Estimation and comparison of energy input-output and efficiency indices for rice-wheat agroecosystems of Doon valley-India

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Abstract

Energy use in the rice-wheat crop production system is a major emitter of global GHG emissions. Understanding of input-wise energy flows in the production system is vital to optimize input-output and also is essential to estimate GHG emissions and Global Warming Potential. Doon valley has energy-intensive agriculture practices and a survey-based assessment was undertaken in Doon valley covering 63 farms. The study estimated total input energy for rice-wheat cultivation as 63825 and 50799 $MJha^{-1}$ respectively. Main contributors are electricity, fertilizer and diesel for both crops, however irrigation water is also a significant contributor in rice. The yield per unit energy use is relatively low and warrants better crop management practices to reduce the environmental footprint of the rice-wheat cropping system.

Keywords: Energy, Agriculture, Sustainable agriculture, Energy productivity, Energy-use efficiency, Rice-wheat system, Doon valley

1. Introduction

To provide more food and adequate nutrition to the rising population of the world, agriculture has become increasingly energy-intensive. Application of chemical fertilizer and burning of fossil fuel in agriculture emit GHGs and other pollutants in air and water. Curtailment of greenhouse gas emissions (GHG) to mitigate climate change is the leading objective for global agriculture. Its contribution in the worldwide GHG emissions is 10-12% and 14% in CO_2 emissions. In India, agricultural accounts for 18% of total GHG emissions. An improved appreciation of energy input flows in the crop production system can assist in developing better crop management practices to tackle environmental and human health challenges[1].

The largest agriculture production system globally is the rice-wheat cropping system covering 24 million hectares The conventional rice-wheat production system is plagued by many sustainability concerns including unsustainable water use, high energy intensity and comparatively high GHG emissions among other crops. The highest energy intensity and GHG emissions are associated with rice. Largest contributor to CO_2 emissions is energy use for irrigation in rice-wheat cultivation[2]. In past decades, GHG emissions in rice-wheat production system has seen an upward trajectory owing to high application of chemical fertilizer, aggressive use of direct energy input in irrigation and increased farm mechanization.

There exist numerous analyses over the estimation of energy consumption and energy indicators for a specific crop but very few studies focused on a particular cropping system. In addition, there is a paucity of literature on the two most significant crops (in terms of area undercover and volume of production) such as rice and wheat in India. Consequently, central aim is to estimate in rice-wheat agroecosystem in Doon valley:

a) Input-wise energy requirement

b) Energy efficiency indicators

2. Material and Methods

2.1. Selection of study area, data gathering methods and input estimation

The share of agriculture in the GDP of the state of Uttarakhand (UK) is around 11%. It is the principal source of livelihood for above 70% of its populace. Agriculture is commercialized in the plains and valleys while farming in the mountains is mostly subsistence. Major crops grown in valleys and plains are rice, wheat and sugarcane. Rice and wheat are the most important strategic crop in the state and are crucial for food security. In 2016-17, the share of rice in the total sown area in the Kharif season was 54%. Similarly, in Rabi season, wheat constitutes around 93% share among major crops.

In this study high-input and irrigated rice-wheat crop production was studied in Doon valley and plains in the state of Uttarakhand in north India (30.15° and 30.25° N, 78.00° and 78.10°E). Per annum rainfall is above 800 mm which predominantly occurs during monsoons. July and August are the wettest months. In summer months temperatures varies between 36º C and 16.7 º C, and 23.4º C and 5.2 º C in winters.

The production of rice and wheat was 2016-17 was 0.59 and 0.79 million tons with average productivity of 2340 and 2310 kgha^{-1} respectively. The primary sources of irrigation are tube wells with a share of 58% followed by canals (28%). Data were collected by random selection of 63 farmers using a questionnaire survey.

Machine usage was captured by tillage, transporting, fertilizer application and spraying. Consumption of diesel fuel was captuted by operation. Human labour was assessed for tillage, seeding, weeding, irrigation, fertilizer, pesticide and harvesting (cutting, threshing and picking). Water for irrigation was computed for rice and wheat in the study area utilizing FAO's CROPWAT simulation software by taking into consideration local climatic parameters and soil data which influence reference crop evapotranspiration (ET_0)[3]. Penman-Monteith method was used to estimate ET_0 and effective rainfall in the model was calculated using the United States Department of Agriculture soil conservation method[4].

2.2. Estimation of energy indices

Total input and output energy and their energy equivalent were calculated using **Error! Reference source not found.**[1,5]. Total energy input is classified into renewable, non-renewable, direct and indirect energies[6]. Water for irrigation, seed, human labour and manure constitute renewable energy resources. Non-renewable resources constitutes diesel fuel, pesticides, electricity, machine use and fertilizers. Direct Energy include diesel fuel, electricity, human labour and water for irrigation. Indirect energy comprised machinery, chemical fertilizer, seed, pesticide and manure. Output energy was estimated using grain and straw/residual yield.

Table 1 Energy equivalents of input and output in irrigated rice-wheat production

Input and output energy and grain yield were uused to capture various energy indices according to Equations 1 to 5[1,7]. The agrochemical energy ratio is the proportion of applied energy through chemicals ─ including pesticides and fertilizers ─ to total energy input.

Equation 1. $$\text{Energy use efficency} = \frac{\text{Total energy output (MJ } ha^{-1})}{\text{Total energy input (MJ } ha^{-1})}$$

Equation 2. $$\text{Energy productivity} = \frac{\text{Grain productivity (kg } ha^{-1})}{\text{Total energy input (MJ } ha^{-1})}$$

Equation 3. $$\text{Net Energy} = [\text{Total energy output (MJ } ha^{-1})] - [\text{Total energy input (MJ } ha^{-1})]$$

Equation 4. $$\text{Agrochemical energy ratio} = \frac{\text{The energy input for agrochemical (MJ } ha^{-1})}{\text{Total energy input (MJ } ha^{-1})}$$

Equation 5. $$\text{Specific energy ratio} = \frac{\text{Total input energy (MJ } ha^{-1})}{\text{Grain productivity (kg } ha^{-1})}$$

3. Results and discussion

3.1. Analysis of input energy in rice production

Quantity of inputs and output for rice-wheat and respective energy equivalents are given in **Error! Reference source not found.**. Total energy input in the cultivation of rice is estimated at 63824.68 MJha^{-1} which is in line with a study conducted in Punjab[8] (energy input between 52,400 ± 13,000 MJha^{-1}). Agriculture in Punjab is similar − irrigated, high input and energy-intensive. Another study[9] estimated energy input for rice in India ranging from 54,8[7]7 to 95,117 MJha^{-1} which is consistent with our findings. According to this study, primary contributors are water for irrigation, electricity and fertilizer reiterating our conclusions.

Table 2 Estimated amount of inputs, output and their energy equivalent in Rice-Wheat cropping system

Among the constituents of total energy input shown in **Error! Reference source not found.**, the maximum share was of electricity (35%) followed by diesel and irrigation water (16% each) and chemical fertilizer (15%). A study[8] conducted on rice in Punjab reported that significant contributors were irrigation water (40%) and chemical fertilizers (24.7%). Another study[10] conducted in India estimated total energy input in irrigated rice between 35,000−45,000 MJha^{-1} in 1985 for producing 4500 kgha^{-1}. The average productivity recorded in our study is 5812.50 kgha^{-1}. The yield and energy input has risen by 1.3 and 1.4 times respectively reflecting an increase in energy intensification of agriculture and resultant improvement in yield. Hence, our estimates are consistent with comparable studies.

Figure 1 Percentage share of various constituents in total energy input in rice production

3.2. Analysis of input energy in wheat production

Total input energy in the wheat cultivation is 50798.91 MJha^{-1}. A comparative study conducted in Iran[1] on high-input (irrigated) wheat agroecosystem reported the total input as 60832.52 MJha^{-1}. Our estimates are consistent with the study. From **Error! Reference source not found.** it can be seen that the biggest contributor is electricity (29%), chemical fertilizer (17%), diesel fuel (16%) and irrigation water (12%).

Figure 2 Percentage share of various constituents in total energy input in wheat production

A 2016 study[1] also reported the maximum shares of electricity (36%), chemical fertilizer (21%), diesel fuel (13%) and water for irrigation (10%) for the irrigated high-input wheat production system. A similar study 40in turkey on irrigated wheat cultivation reported chemical fertilizers as the major contributor in input energy followed by diesel and seed. Interestingly our study (Figure 3) also found seed to contribute 5.50% which is significant compared to rice seed (0.50%). Other significant changes between rice and wheat are in electricity and water use for irrigation. A

Study [12] estimated input energy and output energy for rice-wheat agroecosystem in Middle-Indo Gangetic Plains in India. The energy input for the combined system was calculated at 39,740 ± 17,230 (±SD) MJha^{-1} and output was estimated at 250, 890 ± 40,130 MJha^{-1}. Our estimates for the combined system is 114623.59 MJha^{-1} and 270587.50 MJha^{-1} which are well with the permissible range.

Figure 3 Input wise energy consumption for rice and wheat

It can be seen from **Error! Reference source not found.** that water for irrigation is a key contributor to input energy for rice when compared to wheat. In absolute terms, electricity and water use are significantly higher for rice while other inputs use are more or less alike.

3.3. Analysis of output energy in rice and wheat production

Average grain and straw productivity for rice is estimated at 5, 813 kgha^{-1} and 5,000 kgha^{-1} respectively. This is converted into output energy at 161,313 MJha^{-1}. A study[13] reported average grain yield in rice 6470.80 kgha^{-1} and output energy as 108321.75 MJha^{-1}. Therefore, our estimates are backed by comparable literature.

The productivity of wheat was reported as 3,979 kgha^{-1} and straw output as 4063 kgha^{-1}. This translates into 109,275 MJha^{-1}. A study[1] estimated the average grain yield of high-input and low-input wheat agroecosystem in Iran as 7,000 kgha^{-1} and 1967.50 kgha^{-1}respectively. Our estimates fall well between this range.

3.4. Analysis of energy forms in the rice-wheat production system

Different forms of energy are given in **Error! Reference source not found.**. Direct energy constituted 70% of total input energy in rice with a share of 44,613.28 MJha^{-1}. A study[14] in Malaysia estimated direct energy in high input rice to be around 30%. However, in this study water and energy for irrigation was not incorporated in the analysis. In our study share of water and electricity is 51% of the total energy input. Therefore, our results are not contradictory to existing literature. Direct energy made up 59% of input energy in wheat production with a share at 30,047.85 MJha^{-1}. The residual is indirect energy (30% and 41% for rice and wheat respectively). A study[1] estimated direct & indirect energy in high input wheat and estimated it to be 59% and 41% respectively which conforms with our study.

Table 3 Different forms of energy and their percentage share in total energy input

The studies[1,7] on wheat and corn in Iran concludes that the percentage of indirect energy is less than direct energy in crop production systems due to the high importance of irrigation and fuel to drive machines and motor pumps in the modern crop production system. Reiteratively, various studies7,16,40 and other reports have found similar results that the share of direct energy is evidently more than indirect energy. Our results are consistent with these findings.

Renewable energy has a minor share and non-renewable energy accounted for 75% and 76% share in rice and wheat respectively. Another study on wheat shows that renewable energy use was 21% for high input agriculture[1]. Our results differ due to high use of farm manure usage (6%) in total energy input. According to another study[11] on wheat in Turkey, non-renewable constitute 77% of the total energy inputs and our estimates are well with permissible range.

3.5. Analysis of energy indices

The key energy indices are given in **Error! Reference source not found.**. Energy use-efficiency ratio of energy-ratio and specific (input energy to output yield) are important indicators for efficiency for crop production system even at the farm level. Energy use efficiency was estimated at 2.53 for rice and 2.15 for wheat. If energy use-efficiency is above 1, then the production system is generating energy. A study[1] estimated energy efficiency in high input wheat production as 3.03 which is 20% higher than our estimates. Therefore, there is scope of improvement in energy efficiency via modernization, farm mechanization, better nutrient management and energy-efficient irrigation pumps. A balanced scientific application of nitrogen and minimum tillage leads to curtailment of energy input by 64.70% and 11.20% respectively[15].

Table 4 Forms of energy input and critical indices

Specific energy measures the input energy per kilogram of production and a lower value is a better stage. Specific energy is estimated at 10.98 and 12.77 $MJkg^{-1}$ for rice and wheat respectively. Other studies[8,16] in India for wheat have estimated a specific energy ratio between 3.87 to 8.00 $MJkg^{-1}$ which is significantly better than our estimates. In addition, compared to study on wheat in Iran our estimates are 75% higher[1]. Hence there is scope to improve productivity per unit of energy input. Similarly, another study[12] estimated the ratio for the combined system at 4.4 $MJkg^{-1}$ (compared to our estimate of 11) owing to the fertile Indo-Gangetic plains characterised by the high yield. The potential productivity of rice and wheat in this region reached 10700 and 7900 $kgha^{-1}$ respectively[10] compared to our estimates of yield of 5813 and 3979 $kgha^{-1}$ respectively. For this reason energy use efficiency estimated in[12] is 6.87.

The net energy gain is estimated at 97487.82 and 58476.09 $MJha^{-1}$ for rice and wheat respectively. Per kilogram net energy gain for rice is 16.70 which is significantly higher than wheat (14.70) thereby implying that the production of rice leads to higher energy gain for every unit of production. The combined net energy gain of the rice-wheat cropping system is estimated at 155963.91 $MJha^{-1}$ which is well within the range estimated by[12] for fertile Indo-Gangetic Plains (1537900 to 2685100 $MJha^{-1}$). Our estimates are on the lower end of the range owing to significant lower comparative yield in our study area.

The agrochemical energy ratio for rice is 17% and for wheat its 20%. A high ratio implies large agrochemical footprint and negative environmental effects as nitrogen leaching, pollution in air and water and greenhouse gas emission[17]. The higher consumption of nitrogen in the total input energy is the reason for the higher ratio in wheat. However, the ratio for both rice and wheat is lower than comparable studies[7] in Iran which estimated the ratio in the production of corn as 40% which illustrates a chemical-intensive production system. In our study area, there was a significant application of organic manure (6% for rice and 7% for wheat) leading to the lower application of chemicals per unit of area.

Energy productivity for rice and wheat is estimated as 0.09 and 0.08 $kgMJ^{-1}$ respectively which is low when compared to similar studies. A study[7] estimated energy productivity as 0.18 and another study[1] estimated the ratio for irrigated and unirrigated wheat as 0.11 and 0.14 respectively. This reiterates the need and potential for improving energy efficiency and increasing productivity in Doon valley.

4. Conclusions

The total energy input for rice and wheat was valued at 63825 and 50799 $MJha^{-1}$ respectively. Combine energy input and output for combine crop rotation 114624 and 270588 $MJha^{-1}$ respectively. Primary contributors in the input energy are electricity for water pumps and water for irrigation followed by nitrogen fertilizer and diesel fuel. The input-wise energy estimates can be used to estimate GHG emissions and the global warming potential (GWP) of the rice-wheat cropping cycle in north India for larger policy-relevant interventions. Energy use efficiency in the studied system is low (2.53 for rice and 2.15 for wheat) and the specific energy ratio is high 10.98 $MJkg^{-1}$ for rice and 12.77 $MJkg^{-1}$ for wheat) when compared to comparable studies. This implies that there is a need to optimise energy use, implement energy efficiency measures and improve productivity per unit of energy consumed in the studies system. There is a close association between and GHG emissions, global warming potential (GWP) and non-renewable energy input. Our estimated share of non-renewable sources was 75% for rice and 74% for wheat. Therefore, there is a need to curtail the use of non-renewable energy resources. There is considerable scope in energy savings through improvement in energy efficiency in agriculture water pumps, minimum tillage and harmonizing sowing season with the monsoon season. Optimizing fertilizer management by reducing synthetic fertilizer inputs and increasing organic compost and improving water management is vital. The state departments should converge to introduce energy-efficient practices which will go a long way in ensuring the sustainability of production system in the state.

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References

1. Yousefi, M., Mahdavi Damghani, A., and Khoramivafa, M., Comparison greenhouse gas (GHG) emissions and global warming potential (GWP) effect of energy use in different wheat agroecosystems in Iran. *Environmental Science and Pollution Research*, 2016, **23**, 7390–7397.
2. Rao, N. D., Poblete-Cazenave, M., Bhalerao, R., Davis, K. F., and Parkinson, S., Spatial analysis of energy use and GHG emissions from cereal production in India. *Science of the Total Environment*, 2019, **654**, 841–849.
3. Pereira, L. S., *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56 PHDROUGHT-Predictability assessment and hybridization of seasonal drought forecasts in Western Europe View project no title View project* 1998.
4. Howell, T. A. , E. S. R., *The Penman-Monteith method. Section 3 in Evapotranspiration: Determination of Consumptive Use in Water Rights Proceedings. Continuing Legal Education in Colorado* Denver, CO, 2004.
5. Yuan, S. and Peng, S., Input-output energy analysis of rice production in different crop management practices in central China. *Energy*, 2017, **141**, 1124–1132.
6. Alam MS, A. M. I. K., Energy flow in Bangladesh agriculture. *American Journal of Environmental Science*, 2005, **1**, 213–220.
7. Yousefi, M., Damghani, A. M., and Khoramivafa, M., Energy consumption, greenhouse gas emissions and assessment of sustainability index in corn agroecosystems of Iran. *Science of the Total Environment*, 2014, **493**, 330–335.
8. Singh, P., Singh, G., and Sodhi, G. P. S., Energy auditing and optimization approach for improving energy efficiency of rice cultivation in south-western Punjab, India. *Energy*, 2019, **174**, 269–279.
9. Rao, N. D., Poblete-Cazenave, M., Bhalerao, R., Davis, K. F., and Parkinson, S., Spatial analysis of energy use and GHG emissions from cereal production in India. *Science of the Total Environment*, 2019, **654**, 841–849.
10. Pathank, B. S. , B. A. S., Energy use pattern and potential for energy saving in rice-wheat cultivation. *Energy in Agriculture*, 1985, **4**, 271–278.
11. Cicek, A., Altintas, G., Erdal, G., and Journal, B., *Agricultural Academy Agricultural Science*, 2011.
12. Soni, P., Sinha, R., and Perret, S. R., Energy use and efficiency in selected rice-based cropping systems of the Middle-Indo Gangetic Plains in India. *Energy Reports*, 2018, **4**, 554–564.
13. Marvin Bockari-Gevao, S., Ishak bin Wan Ismail, W., Yahya, A., et al., *Agricultural Engineering), Senior Research Officer, Mechanization and Automation Division 43400 UPM Serdang,*.
14. Marvin Bockari-Gevao, S., Ishak bin Wan Ismail, W., Yahya, A., et al., *Agricultural Engineering), Senior Research Officer, Mechanization and Automation Division 43400 UPM Serdang,*.
15. Alluvione, F., Moretti, B., Sacco, D., and Grignani, C., EUE (energy use efficiency) of cropping systems for a sustainable agriculture. *Energy*, 2011, **36**, 4468–4481.
16. Singh, H., Singh, A. K., Kushwaha, H. L., and Singh, A., Energy consumption pattern of wheat production in India. *Energy*, 2007, **32**, 1848–1854.
17. Pishgar-Komleh, S. H., Omid, M., and Heidari, M. D., On the study of energy use and GHG (greenhouse gas) emissions in greenhouse cucumber production in Yazd province. *Energy*, 2013, **59**, 63–71.
18. Mohammadi, A. and Omid, M., Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. *Applied Energy*, 2010, **87**, 191–196.
19. Samavatean, N., Rafiee, S., Mobli, H., and Mohammadi, A., An analysis of energy use and relation between energy inputs and yield, costs and income of garlic production in Iran. *Renewable Energy*, 2011, **36**, 1808–1813.
20. Erdal, G., Esengün, K., Erdal, H., and Gündüz, O., Energy use and economical analysis of sugar beet production in Tokat province of Turkey. *Energy*, 2007, **32**, 35–41.

Table 5 Energy equivalents of input and output in irrigated rice-wheat production

Input/Output	Unit	Energy equivalent	References
(B) Inputs			
1. Human labor	H	1.96	[18]
2. Machinery	H	62.70	[19]
3.Diesel fuel	L	51.33	[19]
4.Chemical fertilizer	Kg		
(a) Nitrogen		66.14	[20]
(b) Phosphate (P2O5)		12.44	[20]
(c) Potassium (K2O)		11.15	[20]
5. Farmyard manure	Kg	0.30	[1]
6. Pesticides	Kg		
(a) Herbicides		101.20	[1]
(b) Insecticides		199.00	[1]
7. Electricity	Kwh	3.60	[7]
8. Water for irrigation		1.02	[19]
9. Seed	Kg	17.60	[7]
(A) Output			
1. Grain (Rice)	Kg	17.00	[5]
2. Straw (Rice)	Kg	12.50	[5]
3. Grain (Wheat)	Kg	14.70	34
4. Straw (Wheat)	Kg	12.50	[1]

Table 6 Estimated amount of inputs, output and their energy equivalent in Rice-Wheat cropping system

Input	Unit	Quantity of input per unit area (ha)		Total energy equivalents (MJ ha−1)	
(A) Inputs		Rice	Wheat	Rice	Wheat
1. Human labor	H	1120.13	525.22	2195.45	1029.44
2. Machinery	H	68.60	68.22	4300.95	4277.32
3. Diesel fuel	L	193.78	158.33	9946.66	8127.25
4. Chemical fertilizer	Kg				
(a) Nitrogen		125.26	116.34	8284.76	7694.80
(b) Phosphate (P2O5)		62.72	64.69	780.20	804.80
(c) Potassium (K2O)		18.32	27.86	204.23	310.62
5. Farmyard manure	Kg	12500.00	11875.00	3750.00	3562.50
6. Pesticides					
(a) Herbicides	L	5.75	4.57	581.65	462.90
(b) Insecticides	L	5.31	4.72	1056.06	938.47
7. Electricity	Kwh	6221.00	4132.00	22395.60	14875.20
8. Water for irrigation	M3	9878.00	5898.00	10075.56	6015.96
9. Seed	Kg	14.41	153.39	253.56	2699.66
Total input energy (MJ)				63824.68	50798.91
(B) Outputs					
Grain	Kg	5812.50	3979.17	98812.50	58493.75
Straw	Kg	5000.00	4062.50	62500.00	50781.25
Total output energy (MJ)				**161312.50**	**109275.00**

Table 7 Different forms of energy and their percentage share in total energy input

Forms of Energy	Quantity per unit area (MJ/ha)		Percentage of total energy (%)	
	Rice	Wheat	Rice	Wheat
Direct energy	44613.28	30047.85	70%	59%
Indirect energy	19211.40	20751.07	30%	41%
Renewable energy	16274.57	13307.56	25%	26%
Non-renewable energy	47550.11	37491.36	75%	74%
Total energy input	63824.68	50798.91	100%	100%

Table 8 Forms of energy input and critical indices

Indicator	Rice	Wheat	Unit
Total input energy (MJ)	63824.68	50798.91	$MJ\ ha^{-1}$
Total output energy	161312.50	109275.00	$MJha^{-1}$
Grain production	5812.50	3979.17	$kg\ ha^{-1}$
Straw output	5000.00	4062.50	$kgha^{-1}$
Energy use efficiency	2.53	2.15	Ratio
Energy productivity	0.09	0.08	$kg\ MJ^{-1}$
Net Energy	97487.82	58476.09	$MJ\ ha^{-1}$
Agrochemical energy ratio	0.17	0.20	Ratio
Specific energy	10.98	12.77	$MJkg^{-1}$

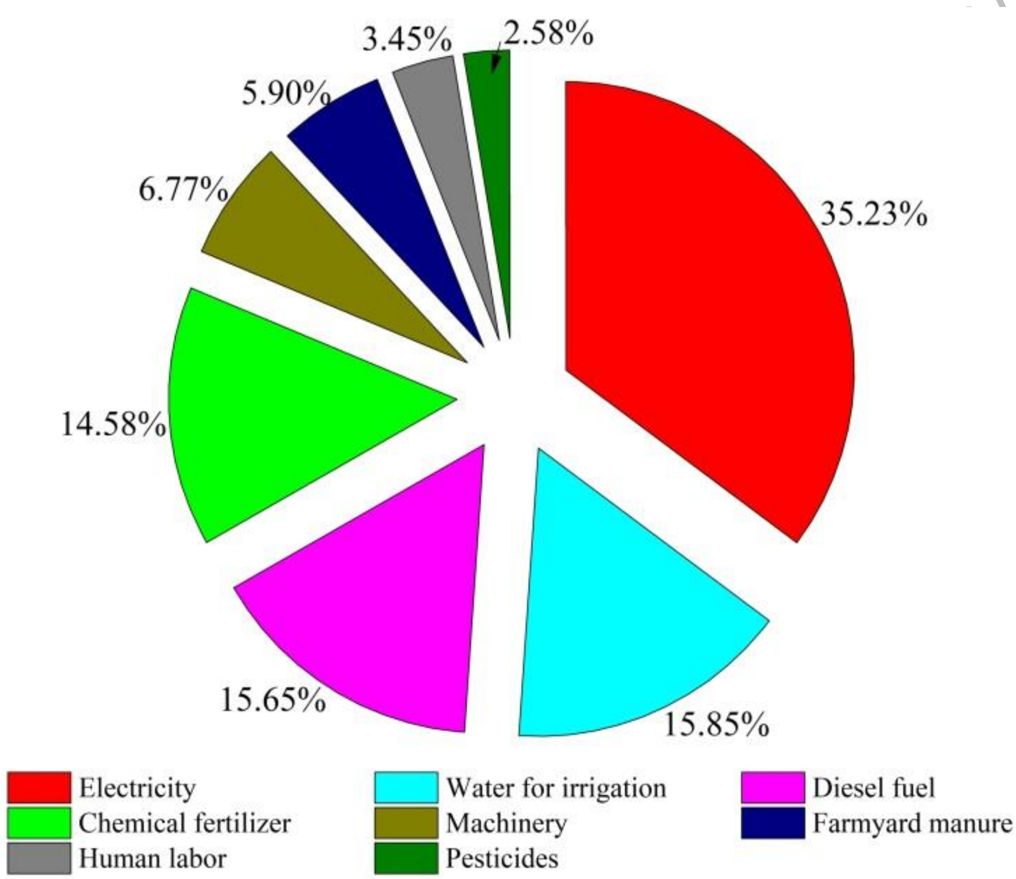

Figure 4 Percentage share of various constituents in total energy input in rice production

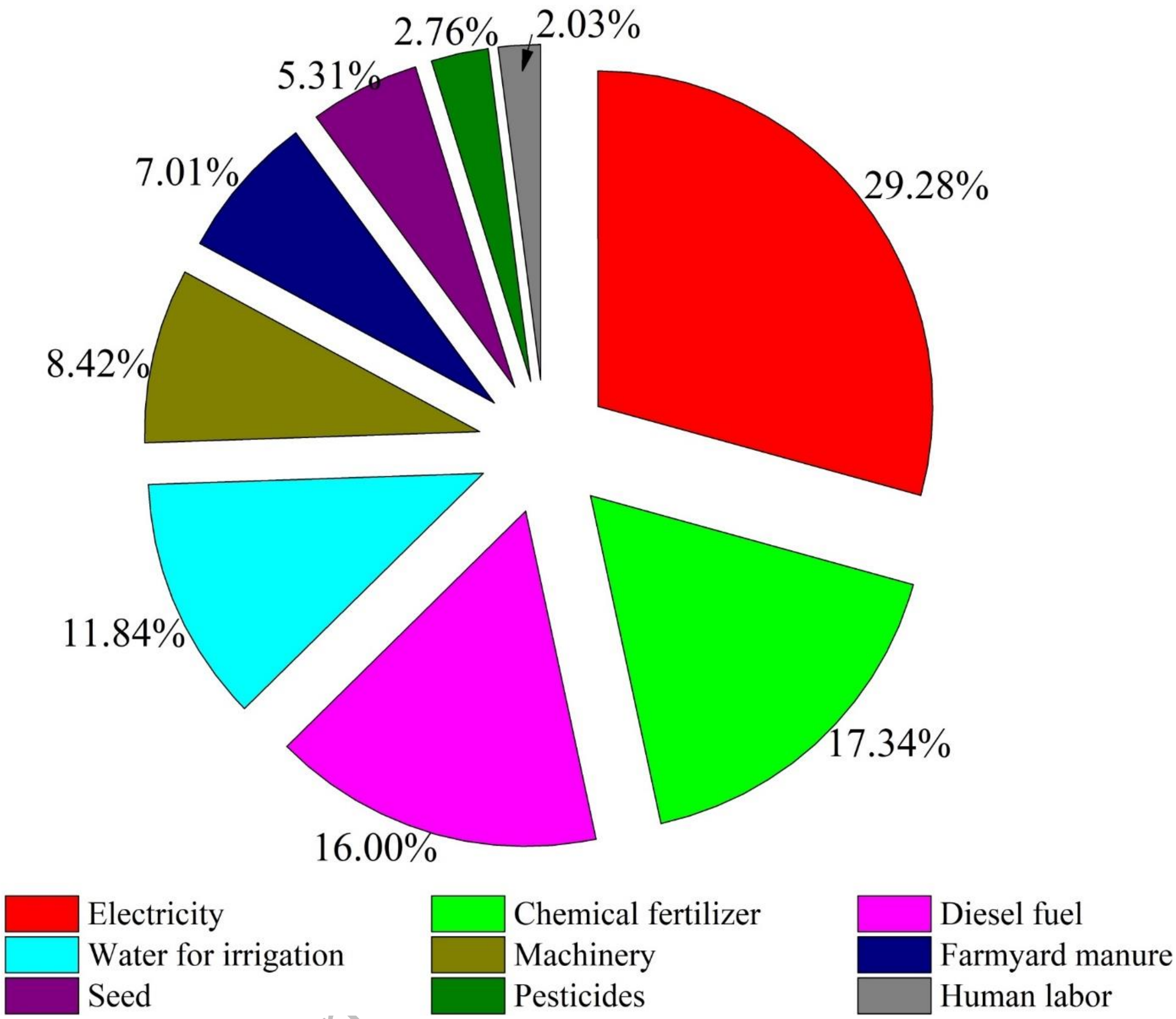

Figure 5 Percentage share of various constituents in total energy input in wheat production

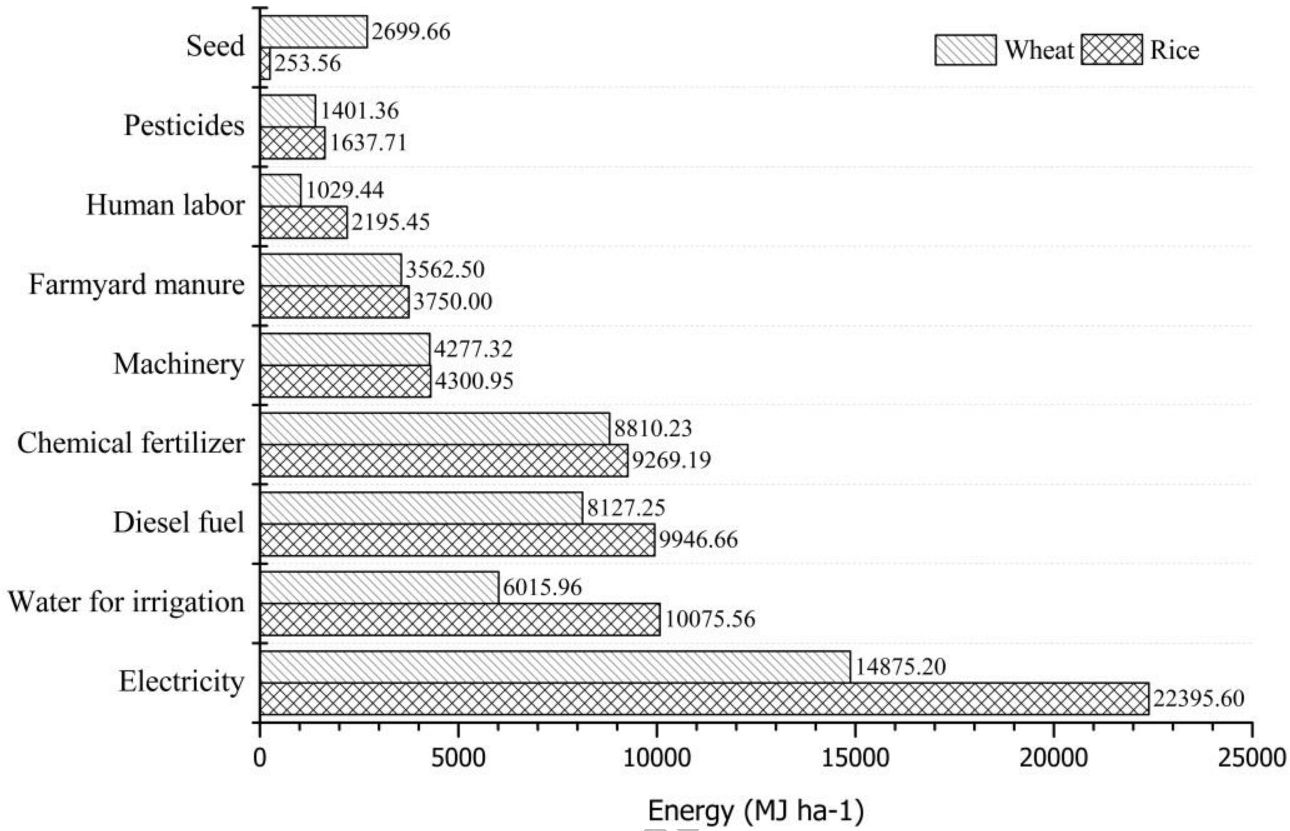

Figure 6 Input wise energy consumption for rice and wheat