*Journal of Agricultural Development and Policy, 2022*
*Volume 32, No. 1, 1-6*

# Economic Growth and Structural Changes in Rajasthan Economy (1955-56 to 2019-20)

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**Abstract**

*This paper highlights the trends of economic growth and structural change in the economy of Rajasthan and discusses its relative share in the national economy of India. It reviews the trends of year-wise growth rate of NSDP and per capita income for Rajasthan state during 1955-56 to 2019-20. The long term rate of growth of income came to about positive more than 3 per cent percent during 2012-13 to 2019-20. The semi-log equation was fitted to the data of NDP for the period 1955-56 to 2019-20 and it shows that the income of the state had increased, on an average, at the rate of 13.47 percent per annum at current prices and 3.75 per cent at constant prices. It is indicative of ups and downs that economy has registered in the growth trajectory. The income concentration ratio of per capita income varied from 0.597 to 0.968 at current prices and from 0.015 to 0.886 at constant prices. The overall index of infrastructural facilities stood at 50.31 in 1965-66 and increased to 74.58 in 2010-11, with all India bases taken as 100 in both the year. The share of primary sectors has gone down from 40.81 percent in 1959-60 to 26.73 percent in 2019-20. Similarly, the share of the tertiary sector improved from 32.29 percent in 1969-70 to 44.70 percent in 2019-20.*

**Keywords:** Economic growth, Structure change, Income, NDP

**JEL Classification:** O4, Q1, P2

## Introduction

Rajasthan is the largest state of India constituting 10.4 per cent of total geographical area and 5.67 per cent of total population of India (GoI, 2011). The state is divided into 7 divisions, 33 districts, which are subdivided into 244 tehsils, 249 panchayat samitees and 9,168 gram panchayats. Physio-graphically, the state can be divided into 4 major regions, namely (i) the western desert with barren hills, rocky plains and sandy plains; (ii) the Aravalli hills running south-west to north-east starting from Gujarat and ending in Delhi; (iii) the eastern plains with rich alluvial soils; and (iv) the south-eastern plateau. Mahi, Chambal and Banas are the three major rivers of the state. The state enjoys a strategic geographical position wherein it is situated between Northern and Western growth hubs in the country and 40 per cent of Delhi Mumbai Industrial Corridor (DMIC) runs through it. The state has well identified 10 agro-climatic zones. The state is endowed with diverse soil and weather conditions comprising of several agro-climatic situations, warm humid in south-eastern parts to dry cool in western parts of the state. About 65 per cent of state's population (i.e. about 56.5 million) depends on agriculture and allied activities for their livelihood. The three major canal irrigations, other than the vast area under arid and dry lands offer great help for agricultural development of the state. Agriculture in Rajasthan is primarily rainfed covering country's 13.27 per cent of available land. The diversity in climatic conditions of the state creates potential to develop horticultural belts. The arid part of the state which receives not more than annual rainfall of 25 cm thrives on agriculture that is done with irrigation systems and painstaking efforts of the poor farmers of Rajasthan. As a major portion of the state is parched, the risk and instability in agricultural production and productivity are high. Rajasthan's economy has undergone considerable transformation in the recent past in terms of growing manufacturing and service sectors, with the reducing share of agriculture (including livestock) in the state's NSDP.

Rajasthan, the largest state of India, is one of the BIMRAU states that came into existence in 1956. It started its quest for development with several handicaps and few advantages. It is a land locked state. Nearly two-third of its area is arid or semi-arid, with low and irregular rainfall characterized with extremes of climate. For a predominately

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agrarian economy these conditions prove a major handicap in ensuring sustainable growth (Vyas 2007). Significant uncertainty leads to sub-optimal resource allocation in its primary, agricultural sector with repercussions in other sectors of the economy. Its high population growth exerts pressure on fragile ecosystem. Weak economic base of the state makes the task of resource mobilization extremely difficult. The cultural history also adds to the woes of the state at times; it makes the task of sustainable growth all the more daunting. In the recent past, economic growth has witnessed rapid increases, but sustenance is a problem. During the last 65 years it has made considerable progress in all sectors of the economy. How far this progress of the state has been commensurate with that of the country as a whole, is the primary question to which the present investigation is addressed. Thus, the present study is taken up with the objectives to assess the growth of State, to estimate and evaluate the trends of the growth for selected periods, to examine and evaluate the character of growth of the state's economy and to identify main constraints that has come in the way of economic growth of the state's economy.

## Data Sources and Methodology

To achieve the first objective of the study, major reliance has been placed on two indicators viz.(a) increase in State Domestic Product (SDP) and (b) changes in per capita income. The study is based on the estimates of Net Domestic Product (NDP) of Rajasthan prepared by the Directorate of Economics and Statistics, Jaipur. The estimates of Net States Domestic Product (NSDP) have been considered both at current and constant prices. So far as growth at current prices does not reflect the real growth of the economy, the growths of income at constant prices have been analyzed in greater detail. The estimates of NSDP at 1955-56 to 2019-20 prices are available for selected periods, comparative data on NSDP from last Seven decade (1959-60 to 2019-20) are also, available. For trend analysis, 1955-56 to 2019-20 periods has been considered in this study. Following semi-log equation has been used for this propose.

$$\text{Log NSDP} = a + b.T$$

Where, T is the time and b is the regression coefficient and a is constant. From this equation growth rate can be worked out as follows: Growth Rate = (Antilog b-1) × 100

For an assessment of change in the relative position of state's economy with the rest of the country, following income concentration ratio has been worked out for per capita income at current and constant prices:

$$\text{Income concentration ratio} = \frac{\text{States Per Capita income}}{\text{Average per Capita income of the country}}$$

For evaluating the direction of change in income concentration ratio, linear trend equation was fitted for the period 1955-56 to 2019-20. Sign of the trend coefficient was taken as an indication of the direction of change in the relative position of the state's economy with the rest of the country. For evaluation of the character of growth of the state's economy, percentage changes in the shares of different sectors have been worked out.

## Results and Discussion

### Growth of Rajasthan States Economy

Rajasthan, the largest (area-wise) state in India, is in the north-western part of the subcontinent. It borders six major states in the northern, western, and central parts of India. Rajasthan is a natural corridor between the wealthy northern and the prosperous western states, making it an important trade and commerce Centre. The natural resources, policy incentives, strategic location and infrastructure in the state are favorably suited for investments in sectors such as cement, tourism, agriculture and allied industries, mineral and mineral processing industries. The state has an agricultural economy with nine agro-climatic zones and various types of soil that help during the cultivation of crops. Now we have to see the growth of NDP, per capita income, position of state economy and constrains of the growth all these parameters have been discussed as follows.

The economy of Rajasthan is largely agrarian in nature with high level of fluctuation in agricultural production and productivity that has resulted in wide fluctuation in Gross State Domestic Product (GSDP) of the state over the years. Despite of this, the state economy has exhibited a healthy growth path during the recent past. As per provisional estimate of Ministry of Statistics and Programme Implementation, GoI, the real NDP of All India at Constant (2011-12) Prices for the year 2019-20 was likely to attain a level of ₹128.23 lakh crore, as against ₹123.93 lakh crore in the year 2018-19 showing positive growth rate of 3.5 per cent in the year 2019-20. This has made Rajasthan as one of the fastest growing states of India. Table 1 shows the growth rates of Net Domestic Product of Rajasthan at constant prices for selected periods since 1955-56. The growth rate showed a good deal of fluctuation overtime. During the first to third five-year plan, net domestic product increased at the rate of 3.24 to 11.14 per cent per annum. During this period, the FYP emphasis was to increase agriculture production and extension of facilities for irrigation and power. The rate of growth decreased to -9.75 to -2.05 per cent per annum during 1974-75 to 1989-90. During this period, the state has faced the absence of rainfall resulting in high drought, political instability and war. The long term rate of growth of income came to about positive more than 3 per cent percent during 2012-13 to 2019-20.

**Table 1. Annual Growth Rates of NDP of Rajasthan**

| Period (End of March) | Total (%) | Per capita (%) |
|---|---|---|
| 1955-56 | 3.24 | 1.3 |
| 1959-60 | 3.85 | 3.2 |
| 1964-65 | 14.77 | 12.1 |
| 1969-70 | 11.14 | 8.8 |
| 1974-75 | -9.75 | -12.3 |
| 1979-80 | -14.55 | -16.9 |
| 1984-85 | -7.19 | -9.6 |
| 1989-90 | -2.05 | -4.2 |
| 1994-95 | 20.76 | 18.3 |
| 1999-2000 | 37.01 | 48.6 |
| 2004-05 | -3.15 | -4.3 |
| 2009-10 | 5.23 | 0.5 |
| 2012-13 | 4.9 | 2.19 |
| 2013-14 | 6.1 | 4.47 |
| 2014-15 | 7.5 | 5.64 |
| 2015-16 | 8.0 | 6.31 |
| 2016-17 | 8.2 | 4.02 |
| 2017-18 | 6.7 | 2.50 |
| 2018-19 | 6.3 | 3.35 |
| 2019-20 | 3.5 | 3.75 |

Semi-log equation was fitted to the data of NDP for the period 1955-56 to 2019-20 and observed, the following results: -

(i) At current prices, log (NDP) = Yt = 21656.1+1.13475 T ,$R^2$ = 0.532, GR =13.75

(ii) At constant prices, log(NDP) = Yt = 106034 +1.03757T,$R^2$ = 0.520 , GR=3.75

In both the regression, $R^2$ happened to be statistically significant at 1 per cent level of significance. The equations showed that the income of the state had increased, on an average, at the rate of 13.47 percent per annum at current prices and 3.75 per cent at constant prices. The states income both at current prices was more than four times the increase at constant prices. Again the trend growth rate in Rajasthan economy for the period 1955-56 to 2019-20 was lower than the all India average a of 1197 per cent at current prices and 3.69 per cent at constant prices reported in world bank data (2020)

To what extent population growth neutralized the growth of net domestic product could be judged from the growth of per capita income. The growth of per capita income indicated the growth of economic development. Table 1 gives the growth rates of per capita income at constant prices for selected periods. As shown in the table, the rate of growth of per capita income varied considerably over different periods. During the first to third five-year plan, per capita income increased at the rate of 1.3 to 8.8 per cent per annum. But this declined to 12.3 to 4.2 per cent during 1989-90. On the whole, per capita income showed fluctuation growth during the entire study period. The low rate of growth of real per capita income reflected the low level of economic performance on the one hand, and high rate of population growth on the other. In Rajasthan, population increased at the rate of 15.2 percent annum during the decade 1951, compared with about 32.97 per cent annum during the decade 1980-81 and 21.31 per cent during the decade 2010-11(Census,2011). The results of estimated semi-log trend equations for the period 1955-56 to 2019-20 was as follows

At current prices, log (NDP/P) =807.239 + 1.05656 T; $R^2$ = 0.557 GR = 8.4 %

At constant prices, log (NDP/P) =216.234 + 1.04438 T; $R^2$ = 0.552GR = 0.62%

The regression coefficient for both the estimated equations was positive. This means that the per capita income, both in real and money terms, had increased during the period. While money income increased at an average rate of 8.40 percent per annum, the real income increased at the annual rate of only 0.62 percent and the corresponding rates of increase for the country as a whole were 9.47% and 2.99 respectively (RBI,2020-21).

The growth of per capita income of the state had all along been lower than the national average. In 1964-65, state's per capita income was 12.1 percent lower than the national average; in 1979-80 it was 16.9 percent less. This showed that the relative position of Rajasthan in the country had considerably deteriorated during this study period. Table 2 shows the income concentration ratio for per capita income at current and constant prices. The ratio varied between 0.597 to 0.968 for per capita income at current prices and between 0.015 to 0.886 at constant prices. The concentration ratio showed wide fluctuations over the period but they were always lower than one.

For estimating the trend in the concentration ratios, linear trend-equations were fitted to the data of concentration ratios for the period 1955-56 to 2019-20. The estimated results were as follows.

(At current prices ) CR = 0.700 + 1.05788T. $R^2$ =.0.822

(At constant prices) CR= 0.015 + 1.05889 T; $R^2$ =0.649

In both the estimated equations, regression coefficients and $R^2$ happened to be statistically significance at 5 percent level and both the regression coefficient were positive, which meant that income concentration ratio had been increasing significantly over time. Besides, the amount of decrease in the value of CR at current prices was more than at constant prices. This meant that the inflationary trends had worsened the relative position of Rajasthan with Indian economy. A similar conclusion was observed by Singariya (2014).

**Table 2. Per Capita Income and Income Concentration Ratio (1955-56 to 2019-20)**

| Year | Per capita NSDP | | Concentration ratio | |
|---|---|---|---|---|
| | At current Prices (Rs.) | At constant prices (Rs.) | At current prices (Rs.) | At constant prices (Rs.) |
| 1955-56 | 260 | 236 | 0.968 | 0.016 |
| 1959-60 | 320 | 248 | 0.896 | 0.016 |
| 1964-65 | 391 | 297 | 0.729 | 0.017 |
| 1969-70 | 497 | 271 | 0.639 | 0.015 |
| 1974-75 | 819 | 491 | 0.660 | 0.027 |
| 1979-80 | 1036 | 522 | 0.607 | 0.027 |
| 1984-85 | 1849 | 1379 | 0.597 | 0.062 |
| 1989-90 | 3241 | 1716 | 0.605 | 0.065 |
| 1994-95 | 6951 | 2101 | 0.692 | 0.070 |
| 1999-2000 | 13619 | 13619 | 0.766 | 0.359 |
| 2004-05 | 16874 | 14908 | 0.649 | 0.327 |
| 2009-10 | 28885 | 19806 | 0.599 | 0.339 |
| 2014-15 | 76429 | 64496 | 0.882 | 0.886 |
| 2019-20 | 118159 | 81355 | 0.881 | 0.860 |

*Source: https://statistics.rajasthan.gov.in*

There are different constraints to economic growth in any country. These constraints differ from one country to another according to different economic situations in these countries. The following are the main constraints that usually affect developing countries as well as developed ones. The level of infrastructural facilities in the state, despite their rapid expansion in recent years, still remains low compared to that of the country as a whole. The overall index of infrastructural facilities stood at 50.31 in 1965-66 and increased to 74.58 in 2010-11, with all India base taken as 100 in both the year. The indices for individual items of infrastructural showed more or less an identical trend and stood lower compared to both the years as shown in Table 3.

From the above indices it is evident that the level of infrastructural facilities has not so far reached the critical minimum required to give a push to the process of economic growth. It may look paradoxical that despite higher growth rates in case of almost all the variables, compared to the growth rates observed for the country as a whole, the growth of the economy in the state was found to be poorer. The explanation for this lies, as stated above, in the relative poverty of infrastructural facilities. One of the major discussions under the growth literature is whether better infrastructure achievements of a region leads to its economic growth or, higher incomes lead to greater demand for, and hence consequent realization of, better infrastructure. The idea behind the former discussion is that insufficient infrastructure endowments may inhibit the investment of productive capital in a state or restrict/reduce its economic activities, thereby lowering output. A considerable section of the literature has noted a relationship between infrastructure and growth (OECD 2006; O'Fallon 2003). Dutta et al. (2007) have noted that public infrastructure investment leads to greater output, employment and improved quality of life. On the other hand, if the growth level is not matched by the required infrastructure stock, then growth prospects in the long run gets affected by the resultant bottleneck and a demand for infrastructure augmentation emerges.

Apart from the low level of infrastructural facilities, another important constraint on growth would appear to be the lack of harmonious growth rates of various sectors of the state's economy (table 4). The share of primary sectors which includes agriculture, mining, forestry and fishing has gone down from 40.81 percent in 1959-60 to 26.73 percent in 2019-20. Similarly the share of the tertiary sector which includes trade, transport, storage, communications, banking, insurance, real estate and community and personal services improved from 32.29 percent in 1969-70 to 44.70 percent in 2019-20.From this it would be clear that during the period 1959-60 to 2019-20 the contribution of primary sector to the NDP declined by about 34.50 per cent whereas, the contribution of secondary and tertiary sector increased by about 78.23 per cent and 3.57 per cent respectively. Such a change in the composition of Net Domestic product should be interpreted as favorable for growth of the economy. Yet contrary to this general belief, the state economy registers any significant improvement for the period under review. On the contrary, it showed signs of deceleration. This perhaps,

**Table 3. Overall index of infrastructural facilities**

| (All India base =100) | 1965-66 | 2010-11 |
|---|---|---|
| Per capita consumption of electricity | 23.28 | 63.33 |
| Percapita industrial consumption of electricity | 17.49 | 67.11 |
| Percentage of Net area irrigated to net cropped area. | 43.59 | 70.03 |
| Road length per 100sq.km | 51.85 | 36.07 |
| No of motor vehicles per lakh of population. | 74.95 | 98.06 |
| Railway route length per 1000sq.km | 68.88 | 99.10 |
| No. of post offices per lakh population | 66.92 | 93.95 |
| Literacy percentage(a) | 63.33 | 66.94 |
| No. of bank branches/per lakh population | 80.95 | 92.45 |
| Per capita bank credit | 23.55 | 57.40 |
| Per capita bank deposits | 38.70 | 76.00 |

*Source: https://statistics.rajasthan.gov.in*
*https://eands.dacnet.nic.in/*
*CMIE (2006)*

**Table 4. Changes in the Composition of the NSDP of Rajasthan ( at constant prices)**

| Sectors | 1959-60 | 1969-70 | 1979-80 | 1989-90 | 1999-00 | 2009-10 | 2019-20 | 1959- 2019 |
|---|---|---|---|---|---|---|---|---|
| Primary | 40.81 | 51.81 | 56.38 | 54.33 | 32.95 | 21.02 | 26.73 | -34.50 |
| Secondary | 16.03 | 15.90 | 16.32 | 16.60 | 23.72 | 29.45 | 28.57 | 78.23 |
| Tertiary | 43.16 | 32.29 | 27.30 | 29.07 | 43.33 | 49.53 | 44.7 | 3.57 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | |

*Source: https://statistics.rajasthan.gov.in*

was due to the fact that the growth of the tertiary sector outstripped the growth of the other sectors, of the economy.

As in the case of country, the different parts of Rajasthan state also reflect vide variations in their levels of income and standard of living. Some districts have greater infrastructural facilities, compared to others and, as a consequence shoed higher income levels. Detailed data on development at the district level are not available. There are, however, reasons to believe that disparities in between different districts do exist. To illustrate, Ganganagar is well irrigated and as a result has shown substantial increase in yields and output levels of agricultural products. By contrast, Jaisalmer, Jodhpur and Bikaner districts still suffer from acute shortage of irrigation water. Their economy is based on the vagaries of the monsoon and shows vide fluctuations from year to year. Similarly, kota districts is known for its industrial complex which provides ample opportunities for employment and other associated tertiary activities, leading to much higher levels of income. By contrast the adjoining district Jhalawar is not so industrially developed. Such disparities lead political pressure for diverting resources to the relatively back ward regions of the state. Obviously, these resources take time to fructify and tend to retard the growth rates, at least in the short period. This is not peculiar to the state of Rajasthan. But the impact of diverting resources from the relatively developed to backward regions is not so serious in the relatively developed status, as in Rajasthan.

The reason for this lies in the absence of requisite real resources like managerial capabilities, environmental opportunities and other infrastructural facilities that are conspicuous by their absence in the backward states to much greater extent than in the states which are fairly developed. It would appear that the requisite political will to resist the pressures that often arise from regional disparities, has been lacking even at the highest levels.

## Conclusion and Policy Implications

The economy of Rajasthan has developed gradually since 1960-61. Growth of per capita real income has, however, been very slow. The long term rate of growth of income came to about positive more than 3 per cent percent during 2012-13 to 2019-20. The Semi-log equation was fitted to the data of NDP for the period 1955-56 to 2019-20 and it's showed that the income of the state had increased, on an average, at the rate of 13.47 percent per annum at current prices and 3.75 per cent at constant prices. The results highlight the need of rapid growth for providing a rising standard of living to ever increasing population as well as to keep pace with the rest of the country. The income concentration ratio of per capita income varied from 0.597 to 0.968 at current prices and from 0.015 to 0.886 at constant prices. The concentration ratio showed wide fluctuations over the period but they were always lower than one. The overall index of infrastructural facilities stood at 50.31 in 1965-66 and increased to 74.58 in 2010-11, with all India bases taken as 100 in both the year. The share of primary sectors has gone down from 40.81 percent in 1959-60 to 26.73 percent in 2019-20. Similarly the share of the tertiary sector improved from 32.29 percent in 1969-70 to 44.70 percent in 2019-20. The contribution of the secondary and tertiary sector has been increased by about 78.23 per cent and 3.57 per cent respectively. The broad conclusion that emerges is that structural change analysis of Rajasthan is indicative of the fact that the last six decade has been characterized by a shift in sector-wise shares in GDP as well as in workforce from primary and secondary sectors to tertiary sector. It shows that that there is an ample scope to improve the economic growth via tertiary sector growth, provided the proper planning of other sector and integration of tertiary sector with commodity sector is done.

## References


CMIE 2006. Estimates of Index of Infrastructural Facilities Reports, Mumbai.

Dutta, Jayasri, Nicholas Horsewood and Nicholas Vasilakos 2007. Industrial Activity in Indian States: The Role of Infrastructure, MPRA Paper No. 7184, https://mpra.ub.uni-muenchen.de/7184/1/MPRA_paper_7184.pdf

Government of Rajasthan (GoR) 2016. Compendium of Some Development Statistics About Rajasthan (1951-52 to 2015-16) Directorate of Economics & Statistics, Department of planning, Rajasthan, Jaipur https://statistics.rajasthan.gov.in/content/dam/planning-portal/Directorate%20of%20Economics%20and%20Statistics/Publication/Other%20publication/Compendium%20of%20some%20development%20statistics%20about%20rajasthan%201951-52%20to%202015-16.pdf.

Government of Rajasthan (GoR) 2021. State Domestic Product of Rajasthan, Directorate of Economics & Statistics, Department of Planning, Rajasthan, Jaipur https://plan.rajasthan.gov.in/content/dam/planning-portal/Directorate%20of%20Economics%20and%20Statistics/Publication/Regular%20Publications/state%20domestic%20product%20rajasthan/State_domestic_product_2020_21.pdf.

https://www.cmie.com/kommon/bin/sr.php?kall=wproducts&tabno=7010&prd=eo&portal

O'Fallon, Carolyn 2003. Linkages between Infrastructure and Economic Growth, Wellington: Pinnacle Research, available online at http://www.med.govt.nz/upload/18053/pinnacle.pdf.

OECD 2006. Promoting Pro-poor Growth: Infrastructure. Paris: Organization for Economic Development and Cooperation. the New Economy: Beyond the Hype. Paris. https://www.oecd.org/greengrowth/green-development/43514554.pdf

PHD Chamber 2011. Economic Analysis of states: A study of Northern & Central states of India. PHD Chamber of Commerce and Industry. https://www.phdcci.in/wp-content/uploads/2018/11/Economic-Analysis-report-Final-tk.pdf.

Singariya M R 2014. Trends of Economic Growth and Structural Changes in Rajasthan. *International Journal of Econometrics and Financial Management*. 2(1): 22-27 DOI: 10.12691/ijefm-2-1-3.

Singh Surjit 2010. Economic Performance of Rajasthan Status and Constraints, IDSJ Working Paper 150 Institute of Development Studies, Jaipur (INDIA) https://www.idsj.org/wp-content/uploads/2017/05/WP-150.pdf.

Vyas V S 2007. Introduction: The Journey, Milestones and Destinations in Vijay S. Vyas, Sarthi Acharya, Srrrjit Singh and V. Sagar (eds.) Rajasthan: The Quest for Sustainable Development, New Delhi: Academic Foundation Chapter 1 https://www.thefreelibrary.com/Rajasthan%3A+The+Quest+for+Sustainable+Development.-a0205747238.

https://data.worldbank.org/indicator/NY.GDP.PCAP.CN?locations=IN

https://censusindia.gov.in/2011census/population_enumeration.html

https://www.macrotrends.net/countries/IND/india/gdp-per-capita


Received: February 3, 2022 Accepted: May 27, 2022

*Journal of Agricultural Development and Policy, 2022*
*Volume 32, No. 1, 7-15*

# Trends in Energy Use in Punjab Agriculture

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**Abstract**

*The composition of energy use in Punjab agriculture has changed substantially, with a significant shift from the animal and human power towards machines, electricity and diesel. Energy use efficiency is in a continuously declining phase as the energy ratio has declined from 11.8 in 1980-81 to 8.9 in 2018-19. For paddy and wheat occupying about 80 per cent of gross cropped area in Punjab, though the energy use efficiency is approximately the same i.e. 5.12 and 5.32, respectively and the respective energy productivity values are 0.15 Kg/MJ and 0.23 Kg/MJ, but the Specific energy of 6.8 MJ/Kg for paddy compared to wheat i.e. 4.4 MJ/Kg stresses the need for the adoption of energy saving technologies especially in paddy cultivation. The share of commercial energy sources in the input energy has been on the rise and forms about 97 per cent of it. Use of direct energy is higher (i.e. 53 per cent) than the indirect energy use. Amongst the direct energy sources, electricity, while fertilizers amongst the indirect energy sources form the major share of the input energy. The overwhelming significance of irrigation water, chemical fertilizers and electricity consumption in the energy input indicates that there exists an opportunity for improving energy productivity of crop cultivation in the state and this can be achieved primarily through the use of proven energy conservation/ management practices and technologies. There is need for proper management of inputs at farm level and this can be achieved by educating the farmers regarding proper utilization of the scarce farm inputs along with creating awareness about the harmful effect of excessive use of energy inputs. In addition to these, Government policies aimed at improved energy efficiency must also be coherent and regard the synergies and trade-offs with the policies addressing issues of productivity, water use and food safety.*

**Keywords:** Commercial, Direct, Energy, Efficiency, Inputs

**JEL Classification:** A10, Q10, Q20, Q30, Q40, Q47

## Introduction

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 by the agriculture sector seems as one of the conditions for sustainable agriculture because it allows financial savings, fossil resources preservation and air pollution reduction (Pervanchon *et al,* 2002). Improvement in the energy efficiency of the agricultural sector has attracted global attention as the key driver for sustainable development and has become one of the best strategies to reduce commercial energy demand and combat climate change (Cardozo *et al,*2018). Energy efficiency improvement and energy saving are conducive to achieve environmentally friendly economic development (Bayar *et al,* 2019).

Energy Analysis provides a relevant view of the specificity of agriculture as a user and a producer of energy simultaneously. Energy Analysis also results into significant approach to explore the causes of variations in energy results. It helps to view efficiency of farming process through the production of various criteria. Energy analysis can therefore play a significant role in the evaluation of sustainability of agricultural process. In this backdrop the present study was carried out to study energy input use pattern and its efficiency in Punjab agriculture.

## Data Sources and Methodology

The present study is based on secondary data collected from different sources like published research papers, reports, manuals and thesis were used. Also, data were extracted from the website of Directorate of Economics and Statistics for the year 2018-19 regarding the input use i.e. human labour, fertilizers, Farm yard manure (FYM), machine use, chemicals, main product and by product for paddy and wheat cultivation in Punjab. The data on inputs and output were converted to energy units using embodied energy equivalents

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for each input and output energy type, and expressed in Mega Jules (MJ) using specific energy coefficients (Table 1). Data on crop grain yield was used for the estimation of straw yield using grain to residue ratio method (Chauhan, 2012).

**Table 1. Energy coefficients used in energy calculation for crop cultivation**

| Energy source | Energy coefficient (MJ/unit) |
|---|---|
| Human labour (h) | 1.96 |
| 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 (litre) | 102 |
| Machinery (h) | 62.7 |
| Diesel (litre) | 56.31 |
| **Main product or Seed/Grain (Kg)** | |
| Paddy and wheat | 14.7 |
| **By product (Kg)** | |
| Paddy and wheat straw (kg) | 12.5 |
| Electricity (kWh) | 11.93 |

*Source: Singh and Singh, 2002*

### Classification of Farm energy Resources

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 labor, electricity and irrigation, while the indirect energy sources (IDE) comprise energy sources i.e. seed, agri-machinery, fertilizers and chemicals used in crop cultivation. The energy sources were also classified into renewable energy (RE) and non-renewable sources (NRE). RE includes seed, human labor and irrigation, while NRE comprises diesel fuel, agri-machinery, electricity, chemical fertilizers and biocides (Ozkan *et al*., 2007 and Hatirli *et al*., 2006).

## Results and Discussion

### Scenario of energy use

In a world level study for trends of input energy, crop production and energy use efficiency for the period 1961–2014, it was observed that the spread of intensification was noticeable across Latin America, MICs, and Asia, while it had already happened in North America and Europe (reaching a maximum there around 1990) and had not reached Africa. It was observed that for Asia in comparison to other regions, the energy input level and crop production level showed a continuously rising trend during 1961 to 2011(Figure 1) while the Energy Use Efficiency (EUE) indicated a constant downward trend.

In case of Indian agriculture, the structure of energy use has changed substantially, with a significant shift from the animal and human power towards machines, electricity and diesel (Jha *et al.,* 2012). The total energy use in the agricultural operations has increased from 425.49 × $10^9$ MJ in 1980–81 to 3219.56 × $10^9$ MJ in 2016–17. The share of direct energy in Indian agriculture is also increasing in a time period of 1980-81 to 2016-17 from the 42.2% to 65.5% while share of indirect energy is decreased from 57.8% to 34.5% in this time period (Figure 2). The energy input per hectare of gross cropped area between 1980–81 and 2000–01 increased drastically from 2.46 × $10^3$ to 12.04 × $10^3$ MJ/ha due to a rapid expansion of tube-well irrigation in the Indo-Gangetic Plains (Jha *et al.,* 2012). During 2016–17, the per hectare energy consumption was 16.23 × $10^3$ MJ/ha. Among the direct sources, the share of electricity in total energy use increased from 40 to 64 per cent while among the indirect sources, nitrogen fertilizers contributed the most, with a share of 31 per cent in 2016–17. The energy values of fertilizers applied to crops have increased from about 245 × $10^9$ to 1100 × $10^9$MJ while the share of indirect energy from pesticides reduced to 0.20 per cent in 2016–17 from 1.27 per cent in 1980–81.

It has also been observed that the level of diffusion of technologies and the use of energy-intensive inputs across crops determines the share of energy in the cost of. In a national level study, the energy share of major crops in India ranged from 55 per cent for rapeseed & mustard to 74 per cent for soybean in triennium ending 2015–16 (Figure 3). Though wheat cultivation in India is highly mechanized, still the share of energy in the total cost for wheat cultivation (56%) is less than that for rice (63%). This is because, traditional energy sources like human labour are used more in rice in comparison to wheat.

Groundnut, potato, maize and cotton crops have higher energy share in the cost of cultivation in contrast to those by pulses, oilseeds and sugarcane. The share of direct energy in form of human & machine labour and machine use varied from 30 per cent in potato to 56 per cent in bajra. In case of rice, it was 48 and was 40 per cent for wheat.

Further, analysis of energy consumption pattern in major states of India during 2015–16 indicated that Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra lead in energy consumption with energy use being more than 3 lakh MJ per hectare (Figure 4). Very high level of electricity consumption for irrigation contributed the

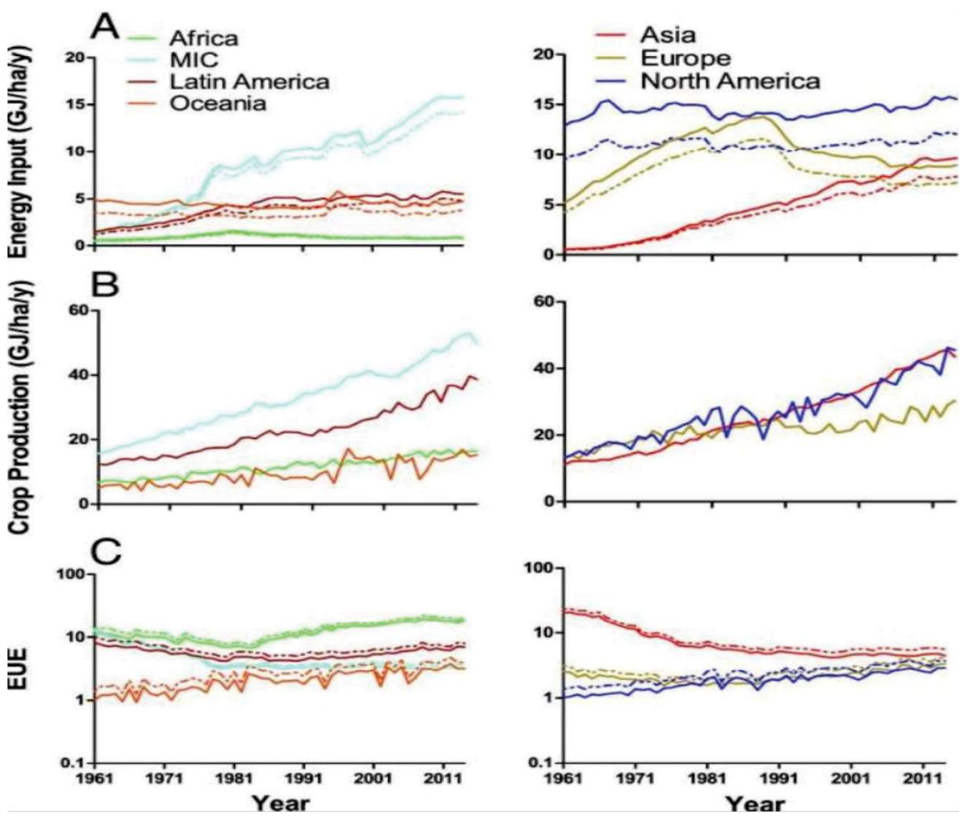


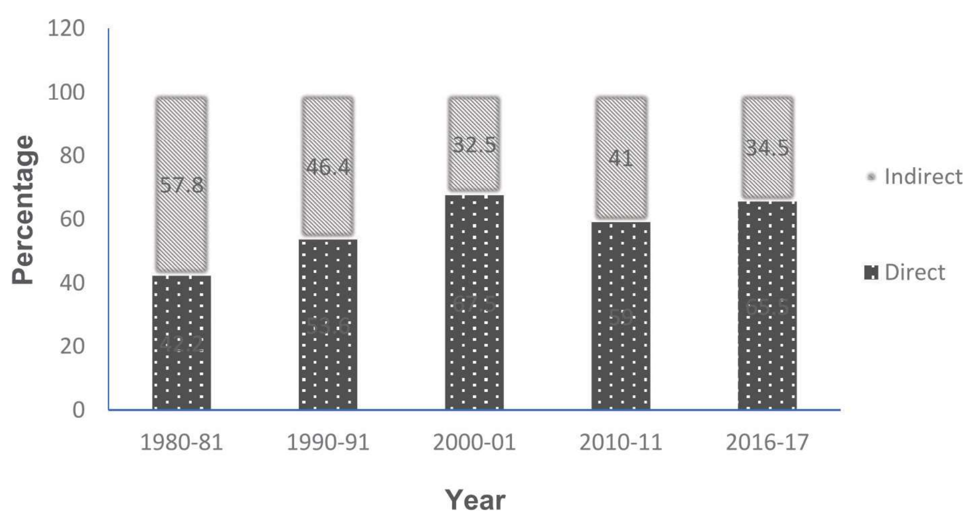

**Figure 1. World Level Energy Scenario**

(A) Annual energy input (GJ·ha−1 ·y−1 ) as the sum of fertilizers (N, P, and K), machinery (construction and maintenance), and fuel.

(B) Total annual energy production from all crops (output; GJ·ha−1 ·y−1 ).

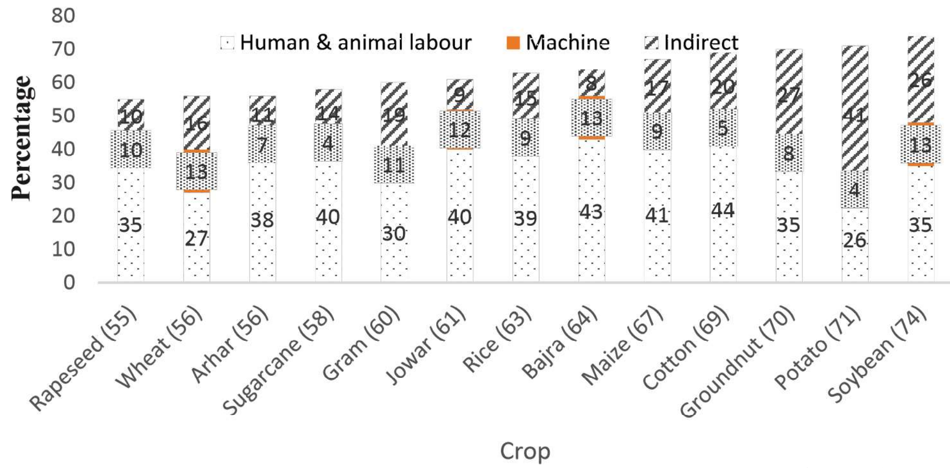
(C) Annual EUE for each continent estimated as the ratio of crop production (GJ) to energy input (GJ). Solid and dashed lines in A and C are for 10- and 30-y machinery lifespans, respectively.

Source: Pellegrini et al., 2018 in which data for input, production, and land are from FAOSTAT, 2017




Source: Jha *et al,* 2021

**Fig. 2. Energy use in Indian agriculture (% share in total energy)**




Source: Jha *et al.,* 2021

**Fig 3. Crop wise shares of direct and indirect energy inputs in total energy cost in India**

*Note:(i) Figures in parentheses indicate per cent share of energy cost in total cost of cultivation of respective crop*

*(ii) Human& animal labour and machine are part of direct energy*

maximum per hectare energy consumption in these states since the groundwater tables in these regions are deep. Energy consumption in Punjab (2.25 lakh MJ/Ha) and Haryana (96 thousand MJ/Ha) is also high as agriculture has become energy-input intensive in these two states since the green revolution. Assam, Jharkhand, Bihar and Odisha consume very less energy in crop cultivation, hence these eastern states are now identified for the second green revolution in the country through improvement in input use.

Energy consumption in relation to food grain yields indicated that Gujarat, Andhra Pradesh, Tamil Nadu and Punjab use more energy and also produce higher yields, while on the other extreme, Assam, Odisha, Uttarakhand and Jharkhand consume less energy in farming and also have lower yield levels. Haryana, Bihar and Uttar Pradesh have achieved higher yield levels despite lower energy consumption per hectare gross cropped area.

## Energy input output balance in agriculture

Analysis of energy balance in Punjab agriculture sector revealed that energy use efficiency is in a continuously declining phase. The energy ratio has declined from 11.8 in 1980-81 to 8.9 in 2018-19(Figure 5). The steady decline in the energy-use efficiency in the state agriculture is a matter of great concern and calls for optimal and proper utilization of energy inputs involved in various farm operations. Therefore, energy analysis becomes the basis for sound management and policy decisions for conservation and efficient management of scarce resources for improved agricultural production.

Punjab agriculture is dominated by paddy-wheat monoculture with these crops together occupying more than 80 per cent of the gross cropped area in the state. Energy analysis for paddy and wheat in Punjab depicts that energy use efficiency is approximately the same for both the crops i.e. 5.12 and 5.32 respectively during 2018-19 (Table 2).

**Table 2. Energy input-output analysis for major crops in Punjab, 2018-19**

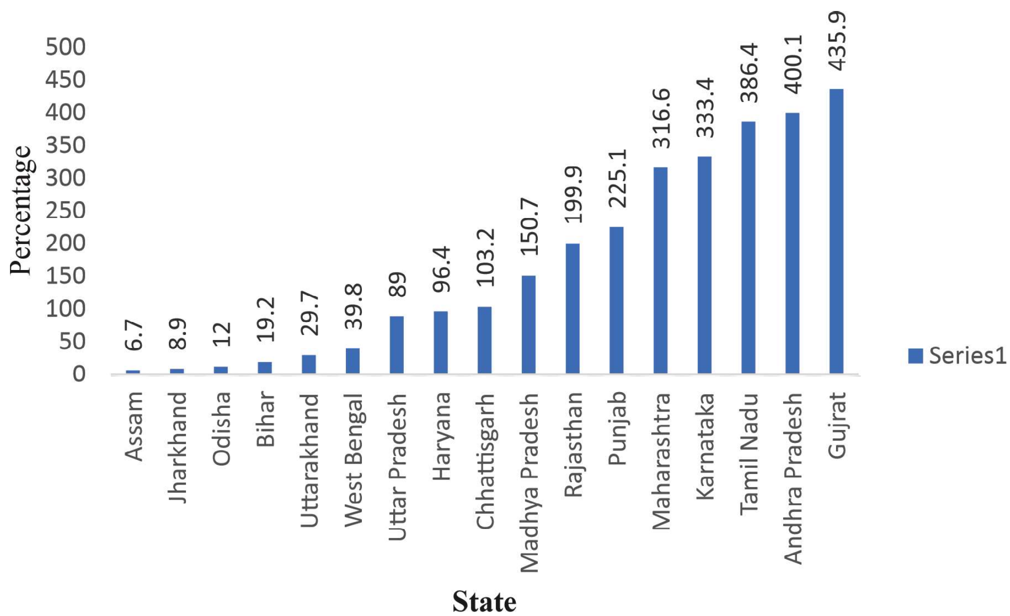
| Particulars | Paddy | Wheat |
|---|---|---|
| EUE | 5.12 | 5.32 |
| Net energy gain (lakh MJ/Ha) | 1.94 | 0.95 |
| Specific energy (MJ/Kg) | 6.8 | 4.4 |
| Energy productivity (Kg/MJ) | 0.15 | 0.23 |

*Source: Author's calculations*

The energy productivity values were 0.15 Kg/MJ and 0.23 Kg/MJ for paddy and wheat respectively. However, in terms of Specific energy i.e total energy used to produce one kg of grains, paddy has a higher requirement i.e. 6.8 MJ/Kg compared to wheat i.e. 4.4 MJ/Kg which again stresses the need for adoption of energy saving technologies in paddy cultivation in the state.

Component wise analysis of energy use for paddy cultivation in South Western Punjab revealed that among different inputs due to high water requirements of paddy crop major share of energy (40.01%) comes from irrigation water followed by fertilizers (24.7%), electricity for pumping water (17 %), diesel fuel (8.8%), chemicals (7.7%), machinery use (0.8%) and seeds (0.3%) as shown in Figure 6.

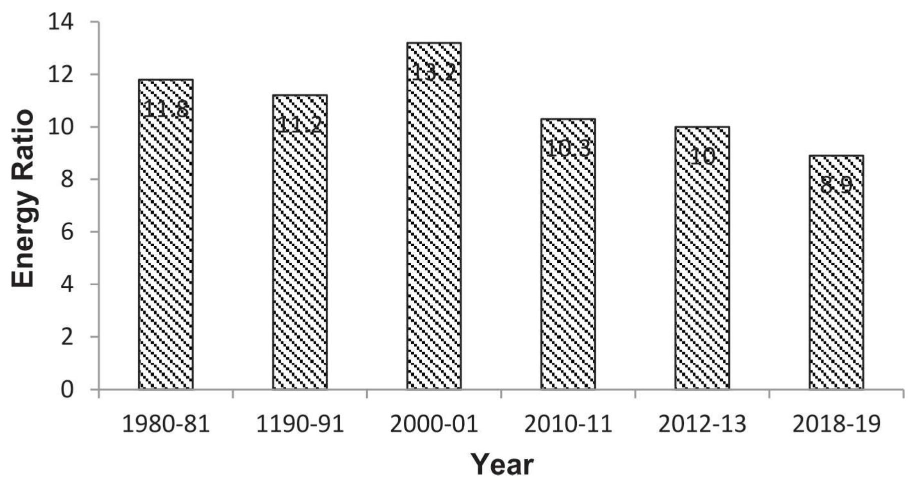
Besides depleting the ground water, the consumption of energy in pumping underground water for paddy cultivation is increasing overtime. Electricity being free for agriculture sector, is again putting a great burden on the state exchequer. The farmers were found to be using more than recommended doses of the fertilizers especially urea in excess because of lack of awareness, low price and easy availability. The study




Source: Jha *et al.,* 2021

**Fig. 4. State wise energy consumption in India (000MJ/ha GCA, 2015-16)**

*Note: Energy consumption per GCA at national level was 178.5 000MJ/ha*




*Source: Kumar H, 2017 and Author's calculations from data extracted from DES for the year 2018-19*

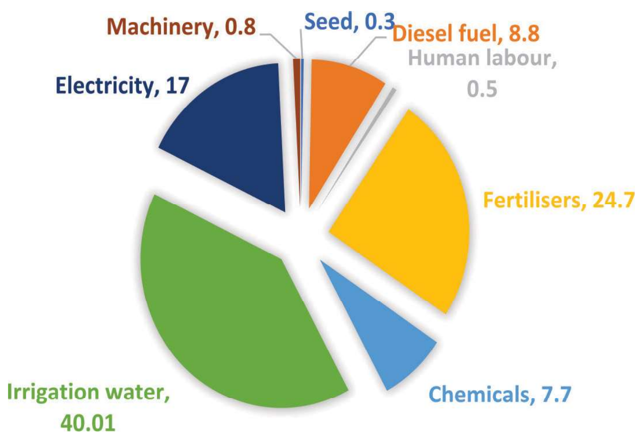
**Fig. 5. Energy Balance in Punjab Agriculture**

pointed towards rational use of irrigation water, electricity and fertilizers with efficient strategies to increase EUE of paddy cultivation in the state. Similarly, a study for Karnataka highlighted the indiscriminate use of nitrogen fertilizers and irrigation water accounting for 36 per cent and 39 per cent of total energy input in the transplanted paddy (Basavalingaiah *et al*., 2020).Another study on the rice production in India revealed that irrigation and fertilizers accounts for the largest share of total energy input (Chaudhary *et al.,* 2017). Thus, there is need to take suitable steps to increase the EUE in paddy cultivation either by minimizing input use or by using them judiciously.

Similarly, in a study for wheat crop cultivation in Punjab, fertilizers took away the major share i.e. (44.5%) and irrigation (15%), electricity for pumping irrigation water and diesel fuel (14.7%) together constituted the major key input energy use sources (Figure 7).

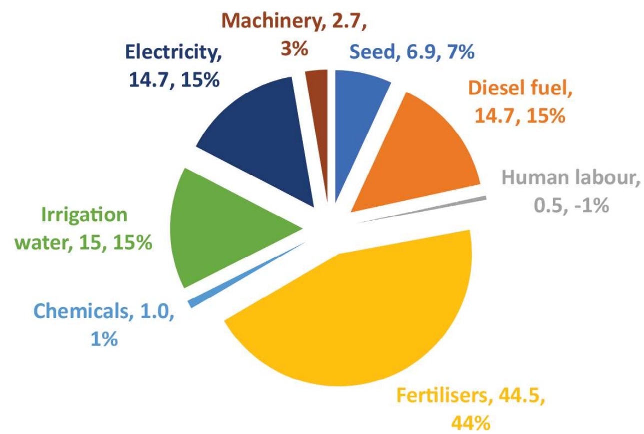
Again, this points towards an urgent need to manage the use of fertilizers in wheat crop to improve the EUE in wheat cultivation of Punjab.

It was also observed that the use of direct energy in




*Source: Singh et al., 2019b*

**Fig. 6. Input energy in paddy cultivation in Punjab (% share)**




*Source: Singh et al., 2019a*

**Fig. 7. Input energy in wheat cultivation in Punjab (% share)**

agriculture is higher i.e.,53 per cent than indirect energy use (47%) in Punjab agriculture (Figure 8). Amongst the direct energy sources, electricity and fertilizers amongst the indirect energy sources form the major share of input energy.

Categorization of energy as commercial and non commercial energy sources indicated that the use of non-commercial energy in Punjab agriculture had a share of about 35.5 per cent in the total input energy use during 1980-71 but with time it has declined to merely 2.3 per cent during 2018-19 (Figure 9).

The use of commercial energy in the state agriculture forms about 97.7 per cent share in the total input energy during 2018-19 though it was about 87.1 per cent during 1980-81of the total input energy needs. All this point out towards judicious use of commercial energy sources along with exploration of the possibilities which can help to raise the share non-commercial energy in the state agriculture.

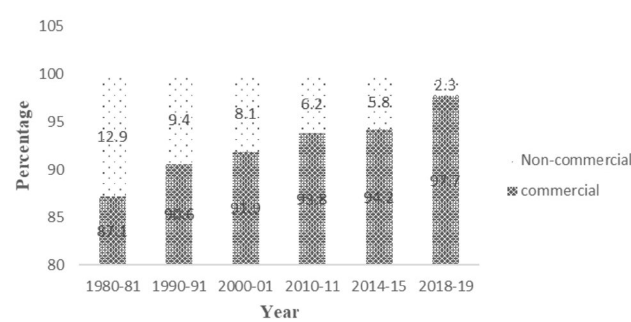
## Energy saving technologies/methods

Different studies indicate that by using the scarce farm inputs in a rational manner, the energy can be saved on farm. In a study for Punjab, it was observed that about 47 per cent of input energy can be saved by using electricity judiciously (Table 3) in paddy cultivation. This can be achieved by adjusting the schedule of irrigation and sowing time of rice. Also, about 26 per cent energy savings is possible in terms of irrigation water, diesel fuel (9.7%), chemical fertilizers (9.4%), biocides (5.4%). The results revealed that the overwhelming significance of irrigation water, chemical fertilizers and electricity consumption in the energy input in rice cultivation underpin the opportunities for energy saving.

The real crop water productivity (marketable yield/ Evapotranspiration) was more by 17 per cent in 25th June transplanted rice than 25th May, 23 per cent in short duration than long duration varieties (Jalota *et al.,* 2009). It may be mentioned here that during 2020-21, paddy area under short duration varieties was only 64.1 per cent in the state. In another study on discerning sustainable interaction between agriculture and energy in India, indicated that irrigation, use of machinery and energy–intensive inputs like fertilizers


*Source: Singh et al 2019b*

**Fig. 8. Input energy in Punjab Agriculture Direct and Indirect (% share in total energy)**




*Source: Kumar H et al., 2017 and Author's calculations from data extracted from DES for the year 2018-19*

**Fig. 9. Input energy use in Punjab Agriculture Commercial and Non-commercial (% share in total energy)**

**Table 3. Energy saving from different inputs on following the recommended amounts in rice cultivation in south-western Punjab, India**

| Input item | Percent share of total input energy saved |
|---|---|
| Seed | 0.2 |
| Diesel Fuel | 9.7 |
| Human Labour | 0.2 |
| Chemical Fertilizers | 9.4 |
| Biocides | 5.4 |
| Irrigation Water | 27.5 |
| Electricity | 46.9 |
| Machinery | 0.7 |

*Source: Singh et al 2019b*

account for the bulk of energy use in agriculture. Since the fast depletion of non-renewable energy sources is widely acknowledged, and Sustainable Development Goal 7 also indicates the need for transition to clean, green and sustainable energy sources, there is need to increase the use of renewable and bioenergy sources. Agriculture plays an important role as a producer of feedstock in the production of biofuels. Given the untapped potential and nascent market for biofuels in the country, promotional policies that can foster the production of this sector without compromising on food security need to be crafted and implemented (Jha *et al.,* 2021).

Adoption of energy saving technologies like direct seeding of rice (DSR) can also be one of the steps to increase farm EUE in agriculture. In a study for Kerala, energy use efficiency for paddy cultivation under transplanting and Direct Seeded (DSR) methods was estimated at 4.4 and 7.3 respectively (Table 4). The reason for higher EUE under DSR was mainly attributed to the large decrease in energy inputs and study also highlighted the scope for saving energy in transplanting method by 6 per cent.

Total energy input is higher in transplanted paddy production while energy efficiency level is higher in DSR indicating the need to decrease dependency on energy which can be achieved either through efficient use of energy or utilizing organic input (Baharudin and Arshad, 2014). Yuan and Peng (2017) reported that in China, in comparison to commonly followed paddy cultivation practices, the adoption of simplified and reduced input practices resulted in increased EUE and energy productivity by about 19 and 25 per cent, respectively.

Similarly in state level study for wheat crop cultivation, use of energy saving treatments by using conservation method of plantings like Happy Seeder, Zero Tillage and Rotavator were observed to be having higher EUE and less specific energy as compared to conventional tillage (Table 5). Higher

**Table 4. Energy Comparison of Transplanted Rice and Direct Seeded Rice in Kerala**

| Parameter | Puddled Transplanted rice | Direct Seeded Rice |
|---|---|---|
| EUE | 4.4 | 7.3 |
| Net energy gain (MJ/Ha) | 120171 | 45403 |
| Specific energy (MJ/Kg) | 6.4 | 4.1 |
| Energy productivity (Kg/MJ) | 0.2 | 0.3 |

*Source: Basavalingaiah et al., 2020*

**Table 5. Energy use efficiency, Energy production, Energy specific under different treatments for wheat in Punjab**

| Treatment | Energy use efficiency | Energy specific ($MJkg^{-1}$) |
|---|---|---|
| Happy seeder | 9.44 | 3.31 |
| Zero tillage | 10.48 | 2.88 |
| Rotavator | 9.11 | 3.65 |
| Conventional tillage | 8.90 | 3.96 |

*Source: Singh and Kaur , 2017*

output input ratio and lower specific energy were recorded under direct drilling methods compared to traditional method for wheat.

Another study for rice-based production systems in Indo-Gangetic Plain region indicated that conservation tillage treatments reduced the energy requirements over conventional tillage treatments and the savings of energy were attributed to reduced energy use in land preparation (69–100%) and irrigation (23–27%), which consumed a large amount of fuel energy (Nandan *et al.,* 2021). Conservation-tillage treatments increased grain and straw yields of crops, eventually increased the output energy (6–16%), net energy (14–26%), energy ratio (25–33%), eventually increased the output energy (6–16%), net energy (14–26%), energy ratio (25–33%), and energy productivity (23–34%) indicating that the zero tillage-based crop establishments in rice-based production systems could be the sustainable alternative to conventional tillage-based agriculture as they conserved non-renewable energy sources, reduced water requirement, and increased crop productivity.

## Conclusion and Policy Implications

There exists an opportunity for improving energy productivity of crop cultivation in the state. Improved energy efficiency can be achieved primarily through the use of proven energy conservation management practices and technologies. These measures include resorting to decreased plough, replacing natural fertilizers (manure and organic fertilizers) with chemicals, returning remains and resorting to precise agriculture based on the judicious use of inputs, utilizing alternate sources of energy like inclusion of legume crops into the crop rotation. There is need for proper management of inputs at farm level and this can be achieved by educating the farmers regarding proper utilization of the scarce farm inputs along with creating awareness about the harmful effect of excessive use of energy inputs.

Though, feeding the increasing population is difficult and perhaps not possible without NRE, but due consideration must be given to the environmental impacts of the use of chemicals and fossil fuels. There is a strong need to achieve a sustainable food production system by increasing the share of RE. In addition to these, Government policies aimed at improved energy efficiency must also be coherent and regard the synergies and trade-offs with the policies addressing issues of productivity, water use and food safety. Improving the energy use efficiency by using less energy to provide the same level of output and service is an important instrument that policy makers can use to ensure a number of positive outcomes that can deliver several government priorities, from economic growth to reduced GHG emissions to energy and food security. In agricultural production the input energy determines the farm profitability which heavily depends upon the farmers' investment in improved farming systems. Thus, there is need for cost-effective energy measures from an economic as well as ecological point of view.

## References


Basavalingaiah K, Ramesha Y M, Venkatesh P, Rajanna G A,Shankar LJ , Shiva D M, Kumar A, Girisha H C, Yogesh G S, Raveesha S, Roopa T K, Shashidhar K S, Kumar B, Ansary DOE and Elansary H O 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**:6439-58. https://doi.org/10.3390/su12166439

Bayar Y and Gavriletea M D 2019. Energy efficiency, renewable energy, economic growth: evidence from emerging market economies. *Quality and Quantity* **53:**2221-34. https://doi.org/10.1007/s11135-019-00867-9

Baharuddin SA and FM Arshad 2014. Energy use in Paddy Production: NKEA'S estate in MADA Area. *Economic and Technology Management Review* **9**:51-59. http://etmr.mardi.gov.my/Content/ETMR%20Vol.9a%20(2014)/Vol9a_6_.pdf

Cardozo NP, De Oliveira Bordonal R and La Scala N 2018. Sustainable intensification of sugarcane production under irrigation systems, considering climate interactions and agricultural efficiency. *Journal of Cleaner Production* **204**:861–71. https://doi.org/10.1016/j.jclepro.2018.09.004

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**:307–17. https://doi.org/10.1016/j.energy.2017.04.131

Chauhan S 2012. District wise agriculture biomass resource assessment for power generation: A case Study from an Indian state, Punjab. *Biomass and Bioenergy* **37**:205-12. https://doi.org/10.1016/j.biombioe.2011.12.011

Government of India. Directorate of Economics and Statistics (DES) , 2018-19. https://eands.dacnet.nic.in/

Food and Agriculture Organization 2017. FAOSTAT online statistical service. Available at faostat.fao.org. Accessed May 15, 2017. https://www.fao.org/faostat/en/#home

FAO 2000. The energy and agricultural nexus. *Environment and Natural Resources Working Paper No.* **4**. FAO, Rome. https://www.fao.org/3/x8054e/x8054e00.htm#P-1_0

Hatirli S A, Burhan Ozkan and Cemal Fer 2006. Energy inputs and crop yield relationship in greenhouse tomato production. *Renewable Energy* **31**:427-38. https://doi.org/10.1016/j.renene.2005.04.007

Jha k Girish, Parveen K V and Aditya K S 2021. Discerning sustainable interaction between agriculture and energy in India. *Current Science* **120**:12. https://www.currentscience.ac.in/Volumes/120/12/1833.pdf

Jha K G, Pal S and Singh A 2012. Changing Energy-use Pattern and the Demand Projection for Indian Agriculture. *Agricultural Economics Research Review* **25**:61-68. http://krishi.icar.gov.in/jspui/handle/123456789/34289

Jalota S, Singh KB, Chahal G.B.S and Gupta R K 2009. Integrated effect of transplanting date, cultivar and irrigation on yield, water saving and water productivity of rice (Oryza sativa L.) in Indian Punjab: Field and simulation study. *Agricultural Water Management* **96(7):**1096-1104. 10.1016/j.agwat.2009.02.005

Kumar H 2017.Energy Input Usage and its Efficiency in Punjab Agriculture. Ph.D. Thesis, submitted to Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, Punjab.

Nandan R, Poonia S P, Singh S S, Nath C P, Kumar V, Malik R K, McDonald and Hazra K K 2021. Potential of conservation agriculture modules for energy conservation and sustainability of rice-based production systems of Indo-Gangetic Plain region. Environmental Science and Pollution Research **28:**246-61. https://link.springer.com/article/10.1007/s11356-020-10395-x

Ozkan B, Fert C, Karadeniz F 2007. Energy and cost analysis for green house and open-field grape production. *Energy* **32**:1500-4. https://doi.org/10.1016/j.energy.2006.09.010

Pellegrini P and Fernandez 2018.Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. *Proceedings of the National Academy of Sciences* **115**: 2335-40. https://doi.org/10.1073/pnas.1717072115

Pervanchon F, Bockstaller C and Girardinc P 2002. Assessment of energy use in arable farming systems by means of an agro-ecological indicator: the energy indicator. *Agricultural Systems*.**72**: 149–72. https://doi.org/10.1016/S0308-521X(01)00073-7

Singh P, Singh G and Sodhi G P 2019a. Applying DEA optimization approach for energy auditing in wheat cultivation under rice-wheat and cotton-wheat cropping systems in north-western India. *Energy* **181**: 18-28. https://doi.org/10.1016/j.energy.2019.05.147

Singh P, Singh G and Sodhi G P 2019b. Energy Auditing and Optimization Approach for Improving Energy Efficiency of Rice Cultivation in South-western Punjab, India. *Energy* **174** : 269-79. https://doi.org/10.1016/j.energy.2019.02.169

Singh A and Kaur J 2017. Energy Consumption and Production Pattern in Direct Drilling Wheat in Punjab. *Current Agriculture Research Journal* **5**:2. https://pdfs.semanticscholar.org/0fc7/77b12d9477fc3e905afdc356c74e78aa276.pdf

Singh S and Singh J 2002. Research digest on energy requirement in agriculture sector. Technical Bulletin, Department of Farm Power and Machinery, Punjab Agricultural University, Ludhiana, Punjab.pp.2-8.

Yuan S and Peng S 2017. Input-output energy analysis of rice production in different crop management practices in central China. *Energy* **141**: 1124-32. https://doi.org/10.1016/j.energy.2017.10.007

Received: January 3, 2022 Accepted: April 2, 2022