Discerning sustainable interaction between agriculture and energy in India

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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 pesticides[2]. 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 sectors[3], but there has been a shift in the structure of energy use. This structural shift is powered through mechanization and use of energy-intensive inputs[4]. Also, there is a regional difference in energy use in Indian agriculture, mainly due to the varying extent of mechanization and input use[5]. 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 (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 2.46×10^3 to 12.04×10^3 MJ/ha due to a rapid expansion of tube-well irrigation in the Indo-Gangetic Plains[2]. As of 2016–17, the per hectare energy consumption is 16.23×10^3 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 245×10^9 to 1100×10^9 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 10^6 MJ of

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Table 1. Energy use in Indian agriculture

Year	Electricity	Diesel	Nitrogen	Phosphorus and potash	Pesticides	Total energy	Energy input (10^3 MJ/ha) Net cropped area	Gross cropped area
	(10^9 MJ)							
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 Mittal[14].

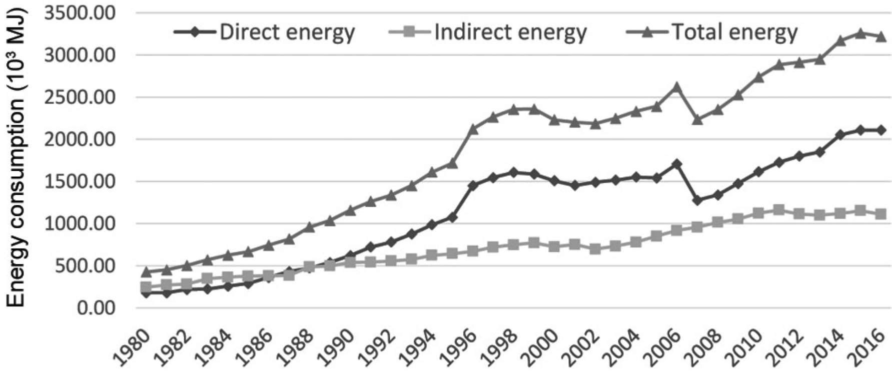

Figure 1. Direct, indirect and total energy consumption in agriculture (10^9 MJ).

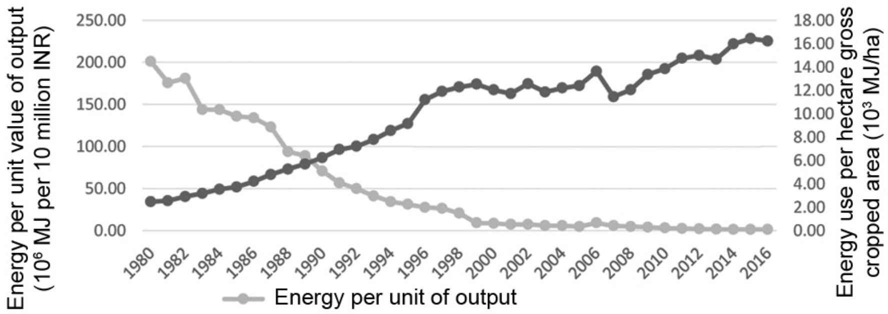

Figure 2. Declining energy use per unit value of output from agriculture and increasing energy use per hectare gross cropped area.

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 201×10^6 to 1×10^6 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	6.037374	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	31.67373	103,304
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	4,410.949	1,875.123	2,399.154	146.742	11.658	51.72908	8,895
Karnataka	314,419.5	12,388.2	5,847.9	579.864	175.674	12.72742	333,424
Madhya Pradesh	143,740.4	3,418.017	3,178.47	307.026	23.383	3.698703	150,671
Maharashtra	302,204.5	9,797.94	3,951.12	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	206,557.3	6,577.008	11,217.06	594.405	66.598	88.69829	225,101
Rajasthan	183,530.4	13,548.19	2,605.194	197.913	4.958	6.130994	199,893
Tamil Nadu	367,390.9	12,016.55	6,333.912	452.991	200.062	40.74703	386,435
Uttar Pradesh	78,082.28	3,862.866	6,528.438	448.107	49.781	47.15564	89,019
Uttarakhand	19,119.18	1,576.68	8,711.856	219.225	37.989	13.88693	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.

Yield (kg/ha)	Energy consumption (MJ/ha): 0–100,000	100,000–200,000	200,000–300,000	>300,00
0–1000				Maharashtra
1000–2000	Assam, Uttarakhand, Jharkhand, Odisha	Madhya Pradesh, Rajasthan, Chhattisgarh		Karnataka
2000–3000	West Bengal, Bihar, Uttar Pradesh			Gujarat
>3000	Haryana		Punjab	Andhra Pradesh, Tamil Nadu

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

as agriculture has become energy-input intensive in these two states since the green revolution. Rajasthan, Madhya Pradesh and Chhattisgarh are the other states that consume a considerably higher level of energy per hectare. 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. To determine if higher energy consumption is associated with high foodgrain yields, we classified the states into different groups based on hectare energy consumption and foodgrain yield (Figure 3). Gujarat, Andhra Pradesh and Tamil Nadu 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.

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: Cost of cultivation (INR/ha)	Energy cost (INR/ha)	Share of direct energy cost (%): Human and animal	Machine	Share of indirect energy cost (%)	Triennium ending 2007–08: Cost of cultivation (INR/ha)	Energy cost (INR/ha)	Share of direct energy cost (%): Human and animal	Machine	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
Groundnut	67,071	48,950	35	8	27	20,794	13,876	37	5	25
Soybean	34,693	25,675	35	13	26	14,473	9,527	35	12	18
Gram	35,606	22,350	30	11	19	14,555	7,465	23	9	19
Arhar	48,349	28,140	38	7	11	14,473	7,241	40	5	10
Cotton	72,313	51,163	44	5	20	26,960	16,681	36	5	19
Potato	116,636	84,355	26	4	41	55,185	37,743	19	4	46
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[7]. 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[8]. Energy from renewable sources reduces the environmental effects, generates fewer secondary wastes, and more importantly, is sustainable[9]. 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[10]. 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 bioethanol 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	2213.63
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	2,398	142	0	2	33,840	36,446
Jammu & Kashmir	5,685	1,431	43	0	0	111,050	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	25,780	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[11].

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

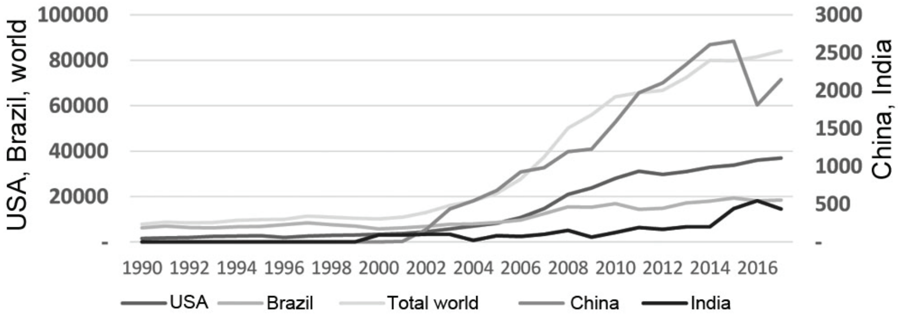

Figure 4. Trend in world biofuel production (KTOE).

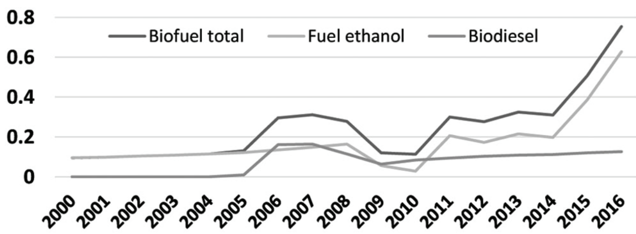

Figure 5. Trend in biofuel production in India (MTOE).

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[12].

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[11].

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[13], 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 425.4×10^9 MJ in 1980–81 to 3219.5×10^9 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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