Discerning sustainable interaction between agriculture and energy in India

K. V. Praveen, Girish K. Jha* and K. S. Aditya

In India, traditionally, the relationship between agriculture and energy has been unidirectional, with agriculture using energy as input in crop production. However, of late, the energy sector is also using agricultural by-products as renewable-fuel feedstock. We examine the dual role of agriculture as a producer as well as consumer of energy. The study finds that the total commercial energy input in agriculture has increased. As an energy producer, the role of the agriculture sector is to produce biofuels which are considered as backstop technology to fossil fuel-based energy sources. However, there are sustainability issues as biofuel crops compete with food crops for resources.

**Keywords:** Agriculture, biofuels, energy, renewable fuel, sustainable interaction.

In India, the widening gap between primary energy production and consumption is a matter of concern. Energy consumption which was higher than its production by 1 MTOE (million tonnes of oil equivalent) in 1980 has increased drastically to more than 12 MTOE in 2016 (ref. 1). Though different sectors contribute to this increase, agriculture has a crucial role to play in maintaining the energy balance. While the input-intensive modern-day agriculture consumes higher levels of non-renewable energy, the potential of the agriculture sector to act as a key renewable energy source for the country is also being recognized. Agriculture uses both direct energy in the form of diesel and electricity, and indirect energy in the form of inputs like fertilizers and pesticides2. With energy prices increasing and better awareness about the importance of renewable energy sources, biofuel production has gained considerable research and policy focus. With this backdrop, the present study examines the dual role of Indian agriculture as an energy consumer and producer. Specifically, it examines structural changes in energy use in agriculture and the prospect of bioenergy production. It also offers insights for policymakers to reduce energy consumption from agriculture and promote stable bioenergy market.

**Energy use in Indian agriculture**

**Temporal energy use pattern**

The total energy use in India doubled between 2002 and 2012, with the industrial and transport sectors proffering the bulk share. The growth in energy use in the agricultural sector is not as high as the other energy-intensive sectors3, but there has been a shift in the structure of energy use. This structural shift is powered through mechanization and use of energy-intensive inputs4. Also, there is a regional difference in energy use in Indian agriculture, mainly due to the varying extent of mechanization and input use5. The total energy use in the agricultural operations has increased from $425.49 \times 10^9$ MJ in 1980–81 to $3219.56 \times 10^9$ MJ in 2016–17 (Table 1). Direct energy use has accounted for a major share in energy use in cropping activities (Figure 1). The energy input per hectare gross cropped area between 1980–81 and 2000–01 increased drastically from $2.46 \times 10^3$ to $12.04 \times 10^3$ MJ/ha due to a rapid expansion of tube-well irrigation in the Indo-Gangetic Plains2. As of 2016–17, the per hectare energy consumption is $16.23 \times 10^3$ MJ/ha.

The source-wise energy use presented in Table 1 indicates that during the study period, among the direct sources, the share of electricity in total energy use increased from 40% to 64%, whereas the share of diesel declined. Among the indirect sources, nitrogen fertilizers contribute the most, with a share of 31% in 2016–17. The energy values of fertilizers applied to crop have increased from about $245 \times 10^9$ to $1100 \times 10^9$ MJ. The share of pesticides, an indirect energy source, has reduced to 0.20% in 2016–17 from 1.27% in 1980–81.

Though the energy use in agriculture is heading upwards, energy efficiency in agriculture is improving over time as suggested by the decreasing energy use to agricultural output ratios (Figure 2). The gross value of agricultural output (2011–12 prices) increased from INR 20 billion in 1980–81 to INR 22,560 billion in 2016–17. The gross value of agricultural output per $10^3$ MJ of
Table 1. Energy use in Indian agriculture

| Year     | Electricity (10^3 MJ/ha) | Diesel (10^3 MJ/ha) | Nitrogen and potash (10^3 MJ/ha) | Phosphorus and potash (10^3 MJ/ha) | Pesticides (10^3 MJ/ha) | Total energy (10^3 MJ/ha) | Energy input (10^3 MJ/ha) | Net cropped area | Gross cropped area |
|----------|--------------------------|---------------------|----------------------------------|-----------------------------------|-------------------------|--------------------------|--------------------------|-----------------|------------------|
| 1980–81  | 172.85                   | 6.69                | 222.89                           | 17.65                             | 5.40                    | 425.49                   | 3.03                     | 2.46            |
|          | 40.62                    | 1.57                | 52.39                            | 4.15                              | 1.27                    |                          |                          |                 |
| 1990–91  | 600.33                   | 21.07               | 484.63                           | 44.65                             | 9.00                    | 1159.68                  | 8.11                     | 6.24            |
|          | 51.77                    | 1.82                | 41.79                            | 3.85                              | 0.78                    |                          |                          |                 |
| 2000–01  | 1010.82                  | 496.65              | 661.76                           | 57.28                             | 5.23                    | 2231.75                  | 15.79                    | 12.04           |
|          | 45.29                    | 22.25               | 29.65                            | 2.57                              | 0.23                    |                          |                          |                 |
| 2010–11  | 1574.37                  | 40.81               | 1003.43                          | 112.90                            | 6.66                    | 2738.16                  | 19.34                    | 13.85           |
|          | 57.50                    | 1.49                | 36.65                            | 4.12                              | 0.24                    |                          |                          |                 |
| 2016–17  | 2066.10                  | 41.74               | 1014.17                          | 91.24                             | 6.33                    | 3219.56                  | 22.98                    | 16.23           |
|          | 64.17                    | 1.30                | 31.50                            | 2.83                              | 0.20                    |                          |                          |                 |

Note: Figures in the second row for each year indicate shares in total. Source: Estimates based on Singh and Mittal14.

Figure 1. Direct, indirect and total energy consumption in agriculture (10^3 MJ).

Figure 2. Declining energy use per unit value of output from agriculture and increasing energy use per hectare gross cropped area.

Energy increased from INR 0.049 billion in 1980–81 to INR 7 billion in 2016–17. In other words, the energy required to generate a unit value of output has declined from $201 \times 10^6$ to $1 \times 10^6$ MJ per unit value of agricultural output. The efficiency gains in agricultural production to energy use suggest movement in the right direction; yet this does not indicate that cultivation is becoming less energy-intensive. The improvement in yield of crops accompanied by output price expansion is the reason for efficiency gain.

Spatial energy-use pattern

Table 2 shows the component-wise per hectare energy consumption in major states of India for 2015–16. Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra lead in energy consumption. Very high level of electricity consumption for irrigation contributes the maximum per hectare energy consumption in these states since the groundwater tables in these regions are deep. Energy consumption in Punjab and Haryana is also high.
Table 2. Component-wise energy consumption per hectare gross cropped area (MJ/ha, 2015–16)

| State          | Electricity | Diesel | N   | P   | K   | Pesticide | Energy use/ha |
|----------------|-------------|--------|-----|-----|-----|-----------|--------------|
| Andhra Pradesh | 316,116.2   | 2,680.356 | 80,353.18 | 722.499 | 165.155 | 16.43143 | 400,054      |
| Assam          | 1,513,507   | 3,119,574 | 1,893,144 | 68,709 | 49,312 | 6.037347 | 6,650        |
| Bihar          | 6,252,446   | 2,562,105 | 9,828,714 | 491,064 | 92,326 | 13.18164 | 19,240       |
| Chhattisgarh   | 96,234.7    | 2,928.12  | 3,718,416 | 330,669 | 60,099 | 31.67408 | 333,424      |
| Gujarat        | 425,699.3   | 4,392.18  | 5,481,27 | 285,714 | 55,811 | 15.69999 | 435,930      |
| Haryana        | 78,319.46   | 7,151.37  | 10,280.79 | 527,694 | 21,574 | 74,89598 | 96,376       |
| Jharkhand      | 4,410.940   | 1,875.123 | 2,399,154 | 146,742 | 11,658 | 51,72908 | 8,895        |
| Karnataka      | 314,419.5   | 12,388.2  | 3,718,416 | 330,669 | 60,099 | 31.67408 | 333,424      |
| Madhya Pradesh | 143,740.4   | 3,178.47  | 307,026 | 23,383 | 3,698703 | 150,671 |
| Maharashtra    | 302,204.5   | 9,797.94  | 419,913 | 130,114 | 73,90007 | 316,577 |
| Odisha         | 6,579.568   | 2,826,762 | 2,389,458 | 178,821 | 47,503 | 18,61402 | 12,041       |
| Punjab         | 206,567.3   | 11,217.06 | 594,405  | 66,598  | 88,69829 | 225,101 |
| Rajasthan      | 183,530.4   | 13,541.19 | 2,605,194 | 197,913 | 4,958  | 6,130994 | 199,893      |
| Tamil Nadu     | 367,390.9   | 12,016.55 | 452,991 | 200,062 | 40,74703 | 386,435 |
| Uttar Pradesh  | 78,082.28   | 3,862,866 | 6,528,438 | 446,107 | 49,781 | 47,15564 | 89,019       |
| Uttarakhand    | 19,119.18   | 1,576.68  | 219,225  | 37,989  | 13,86693 | 29,679  |
| West Bengal    | 28,502.23   | 5,071.279 | 5,467,938 | 538,905 | 234,969 | 33,6662 | 39,849       |
| All India      | 167,675.8   | 5,152.365 | 5,141,304 | 378,288 | 78,591 | 35,15824 | 178,462      |

Source: ref. 15.

Figure 3. Grouping of states based on energy use per hectare gross cropped area (MJ/ha) and foodgrain yield (kg/ha).

Drivers for energy use in Indian agriculture

The level of diffusion of technologies and the use of energy-intensive inputs across crops determine the share of energy in the cost of cultivation. The energy share of major crops in India ranges from 57% for jowar to 74% for soybean in TE (triennium ending) 2015–16 (Table 3). Wheat cultivation in India is highly mechanized; still, the share of energy in the total cost for wheat cultivation (61%) is less than that for rice (66%). This is because, in the estimation, we have also included traditional energy sources like that of human labour, which is used more in rice in comparison to wheat. Groundnut, potato, maize and cotton are some other crops that have higher energy share in the cost of cultivation. In contrast, pulses, oilseeds and sugarcane are cultivated using comparatively less energy. Between TE 2007–08 and TE 2015–16, energy use by all the crops, except jowar, showed an increasing trend.
Table 3. Energy share in the cost of production of selected crops in India

| Crop      | Triennium ending 2015–16 | Triennium ending 2007–08 |
|-----------|--------------------------|--------------------------|
|           | Cost of cultivation (INR/ha) | Energy cost (INR/ha) | Share of direct energy cost (%) | Share of indirect energy cost (%) | Cost of cultivation (INR/ha) | Energy cost (INR/ha) | Share of direct energy cost (%) | Share of indirect energy cost (%) |
| Rice      | 61,377                    | 40,691                   | 39  | 9  | 15 | 23,080 | 13,529 | 38  | 7  | 14 |
| Wheat     | 46,990                    | 28,905                   | 27  | 13 | 16 | 24,193 | 11,565 | 18  | 14 | 16 |
| Maize     | 51,798                    | 36,666                   | 41  | 9  | 17 | 16,351 | 10,031 | 38  | 8  | 16 |
| Bajra     | 37,821                    | 26,428                   | 43  | 13 | 8  | 10,538 | 6,678  | 40  | 14 | 9  |
| Jowar     | 31,099                    | 17,977                   | 40  | 12 | 9  | 10,965 | 7,220  | 48  | 8  | 10 |
| Rapeseed  | 41,279                    | 25,314                   | 35  | 10 | 10 | 15,704 | 6,913  | 22  | 14 | 9  |
| Soybean   | 67,071                    | 48,950                   | 35  | 8  | 27 | 20,794 | 13,876 | 37  | 5  | 25 |
| Gram      | 34,693                    | 25,675                   | 35  | 13 | 26 | 14,473 | 9,527  | 35  | 12 | 18 |
| Arhar     | 36,606                    | 22,350                   | 30  | 11 | 19 | 14,555 | 7,465  | 23  | 9  | 19 |
| Coulton   | 48,349                    | 28,140                   | 48  | 5  | 11 | 14,473 | 7,241  | 40  | 5  | 10 |
| Potato    | 52,131                    | 51,163                   | 44  | 5  | 20 | 26,960 | 16,681 | 36  | 5  | 19 |
| Sugarcane | 142,304                   | 89,853                   | 40  | 4  | 14 | 56,256 | 29,723 | 33  | 4  | 16 |

Source: ref. 16.

Table 4. Average shares of machine labour charges in the cost of cultivation of rice and wheat (%)

| State          | 1980–1991 | 1991–2001 | 2001–2009 | 2009–2015 |
|----------------|-----------|-----------|-----------|-----------|
| Rice Andhra Pradesh | 4.01      | 5.49      | 7.56      | 11.15     |
| Karnataka      | 1.11      | 5.92      | 7.87      | 11.28     |
| Odisha         | 0.24      | 1.00      | 2.63      | 4.51      |
| Punjab         | 7.43      | 9.49      | 10.6      | 8.30      |
| Tamil Nadu     | 1.81      | 7.37      | 11.02     | 13.71     |
| Uttar Pradesh  | 2.83      | 6.05      | 7.55      | 8.11      |
| West Bengal    | 0.38      | 1.81      | 3.01      | 4.84      |
| Wheat Haryana | 12.44     | 11.69     | 14.28     | 13.52     |
| Madhya Pradesh | 4.53      | 8.28      | 10.48     | 14.42     |
| Punjab         | 12.33     | 10.72     | 15.21     | 14.69     |
| Rajasthan      | 8.3       | 9.84      | 10.5      | 10.64     |
| Uttar Pradesh  | 9.15      | 10.63     | 14.06     | 12.85     |

Source: ref. 16.

From Table 4, a higher level of mechanization is evident from the increasing cost of machine labour charges in the cost of cultivation of rice and wheat over time. The tractor density increased from 8.7 tractors per 1000 ha of net sown area in 1982 to 42 tractors per 1000 ha in 2012 (ref. 6). Correspondingly, diesel consumption for cropping increased from 149,000 tonnes in 1985 to 630,000 tonnes in 2015. Expansion of area under irrigation is another energy driver for agriculture. Electricity consumption in agriculture, mainly used for pumping water, has increased from 23,422 GWh in 1985 to 173,185 GWh in 2015. Increasing use of nitrogenous fertilizer is another driver for the increase in energy use in agriculture. Nitrogen consumption has increased from 5,660 to 17,372 thousand tonnes between 1985 and 2015. Table 5 presents the state-wise fertilizer consumption and subsidy received. Both electricity and fertilizers are provided at subsidized rates in India. The regional differences in fertilizer use are attributed to a gamut of factors like cropping pattern, agro-climatic conditions, and access to irrigation and finance.

Agriculture as a producer of energy

World over, the energy sector has encountered conflicting objectives of ensuring energy security and a sustainable future for all. Energy from renewable sources reduces the environmental effects, generates fewer secondary wastes, and more importantly, is sustainable. Table 6 presents the source-wise estimated potential of renewable energy for major states in India. Though the share of biomass power is very less compared to the total renewable energy potential, it is substantial often used complementarily with fossil energy through blending. Biofuels, the backstop technology to fossil fuel-based energy, are a sustainable and environment-friendly energy source. India has taken a stand that biofuel generation in the country will not be at the cost of food security. Hence only non-edible sources like *Jatropha* and Pongamia, and molasses are the major feedstock for biodiesel and bio-ethanol production.

Indian biofuel stratagem

The National Biofuel Mission, 2003 is the earliest among the biofuel policies of India under which the potential of producing biofuel through *Jatropha* cultivation was identified.

Further, ethanol blended petrol (EBP) was launched in 2013 to ensure a sustainable market for the biofuel sector by mandating a 5% blending of ethanol in petrol. In 2018, identifying the necessity to widen the feedstock range required to produce biofuels, the National Biofuel Policy...
Table 5. Fertilizer consumption and subsidies across states (2016)

| State                | Fertilizer consumption ('000 tonnes) | Fertilizer subsidy (billion INR) | Share of states in fertilizer subsidy | Share in GCA | Subsidy/ha GCA (INR) |
|----------------------|-------------------------------------|---------------------------------|--------------------------------------|--------------|----------------------|
| Andhra Pradesh       | 1,698.15                            | 45.97                           | 6.35                                 | 4.05         | 5655.29              |
| Bihar                | 1,696.85                            | 45.93                           | 6.34                                 | 3.77         | 6059.50              |
| Gujarat              | 1,516.75                            | 41.06                           | 5.67                                 | 6.22         | 3287.90              |
| Haryana              | 1,647.40                            | 44.59                           | 6.16                                 | 3.22         | 6891.13              |
| Himachal Pradesh     | 56.24                               | 1.52                            | 0.21                                 | 0.47         | 1614.34              |
| Karnataka            | 1,779.76                            | 48.18                           | 6.65                                 | 6.11         | 3927.22              |
| Madhya Pradesh       | 1,966.54                            | 53.23                           | 7.35                                 | 11.97        | 2213.86              |
| Maharashtra          | 2,724.58                            | 73.75                           | 10.18                                | 11.61        | 3161.44              |
| Odisha               | 519.70                              | 14.07                           | 1.94                                 | 2.57         | 2722.03              |
| Punjab               | 1,943.71                            | 52.61                           | 7.27                                 | 3.91         | 6704.02              |
| Rajasthan            | 1,530.64                            | 41.43                           | 5.72                                 | 13.00        | 1586.22              |
| Tamil Nadu           | 1,144.36                            | 30.98                           | 4.28                                 | 2.94         | 5252.84              |
| Telangana            | 1,316.25                            | 35.63                           | 4.92                                 | 3.13         | 5666.15              |
| Uttar Pradesh        | 4,230.09                            | 114.50                          | 15.81                                | 12.89        | 4421.60              |
| West Bengal          | 1,615.66                            | 43.73                           | 6.04                                 | 4.79         | 4547.03              |
| All India            | 26,752.60                           | 724.15                          | 100.00                               | 100.00       | 3605.27              |

Source: ref. 17. GCA, Gross cropped area.

Table 6. Estimated potential of renewable power (MW) in India (2016)

| State                | Wind power | Small hydropower | Biomass power | Cogeneration bagasse | Waste to energy | Solar | Total |
|----------------------|------------|------------------|---------------|----------------------|-----------------|-------|-------|
| Andhra Pradesh       | 14,497     | 978              | 578           | 300                  | 123             | 38,440| 54,916|
| Assam                | 112        | 239              | 212           | 0                    | 8               | 13,760| 14,330|
| Bihar                | 144        | 223              | 619           | 300                  | 73              | 11,200| 12,559|
| Chhattisgarh         | 314        | 1,107            | 236           | 0                    | 24              | 18,270| 19,951|
| Gujarat              | 35,071     | 202              | 1,221         | 350                  | 112             | 35,770| 72,726|
| Himachal Pradesh     | 64         | 2,393            | 142           | 0                    | 2               | 111,050| 118,208|
| Jammu & Kashmir      | 5,685      | 1,431            | 43            | 0                    | 0               | 118,208| 118,208|
| Jharkhand            | 91         | 209              | 90            | 0                    | 10              | 18,180| 18,580|
| Karnataka            | 13,593     | 4,141            | 1,131         | 450                  | 0               | 24,700| 44,015|
| Kerala               | 837        | 704              | 1,044         | 0                    | 36              | 6,110 | 8,732 |
| Madhya Pradesh       | 2,931      | 820              | 1,364         | 0                    | 78              | 61,660| 66,853|
| Maharashtra          | 5,961      | 794              | 1,887         | 1,250                | 287             | 64,320| 74,500|
| Odisha               | 1,384      | 295              | 246           | 0                    | 22              | 23,780| 27,728|
| Punjab               | 0          | 441              | 3,172         | 300                  | 45              | 2,810 | 6,768 |
| Rajasthan            | 5,050      | 57               | 1,039         | 0                    | 62              | 142,310| 148,518|
| Tamil Nadu           | 14,152     | 660              | 1,070         | 450                  | 151             | 17,670| 34,152|
| Uttar Pradesh        | 1,260      | 461              | 1,617         | 1,250                | 176             | 22,830| 27,593|
| Uttarakhand          | 534        | 1,708            | 24            | 0                    | 5               | 16,800| 19,071|
| All-India total      | 102,772    | 19,749           | 17,536        | 5,000                 | 2,556           | 748,990| 896,602|

Source: ref. 18.

2018 was implemented. According to this Policy, in addition to molasses, the potential of garbage and biomass available in the country would also be tapped by the sector. While the overall responsibility to ensure an effective biofuel policy regime rests with the Ministry of New and Renewable Energy, Government of India, the involvement of multiple ministries for pricing, procurement, research and impact assessment stress on the necessity for complementary actions.

Status of India’s biofuel production

India has not yet been able to become a major contributor to the world biofuel production. The world’s biofuel production in 2017 was 84,121 KTOE (kilo tonnes of oil equivalent). USA is the frontrunner in biofuel production in the world with a share of 43.9%, followed by Brazil (22%). Currently, India’s biofuel production is 435 KTOE, which accounts for only 0.5% of the global production. The positive aspect, however, is that biofuel production in India is growing over the years. Between 2006 and 2017, it grew at a compound annual growth rate of 22%, in comparison to the average world growth rate of 11%. In contrast, when we analyse Figure 4, it becomes evident that China, which had a similar biofuel production level as that of India in 2000, made a quantum jump and was able to reach the mark of 2000 KTOE by 2017. During the same period, India could rise to the level of only 500 KTOE. This calls for
introspection of the policies that have been undertaken to support the biofuel sector in the country.

Fuel ethanol is the major biofuel produced in India (Figure 5). In 2016, India produced more than 0.6 MTOE of fuel ethanol and 0.1 MTOE of biodiesel. To achieve the targets of 20% blending rate of bioethanol with petrol, ethanol production has to be enhanced at least three times the present level or imports need to be increased.

However, the production enhancement requires disturbing the cropping pattern by diverting more area to sugarcane. Such a diversion will also have environmental consequences, since sugarcane consumes more water than most other crops. The efficiency in the utilization of total molasses generated in the country for bioethanol production also needs to be assessed. Similarly, to produce biodiesel required to meet its blending rate targets with diesel, *Jatropha*, the main feedstock will have to be grown in more area. About 26 m ha area has to be brought under *Jatropha* cultivation to meet the 20% blending rate.

Considering the economic and yield constraints in *Jatropha* cultivation, Government intervention is essential. This is because, in South India, several farmers discontinued *Jatropha* cultivation due to non-realization of the anticipated profit.

**Sustainable interaction between energy and agriculture**

A sustainable interaction between agriculture and energy has to be achieved considering the higher production, and enhanced clean and green energy-use trade-off. The objective has to be to increase the energy-use efficiency in agriculture and a transition to renewable energy sources without compromising agricultural production. As a producer of energy, the role of the agriculture sector is more complicated. For a developing country like India, increasing the area under biofuel stock involves a trade-off with food security, as arable land is limited. Besides, if in the future, biofuel technology becomes popular and growing feedstocks becomes profitable, there is a threat that the farmers will substitute the food crops with such feedstock crops affecting food security. The support through subsidies and other programmes should thus be carefully implemented by the government, keeping in view both biofuel targets and food security. Finally, the industry for energy generation from biomass is still in the nascent stage in India. Considering the potential of this sector, and the availability of huge quantities of biomass in the country which are currently being wasted, for instance by straw burning, a stable strategy needs to be formulated at the national level to reap the benefits.

**Conclusion**

This study elaborates two important dimensions of the relationship between agriculture and energy; the role of agriculture as a consumer as well as a producer of energy. We found that the total commercial energy input in Indian agriculture has increased from $425.4 \times 10^9$ MJ in 1980–81 to $3219.5 \times 10^9$ MJ in 2016–17; however, the efficiency in energy use has also increased over the years. Irrigation, use of machinery and energy–intensive inputs like fertilizers 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, India is striving 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.

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