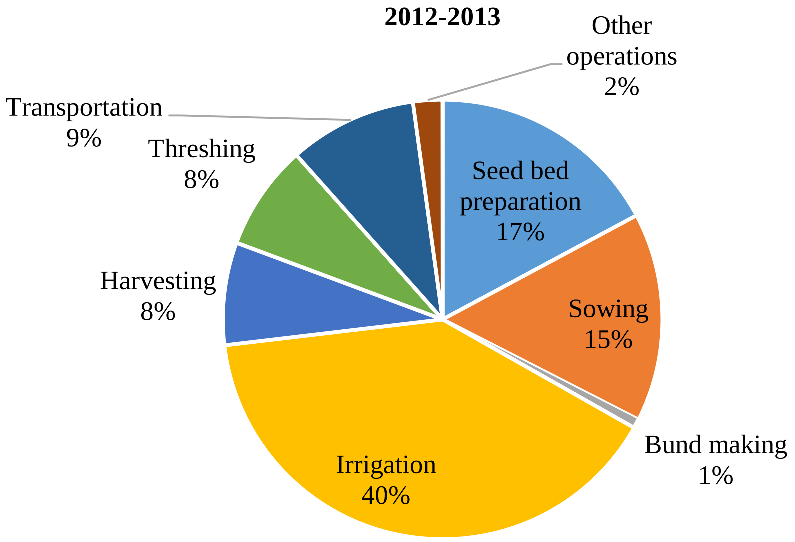
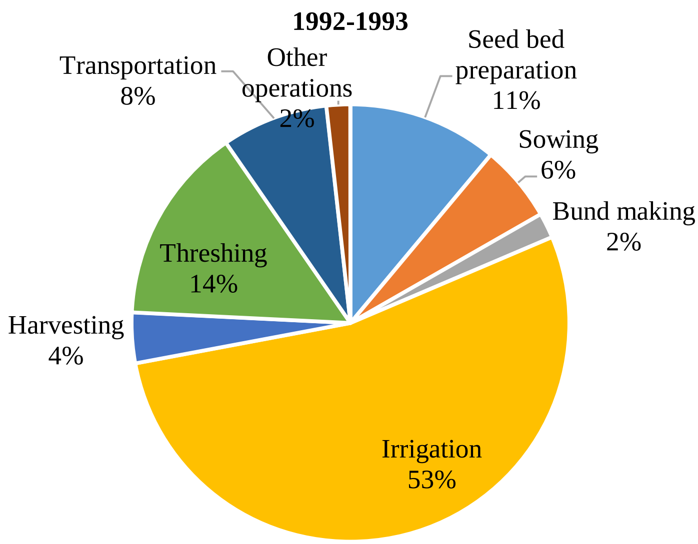


Figure 7 Operation wise energy use pattern in village Sonsa



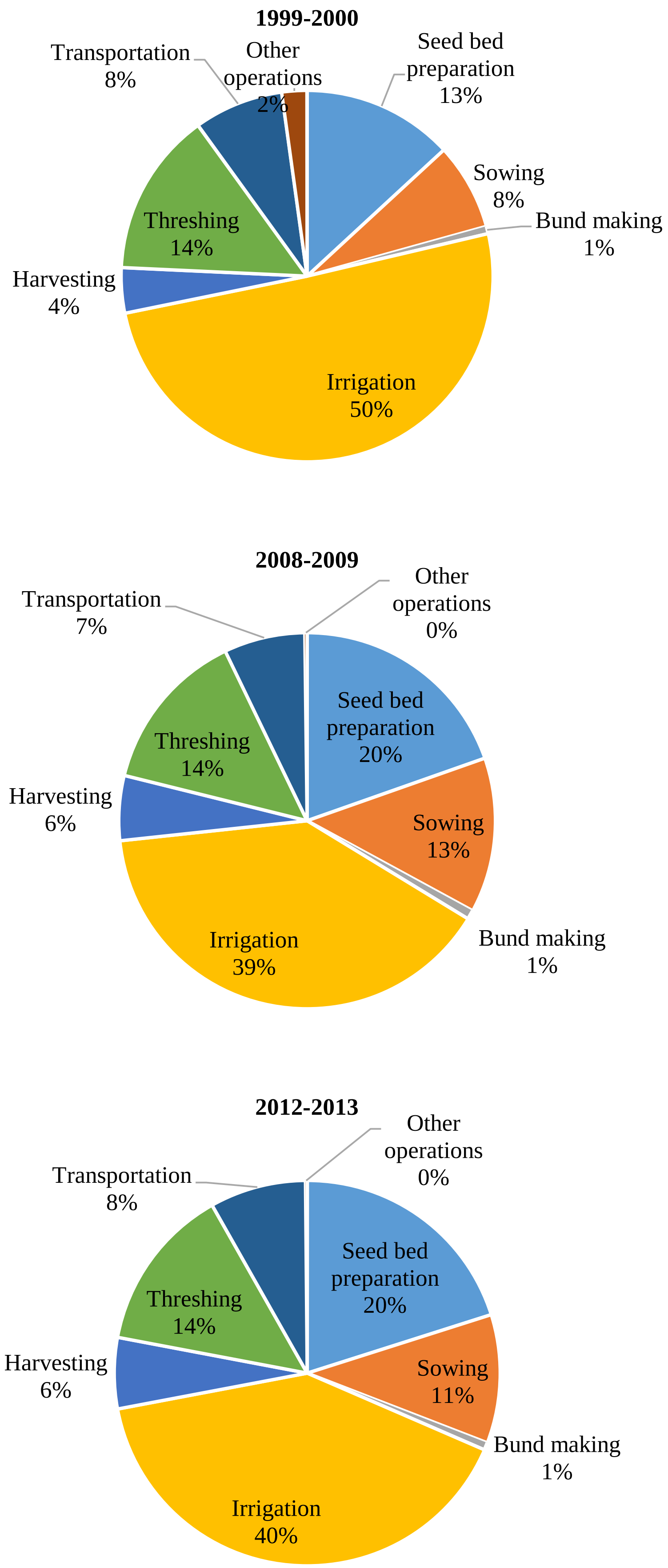
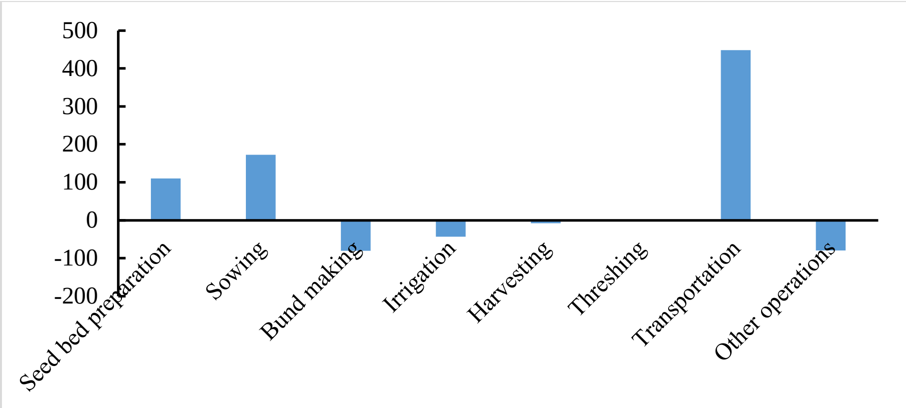
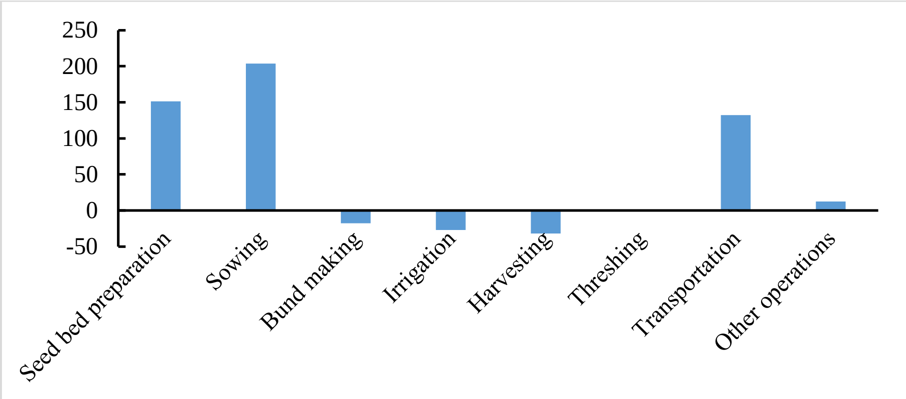


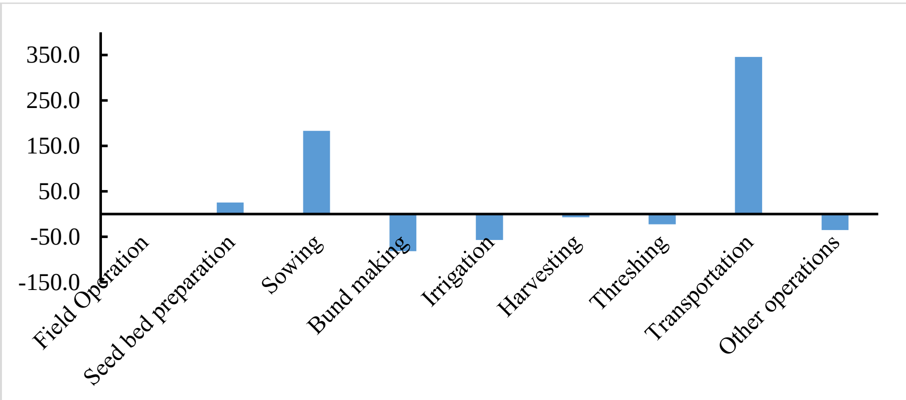
Figure 8 Operation wise energy use pattern in village Kanadia



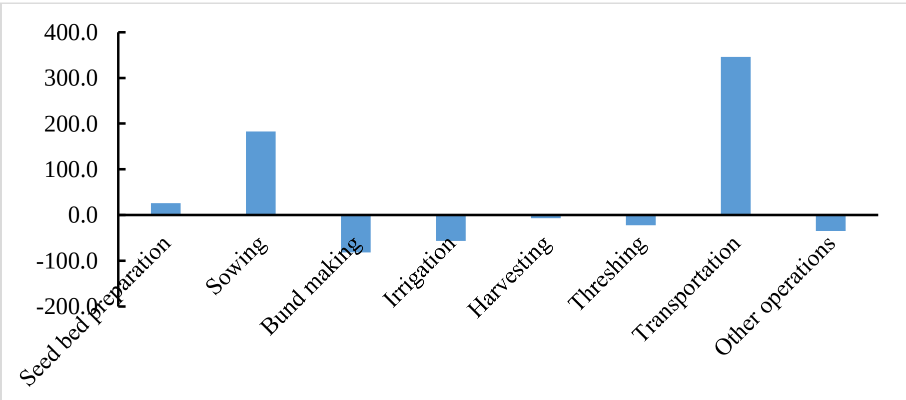
(a) Singod



(b) Phanda



(c) Sonsa



(d) Kanadia

Figure 9 Changes in operation wise energy use pattern (%) year 1992-93 to 2012-13

3.3 Source wise input energy use pattern

In the initial period of study (1992-93) heavy reliance was put on electricity and the supply of fertilizer was not sufficient due to supply issues and limited awareness among farmers of Singod. However due to technological and agricultural advancement there has been substantial increase in diesel and fertilizers inputs in the period of study (2008-09). This has also resulted in the composition of change in energy use, specifically energy input from human and animal has drastically reduced over these years**.** In order to distinguished between the direct energy use pattern used by different farm category in survey villages during different round of survey tables are prepared and discussed.

Figures 10-13 show that the source wise energy uses under different category for different villages. The use of non-commercial energy sources (human, animal, fuel wood, agricultural waste, farmyard manure) were reducing over time and transformed to commercial energy sources (Petrol, Diesel, Electricity, Chemical, Fertilizers, Machinery). Over the surveyed period uses of non-commercial energy source reduced by 280.9% and commercial source of energy increased by 17.2% in village Singod. Similar results were found for other locations and the use of commercial energy resources increased by 21.6%, 2.4%, and 3.4% and the use of non-commercial energy resources decreased by 94.27%, 366.8%, and 111.7% for Phanda, Sonsa and Kanadia, respectively. This shows there was huge transformation from non-commercial energy sources to commercial energy sources. Use of renewable source of energy (human, animal, fuel wood, agricultural waste, seed and farmyard manure was decreased by 41%, 10.5%, 61.9% and 27.8% and use of non-renewable source of energy (petrol, diesel, electricity, chemical, fertilizer, machinery) increased by 13.3%, 20.4%, 24.5% and 10.3% for Singod, Phanda, Sonsa and Kanadia, respectively. The result shows continuous reduction in renewable source of energy. The use of direct energy (human, animal, fuel wood, agricultural waste, petrol, diesel, electricity) sources were decreased by 44.8%, 7.6%, 53.3%. 5.7% and use of indirect source of energy increased by 49.3%, 38.6%, 28.3%, 1.6% for Singod, Phanda, Sonsa and Kanadia, respectively.

The use of diesel, chemical fertilizer, and electricity increased tremendously and none of the farmer found operating with bullock pair in recent years.

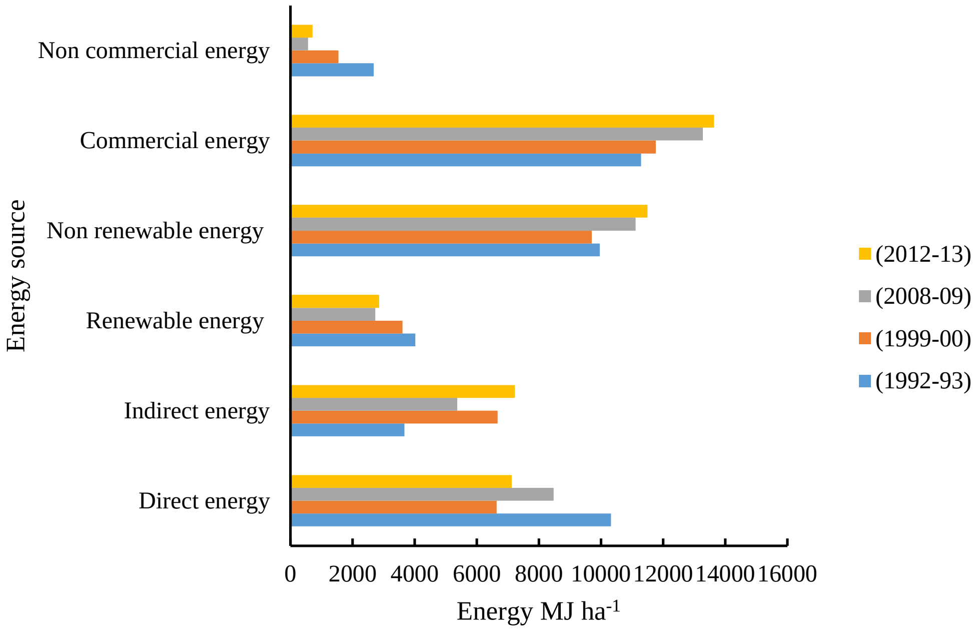


Figure 10 Source wise energy classification for village Singod

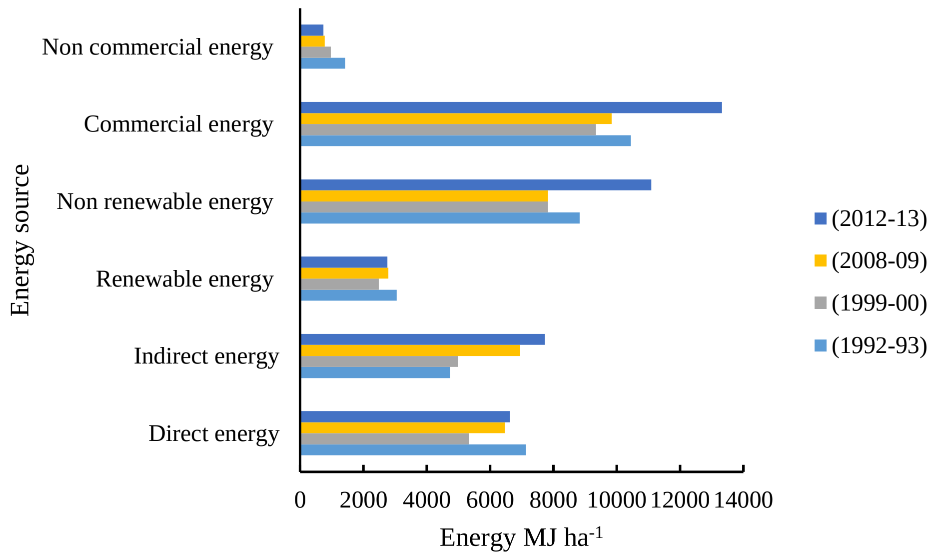


Figure 11 Source wise energy classification for village Phanda

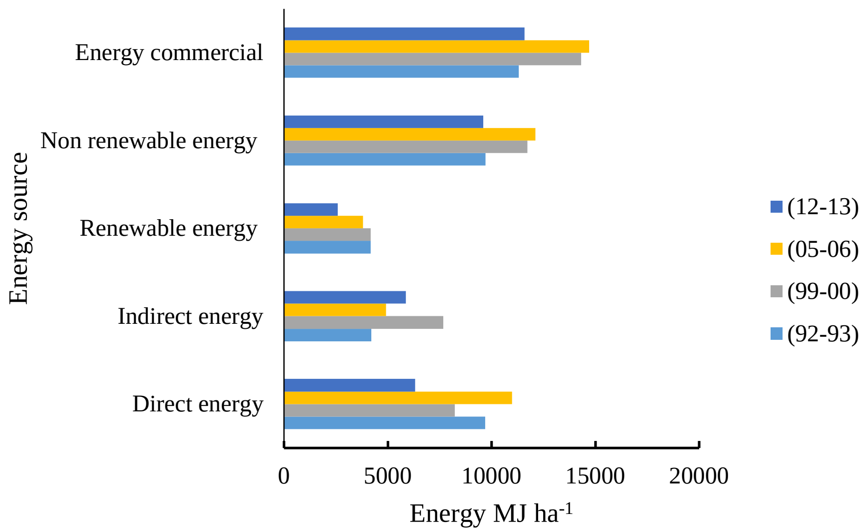


Figure 12 Source wise energy classification for village Sonsa

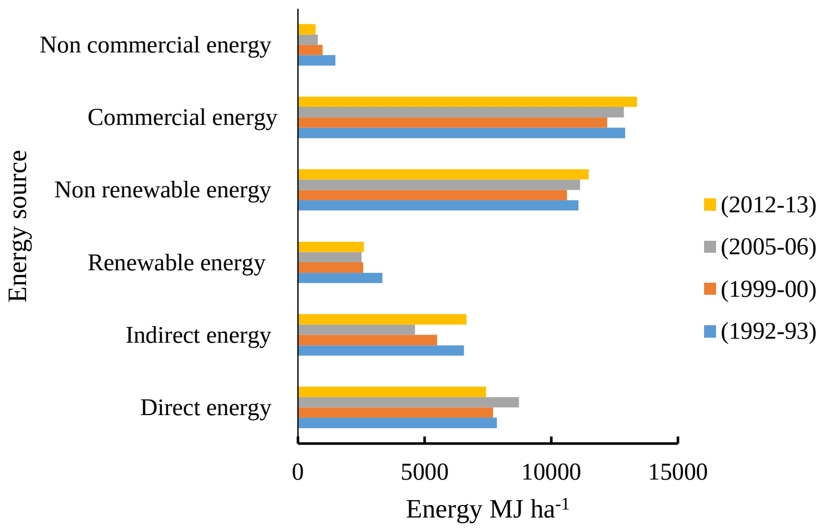


Figure 13 Source wise energy classification for village Kanadia

3.4 Yield and output energy

In Singod, the changes in energy use pattern have been found very productive and positive. The productivity of wheat increased from 0.21 kg MJ^{-1} to 0.27 kg MJ^{-1}. The increment of about 29%. The yield increased from 2.99 t ha^{-1} to 3.85 t ha^{-1}. The increment of 28% over the period of surveys (Table 3). The energy consumption decreased from 4.65 MJ kg^{-1} to 3.72 MJ kg^{-1}. This shows the saving of energy by 20%. The energy use efficiency increased from 5.83 to 7.30 shows the significant increase in energy use efficiency by 25.21% over the period of surveys. The wheat crop yield was increased over the period and there was 33.36%, 16.88%, and 35.57% higher yield was recorded for Phanda, Sonsa and Kanadia, respectively. Specific energy was on decreasing trend and there was 42.24%, 33.83%, and 38.82% reduction was observed for Phanda, Sonsa and Kanadia, respectively. The energy use efficiency was increased by 42.15%, 33.46% and 38.57% for Phanda, Sonsa and Kanadia, respectively. The increase in the productivity in recent years shows that as the use of energy increased the increment in yield was proportionately higher and it can be concluded that there is still be possibility to increase the yield of wheat by increased energy inputs.

Table 3 Yield of wheat and output energy analysis

Year	Singod			Phanda			Sonsa			Kanadia		
	Yield (t ha^{-1})	Specific energy (MJ kg^{-1})	Energy use efficiency	Yield (t ha^{-1})	Specific energy (MJ kg^{-1})	Energy use efficiency	Yield (t ha^{-1})	Specific energy (MJ kg^{-1})	Energy use efficiency	Yield (t ha^{-1})	Specific energy (MJ kg^{-1})	Energy use efficiency
1992-1993	2.99	4.65	5.83	2.23	5.32	5.1	2.61	5.34	5.11	2.89	4.97	5.47
1999-2000	3.04	4.37	6.22	2.59	3.98	6.83	3.12	5.07	5.35	4.14	3.29	8.26
2008-2009	3.93	3.62	7.70	3.57	3.22	7.25	3.57	4.44	6.11	4.37	3.19	8.62
2012-2013	3.85	3.72	7.30	2.97	3.74	7.25	3.05	3.99	6.82	3.92	3.58	7.58

4 Conclusion

The level of productivity depends upon level of energy inputs applied on different farm operation. The trend of use of direct energy resources have been dynamic in study area with the major shift to non-renewable and commercial sources as electricity, fertilizer, and diesel; it has become imperative to ensure timely and adequate supply of these resources so that energy investments made are fully exploited. Marginal and small category farms utilized lesser than average energy for almost all the operations whereas medium and large farms consumed comparatively higher than average energy for most of the operations. It is also seen that higher the farm size utilizes higher energy use per unit area. It is very positive fact that in recent years the energy use efficiency increased to a greater extent in study area. The energy productivity was 0.21 kg MJ^{-1} in Singod in first round of survey and increased to 0.27 kg MJ^{-1}in the year 2012-13 with an increased efficiency of 28%. Similar increment of 17%, 39% and 35% was noticed in Phanda, Sonsa and Kanadia. Better management of physical inputs, timeliness of operations, saving in unnecessary tillage, quality seed, use of superior chemicals for plant protection, uniformity of water use resulted into a great positive effect which can be seen by energy use efficiency and yield for the production of wheat in study area.

Acknowledgements

The authors express their sincere thanks to the Indian Council of Agricultural Research, New Delhi, for supporting the programme of studies. The authors are grateful to the Vice-chancellor JNKVV Jabalpur for his encouragement and making the college facilities available. Finally, the services rendered by farm machinery students and staffs engaged during study period are thankfully acknowledged.

Conflict of interest

Authors declares no conflict of interest.

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