Reduction of Energy Consumption in Agriculture for Sustainable Green Future

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Abstract

Ever augmenting population pressure and energy crisis are twin challenges for the food environment, and economic security. Green revolution marked the agricultural production in India due to the intensive use of fertilizers, pesticides, irrigation and mechanization pressure, which leads to high energy consumption pressure. Escalated energy demand has also driven the GreenHouse Gases (GHGs) emission that remains a threat for green future. Therefore, urgent need to identify the traditional agricultural practices to reduce energy consumption and improve the Energy Use Efficiency (EUE) through the best management practices. This chapter is focusing on reducing energy demand and enhances the EUE. Many practices are recognized as effective for sustainable green energy use with better resource utilization patterns. Resources efficient and conservational technologies for best and alternative use of power, fuel, seed, nutrient, water, electricity, management practices, etc. need be adopted. Conservation

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agriculture (CA)-based cropping with legume and residue retention, integrated use of available resources, combining agriculture with forestry and animals, efficient postharvest operations and transporting, reducing dependency on nonrenewable resources are sustainable and energy-efficient approaches for the green future. It will help producers, researchers, policymakers, and the government planners to make a roadmap for the green future and advance sustainability.

Keywords

Agriculture · Energy consumption · Energy use efficiency · Policies

Abbreviations

%	Percent
ai	Active ingredient
$b\ d^{-1}$	Barrel day^{-1}
BU	Billion units
CA	Conservational agriculture
CT	Conventional tillage
DSR	Direct seeded rice
EUE	Energy use efficiency
FYM	Farm yard manure
GHG	Green house gas
GJ	Giga joule
ha^{-1}	Per hectare
INM	Integrated nutrient management
K_2O	Di-potassium oxide
kg	Kilogram
kPa	Kilo Pascal
KTOE	Kilo ton oil equivalent
kWh	Kilo watt hours
LCC	Leaf color chart
LMT	Lakh metric ton
m^3	Cubic meter
Mha	Million hectares
MJ	Mega joule
MT	Metric tons
Mt.	Million ton
MTOE	Million ton oil equivalent
MW	Mega watt
MWh	Mega watt hours
N	Nitrogen
NDVI	Normalized difference vegetative index
NUE	Nitrogen use efficiency
P_2O_5	Phosphorus pentoxide

T	Ton
TOE	Ton oil equivalent
TWh	Terra watt hours
WUE	Water use efficiency

7.1 Introduction

The world population is on the rise and the existing trend of the escalating population will be expected between 8.3 and 109 billion by 2050 according to the UN organization estimates (Prosekov and Ivanova 2018). About 50–75% increase in the food supply will be required to feed the rapidly mounting global population depending upon the region (Prosekov and Ivanova 2018). This augmented population growth rate has posed serious threats to agricultural and environmental sustainability as well as global energy consumption. Moreover, the changing climatic scenario has become a real observable fact that directly or indirectly puts pressure on already overexploited existing natural resources and offer somber challenge to global food security. The world food production is mainly challenged by two major factors, i.e., climate change and energy consumption in agriculture which became talk-of-world now a days. These twin factors have direct impact on agricultural yields and challenge global food security. To produce sufficient food for the increasing population, agricultural intensification is increased in the existing cropland which ultimately put environmental sustainability at stake and energy consumption at the pinnacle. About 30% of global energy consumption is through the agriculture and food industry (FAO 2011). Meanwhile, energy consumption is directly affected by the changing climatic scenario. More the impact of climate change more will be the energy consumption in adjusting the whole agricultural methodology for cultivating a particular crop.

The pre-green revolution era utterly relied upon human and animal power for operating traditional tools and implements where commercial energy consumption was almost negligible. Rise in food demand increased the competition for water, land, and inputs to produce sufficient food. Moreover, agriculture sector requires huge energy and inputs to meet the global food production as agriculture being a production-oriented sector. In the post-green revolution era, initiatives and steps were taken by successive governments to reinforce the agriculture sector by increased use of inputs (fertilizers and pesticides), development of packages and practices for sowing crops, investments in building and irrigation infrastructures at farms, etc. Strengthening the agriculture sector requires the direct or indirect use of energy at each level in the farms.

7.1.1 Direct Energy

Gasoline, natural gas, electricity, diesel-and petroleum-based fuels are chiefly considered as direct energy consumption sources and are used directly in the farm. Diesel-and petroleum-based energy sources are mainly used for the transportation (tractors, combine harvesters, trucks, etc.) of off-farm inputs and outputs, harvesting crops, operating machinery for preparing fields, sowing, transplanting, spraying pesticides, etc. Electricity consumption is possible at each farm level, i.e., operating irrigation pumps, lighting, cold storages, greenhouses for maintaining temperatures, operating machinery for drying, postharvest packaging and processing, milking machines in the dairy sector, etc.

7.1.2 Indirect Energy

The activities that are operated off the farms like fertilizers and pesticides manufacturing, chemicals (for scientific researches) and inputs production, manufacturing of farm machinery and equipment consumed indirect energy. Besides these oils and lubricants were also used for farm machineries and equipment's maintenance.

Agricultural sector uses both direct and indirect energy for cultivating crop, livestock and postharvest value additions, and operations. For the growth of the agriculture sector, several policies and initiatives were taken into consideration by the government. In which, the government and private sectors worked jointly and realized the importance of agriculture. This led to an increase in the level of mechanization over the years ultimately results in total energy consumption (direct and indirect energy) in the agriculture sector.

7.1.3 Global Energy Use Pattern of Agriculture

The world's total energy consumption accounts for about 553.9 MTOE and is expected to grow in the future due to ever-escalating population (ES 2019). China is the largest energy consumer in the world followed by the America and India. Globally, the agriculture sector including fishing consumes about 2.07% of the total world's available energy in the form of electricity, coal, and oil (Fig. 7.1). Electricity consumption in agriculture sector has increased from 29,478 KTOE (1990) to 58,873 KTOE (2018) but share remains steady (3%) with an increasing demand over various demanding sectors (IEA 2019). Coal contributes to be the largest share for electricity generation in all demanding sectors and accounts for 38% of total electricity generation compared with other sources of power generation (BPSRWE 2019). The increasing demand for electricity indirectly put pressure on exploiting coal. The oil consumption also shows an increasing trend with an average of 1.4 million b d^{-1} (BPSRWE 2019). Total crude oil consumption in the agriculture sector increased from 1,04,939 to 1,11,062 KTOE during the years 1990 to 2018. Now, the

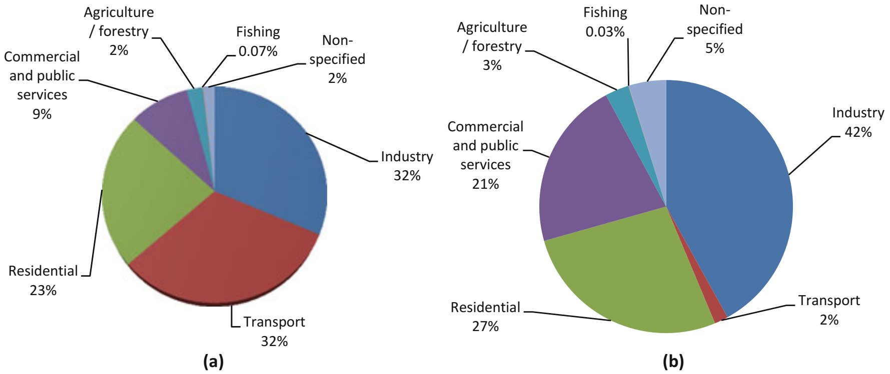

Fig. 7.1 Sector-wise (**a**) energy and (**b**) electricity consumption of the world in 2018 (Source: ES 2019; IEA 2019)

agricultural sector accounts for 15% of the total world's oil consumption and demand is likely to increase in future (IEA 2019).

7.1.4 Energy Use Pattern in Indian Agriculture

India stands among top energy-demanding countries in the world. Further, energy use is highly increased in each demanding sector by virtue of its growing economy; about 11% increments in total energy demand is expected by 2040 (BP 2020). At the same time, the energy production cost is increasing at a faster rate. Energy intensity of India is facing rapid dwindle; 65.5 TOE/Cr Rupees in 2011 to 55.8 TOE/Cr Rupees in 2018 (BEE 2019). Meanwhile, per capita, energy consumption trend in demanding sectors is also at a peak from 0.466 TOE to 0.559 TOE during this period.

Agriculture is the most important sector in energy consumption; contributing about 5% of the total energy supplied (Fig. 7.2). This showed hasty augmentation in energy demand by twofold in the last decades due to commercialization and diversification (Fig. 7.3). Indian agriculture also consumes the huge amount of electricity 18% (203BU) and demand is growing rapidly; potentially tripled in future. This increasing demand is owing to the modernization of inputs, machines equipment and modern technologies. Agriculture stands third major electricity consumer sector after industrial and residential sectors (Fig. 7.2). Meanwhile, the government of different states provides mostly free or high subsidies electricity for agricultural purposes but the farmers pay less attention in saving energy.

Electricity, the direct energy source is obligatory in farms due to mechanized crop or animal equipment and ensures timely energy supplies at each level of the production cycle. This holds true for maximum profits at farms and timely management of climacteric and non-climacteric commodities. In 2018, agricultural electricity consumption in India accounts for about 18,195 KTOE (Fig. 7.3). In 1990, even

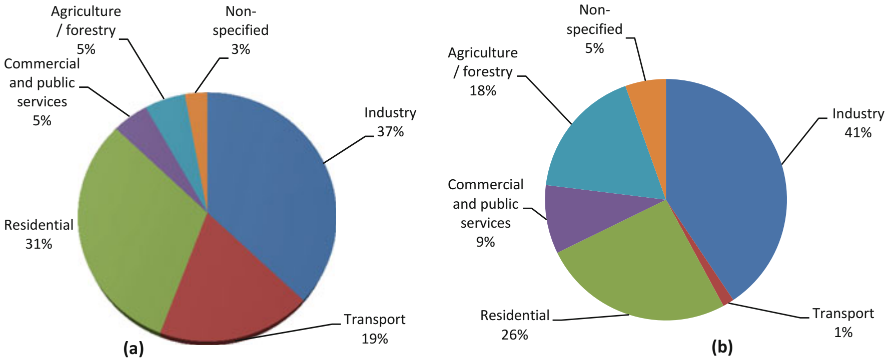

Fig. 7.2 Sector-wise (**a**) energy and (**b**) electricity consumption of India in 2018 (Source: IEA 2019; BEE 2019)

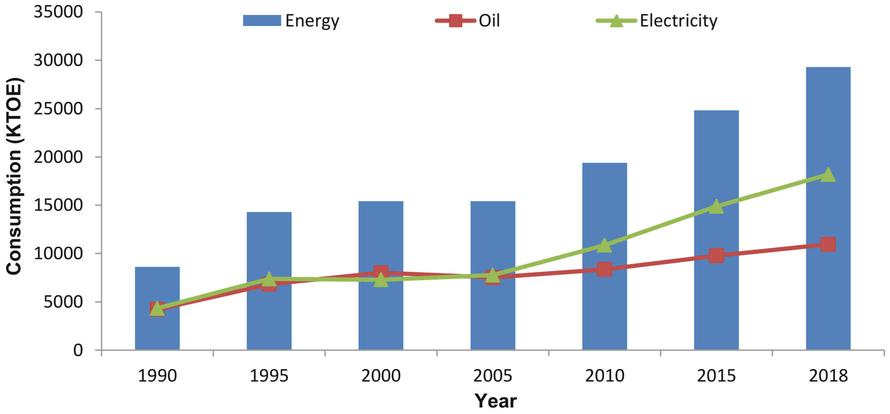

Fig. 7.3 Energy use trend of Indian agricultural sector in past three decades (Source: BEE 2019)

though in the post-green revolution era, there is an even out demand for electricity that accounts for 4327 KTOE in the agriculture sector compared with other demanding years. Thereafter, trend of electricity consumption in the decades 2005 to 2018 witnessed a sharp increase and had been swinged from 4 digits to 5 digits (7764 KTOE to 18,195 KTOE). Based on current data, India's electricity demand in agriculture sector will rise further and could be tripled by 2040, with potentially used agro-production chains, cold storage infrastructures, farm machineries, chaff-cutters, root-cutters and irrigation tube wells/pumps. India's per capita electricity consumption also stands from 2.06 to 3.26 MWh in the decades from 1990 to 2018 (GOI 2020a). Industrial sector is also involved in the production process of farm-based equipment and machines, pesticides, fertilizers, phytohormones, chemicals, and agricultural inputs together representing 41% of total electricity consumption as depicted in the pie-chart (Fig. 7.2). It has been reported that demand of the agricultural sector for energy, electricity, and oil is consciously increasing. Therefore, achieving energy efficiency along with reducing energy consumption are twin challenges that needs to be achieve nowadays.

7.1.5 Need for Achieving Energy Efficiency

Direct energy demand hits the highest point in the past few years in each demanding sector. The demand for sequestered energy inputs (indirect energy inputs) like fertilizers, herbicides, pesticides, and insecticides also increased due to large-scale commercial farming. The production, distribution, and transport processes of these inputs also require energy. Fertilizers and pesticides are most energy-intensive agricultural inputs as these inputs became the preferred ones in each cultural practice of crops. Nitrogen is the principal fertilizer and its production process requires a huge amount of energy. Urea is predominately preferred and production is more; India producing 249.25 LMT (GOI 2020b).

Besides fertilizers, irrigation is the principle input for sustainable food production; about 60% of food grain production is owing to utilizing groundwater. Energized pump sets are used by the Indian farmers for pumping groundwater for an assured source of irrigation. A total of 21.3 million energized pump sets are available in India (CEA 2019). Broadly speaking the calculation of energy consumption by an energized pump set was 6004 kWh of electricity annually (CEA 2019). Indian farmers are getting insufficient electricity supplies at farms for which they use diesel pump sets as a standby in commercial farming. Therefore, diesel demand in the last two decades was also increased in the agricultural sector. Similarly, tractors, combine harvesters as well farm practices right from sowing to harvesting and postharvest operations required a huge amount of nonrenewable energy. Therefore, consumption of both direct and indirect energy increased in decades.

It is cleared from aforesaid facts and figures that both direct and indirect agricultural energy consumption in the world and India is at peak. Industrialization, urbanization, and increased mechanization in agriculture marked the higher demand of both renewable and nonrenewable energy resources from time immemorial. In view of this, energy efficiency is need of time and is a win–win strategy. Since, we are on the verge of the energy crisis, the efficient use of energy in agricultural sector assumes importance. In this chapter, attention to agricultural enterprises, practices and policies, are considered to solve this huge crisis. Direct and indirect energy use patterns along with efficient technologies and approaches are discussed in further sections.

7.2 Traditional Farming and Energy Use

7.2.1 Crops and Cropping System

The agricultural productivity and food sustainability are regulated by appropriate cropping system in a particular agroecology. Energetics of cropping/system is directly linked with the productive potential of crops and varieties. Energy analysis in terms of efficiency and its use in a cropping system provides effective and equilibrated use of agroecological resources. Though along with crop, the high yielding varietal selection also affects energy dynamics. Numerous reports across the globe indicated the effects of cropping patterns and its management. Input intensive crops like rice, wheat, maize, etc. consume more energy while their productive potential affects the energy productivity. A good relationship between the energy input–output process offer opportunity in balanced crop production with the least specific energy and carbon footprints. Energy cost and crisis are increasing nowadays and make agriculture less profitable due to high production costs (Jha et al. 2012).

Jha et al. (2012) indicated energy cost of different crops; cost of cereals (rice, wheat, and maize) was higher (10–13 thousand rupees ha^{-1}) than millets (pearl millet, sorghum), oilseeds (rapeseed and mustard, soybean), and pulses (pigeon pea, chickpea). Input intensive crops and varieties have high energy requirement and energy costs. Commercial crops like cotton, potato, and sugarcane had much higher energy cost (Jha et al. 2012) than cereals due to additional tillage, fertilizers, human labor, etc. Crops differed in water requirement besides other inputs. Water guzzling crops also enhance energy use for pumping more water and has higher energy cost like rice; 47.8 MJ US\$$^{-1}$ (Singh et al. 2020a). Crop energy requirement also varies due to extend of mechanization and human labor use. In spite of lower mechanization index of maize, it needs more input energy than wheat, rye, and rapeseed (Alluvione et al. 2011) due to continuous engagement of human labor for various intercultural operations like weeding, earthing-up, and harvesting, etc. Howbeit the efficiency of input energy conversion of maize is more than soybean due to better productive potential. In a comparative study of cluster bean, maize, cotton, wheat, and mustard total least energy input was achieved in cluster bean and highest in cotton (Singh et al. 2003). Input energy not only varies with crops but also with the locations; wheat grown in western Rajasthan requires more (17–20%) energy than Madhya Pradesh, Uttar Pradesh, and Punjab (Singh et al. 2007). Rajasthan is a relatively dry area where irrigation cost is more. Energy demand patterns also differed in horticultural crops. Among the vegetable crops, tomato and chili require more input energy than lettuce (Kuswardhani et al. 2013). Pepper has paralleled energy demand with tomato, cucumber, and eggplant but theefficiency of conversion during the production process is less (Canakci and Akinci 2006). Citrus production in Turkey suggested that mandarin requires less total energy than lemon and orange while indirect and nonrenewable energy consumption is more in lemon (Ozkan et al. 2004).

Table 7.1 Energy use pattern of different cropping systems

Cropping system	Input energy (GJ ha^{-1})	Energy output (GJ ha^{-1})	Energy ratio	References
Double cropping				
1. Cereal-cereal				
Rice–Rice	65.4	183.9	2.8	Shilpa et al. (2018)
Rice–oat	11.2	78.2	6.9	Kumar et al. (2016)
Rice–wheat	25.6	191.7	7.4	Singh et al. (2019a, 2020a)
Rice–buckwheat	5.9	22.4	3.8	Banjara et al. (2019)
Maize–wheat	22.6		3.11	Gosh et al. (2015)
2. Cereal–legume				
Rice–chickpea	4.5	24.7	3.8	Banjara et al. (2019)
Rice–lathyrus	3.7	25.4	6.9	Ganajaxi et al. (2011)
Soybean–wheat	13.4	23.7	5.5–7.5	Mandal et al. (2002)
Groundnut–wheat	22.2	183.8	8.3	Ganajaxi et al. (2011)
3. Cereal–oilseed	3.7–6.3	22.3–53.9	6.1–8.5	Banjara et al. (2019)
4. Legume–legume	15.7–19.8	92.7–175.5	5.9–8.9	Ganajaxi et al. (2011), Singh et al. 2008
Multiple cropping system				
With legumes	13.5–13.6	194.0–341.9	14.2–15.3	Pooniya et al. (2015), Yadav et al. (2016), Khan and Hussain (2007)
Without legume	31.9–39.9	373.9–403.8	9.4–12.6	Khan and Hussain (2007)

Disparity of energy consumption among various crops could alter by efficient cropping system. A combination of crops in a cropping pattern and its management is equally clarifying the energy consumption, its conversion in usable form. Various literature on energy budgeting in a cropping system indicated that cereal–cereal cropping is least beneficial and require more energy with lesser EUE (Table 7.1). Rice–wheat cropping system covers highest area in the northern India (13.5 mha) and exploits huge energy and natural resources. Diversification and intensification of cropping systems is important management practice. In terms of good energy conversion, cereal-legume or cereal-oilseed cropping system is valuable for energy balance and ecological sustainability. Inclusion of legumes in the cropping system required lesser nutrient and input demand with efficient utilization of available resources. Energy input–output analysis of various multiple cropping systems indicated that taking more crops in a year requires more input energy (13.5–39.9 thousand MJ ha^{-1}) than double cropping. However, utilization of input energy

(EUE) was high suggesting if all available resources are not scarce, we must take multiple crops on farm. This indicates better energy output of intensified cropping system. On the whole, it must be said that inclusion of legumes in multiple cropping and oilseeds in double cropping is more efficient and advantageous practice in terms of energy ratio and energy utilization during cropping process. However, cropping intensification through the inclusion of legumes is the foremost and energy consumption practice and is a major concern.

7.2.2 Tillage and Land Preparation

Indian agriculture is associated with heavy use machineries for intensive tillage (Gupta et al. 2016). Energy-intensive tillage is the major concern for global greenhouse production as it directly uses a high amount of direct and nonrenewable energy sources (diesel). During the post-green revolution era, mechanization became popular among farmers to obtain good tilth and friable seedbeds. Therefore, demand for fossil fuel drastically increased with the use of tractors. Heavy fuel demand in tillage leads to emission of CO_2; which has curtailed to half by 2050 (IEA 2013; Ethrel et al. 2015). Efficient energy use in agriculture is of prime importance without affecting productivity and food security of livelihood. Economics of crop production is highly related to energy consumption (Lu and Lu 2017). Tillage and crop establishment not only contributes 25–30% of crops production cost but also consume a high amount of energy, i.e., 10–29%, depending upon crop and intensification of mechanization (Saharawat et al. 2011; Pathak et al. 2011; Kumar et al. 2013; Jha et al. 2012; Shilpa et al. 2018). Direct energy cost in tillage could be escalated by the adoption of alternative methods or reducing its intensity.

Efficient machineries and curtailing mechanization index in crop production could save energy by 18–83% (Sørensen and Nielsen 2005; Mandal et al. 2015a, b). Conservational agriculture is an alternative strategy to reduce energy consumption in tillage operations as well as reducing the cost of cultivation (Balwinder-Singh et al. 2011). CA results in improved yield in terms of good soil health, aeration, and water holding capacity (Hamzei and Seyyedi 2016). Conservational tillage can enhance net energy gain and reduce net global warming potential (Ghimire et al. 2017; Lu and Lu 2017). In an experiment at western Uttar Pradesh, India; the sowing of wheat in rice–wheat cropping system through zero-tillage achieved 5–20% higher EUE due to 10–13% lesser energy demand and 3–5% higher energy output over conventional tillage and rotavator tillage (Kumar et al. 2013). Similarly, Hamzei and Seyyedi (2016) advocated the use of conservational tillage for higher EUE due to reduced energy inputs over conventional tillage. Residue retention in no-till maize requires 29.23% lesser nonrenewable energy than moldboard tilled planting while achieving 16.4% higher EUE (Lu and Lu 2017). In the same way, Nath et al. (2017) reported higher net energy returns (14.9%) and energy productivity (8.2%) with zero-tilled wheat sown with residue retention whereas, in mung bean, the increments were 14.9 and 8.0%, respectively. Conservational tillage practices always play an important role in reduction of energy demand (0.8 to

Table 7.2 Input energy reduction (%) in conservational tillage practices over traditional

Crops/cropping system	Zero tillage	Reduced/minimum/ raised bed	Rotavator	References
Pigeon pea	30.5	15.2	–	Pratibha et al. (2015)
Castor	31.3	11.5	–	
Wheat	3.5–13.06	10.5	0.8–10.9	Singh et al. (2020b), Kumar et al. (2013)
Maize	24.8	25.5	–	Yadav et al. (2016)
Maize–wheat	80.0	50.0–60.0	–	Sharma et al. (2011)
Soyabean–wheat	28.4	10.8	–	Singh et al. (2008)
Soyabean–lentil	29.9	9.0	–	
Soyabean–pea	37.3	13.8	–	

80.0%) over conventional practices (Table 7.2). However, zero-or no-tillage for all crops and cropping systems are more efficient in energy saving than reduced or minimum tillage while maintaining ground cover and reducing GHG emission from agricultural soil as well. In the nutshell, it must be important to say that conservational tillage with the right methods of sowing; mean a lot in reducing the energy demand and carbon footprints.

7.2.3 Methods of Sowing

Crops sown with various methods perform differently with energy budgeting. Methods that need more human labor along with intensive mechanization consume a high amount of direct and indirect energy. For example, rice required more energy when transplanted in conventionally puddled soil due to heavy use of tractors in puddling and human labor in transplanting (Banjara et al. 2019). Reducing energy demand by lowering mechanization and labor demand is a prominent approach. Bhushan et al. (2007) advocated no-tilled DSR for lower machine labor as well human labor in rice establishments. Therefore, direct energy as well nonrenewable energy (fuel) cost must be low. Human labor has input energy equivalent to 1.96 MJ hour^{-1} (Shahin et al. 2008; Kumar et al. 2013). Conventional wheat sowing practices required more input energy (1.1 GJ ha^{-1}) than direct drilling in soil (0.3 GJ ha^{-1}) and produced 22.4% lesser energy output (Arvidsson 2010). Wheat required lesser total energy input if sown in furrow irrigated raised bed techniques or zero-till drill in soil. The energy requirement for zero-tilled drill sown and on furrow irrigated raised bed wheat were 9–13% lower in IGP belt of India (Kumar et al. 2013).

It is obvious that, the benefit of direct drilling of seeds in soil had lower energy requirement due to negligible/less draft and fuel requirement. Direct drilling of rice seeds in soil is the utmost promising technique in terms of energy saving owing to bypass the energy requirement in nursery culture, puddling operation, and transplanting either with transplanter or human labor. The DSR techniques save about 22% energy input compared to transplanting (Mandal et al. 2015a, b). Use of machineries for rice transplanting significantly uplift the energy requirement by 17% over traditional manual transplanting; even 80% higher nonrenewable energy requirement. System of rice intensification had higher energy requirement than DSR but was able to achieve higher energy use efficiency (10.91) than mechanical transplanting (8.58) of rice (Mandal et al. 2015a, b).

Human labor requirement in rice sowing/transplanting has a significant role in energy requirement (Saharawat et al. 2010). Crop establishment of rice and wheat are different from each other. In general, rice required higher mechanization as well human labor (70–72%) than wheat cultivation in India. Traditional methods of wheat cultivation are energy-intensive practices due to higher draft force requirement in conventional rice–wheat cropping pattern. Newly developed happy seeders for wheat establishment are now gaining importance and provides opportunity of direct seeding of wheat in standing rice stubbles leftover in field. A single operation of seeding and bed preparation by a happy seeder could able to save about 50–70% fuel requirement than conventional methods (Singh et al. 2020b).

7.2.4 Crop Residue Management

India produced a huge quantity of crop residue (500Mt) every year; of which about one-third is being burnt on farm and accused of significant environment quality deterioration (Chen et al. 2019; Zhao et al. 2020; Sarkar et al. 2020). Proper management of crop residue not only improves soil and environment quality but also enhance crop productivity. Conservational agriculture uses crop residue as a surface covering material and minimizes such negative impact on soil. A successful management opens new avenues for nutrient recycling in agroecosystem during decomposition, control erosion and pest, reduce crop water demand, and facilitated lesser or non-dependence on synthetic amendments (Zhao et al. 2020). In situ carbon sequestration in the soil through mulching or incorporation of residue in soil significantly reduced GHG emission through burning. Onsight residue burning is the major problem in Punjab, Haryana, and western U.P. of India in rice–wheat cropping system; about 25Mt of rice–wheat residue burning contributed to 0.05% of total GHG emission of India (Gadde et al. 2009; Sarkar et al. 2020) and emits about 37Mt of CO_2 along with 31,250 billion MJ energy losses.

Crop productive potential and energy use has a direct and positive correlation (Jat et al. 2020). Residue acts as the indirect energy source in crop energy inputs. These enhance soil fertility as it contains about 40% carbon which directly contributed in soil C enhancement. Conservational agriculture-based crop residue management could save about 3000 MJ of energy ha^{-1} (Sangar et al. 2005). It could also defy terminal heat stress in wheat (Kumar et al. 2018; Sharma et al. 2015; Singh et al. 2009; Lohan and Sharma 2012; Jat et al. 2020) which is the major problem in India especially in rice–wheat cropping system (13.5 mha) and able to reduce in situ burning.

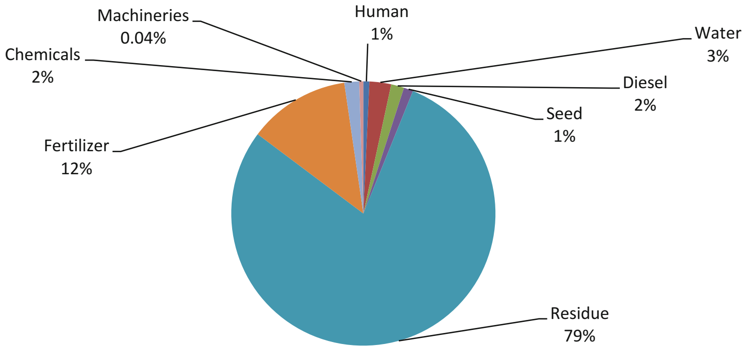

Fig. 7.4 Source wise share of energy input in conservational agriculture (Source: Jat et al. 2020)

Effective residue management may be possible through mulching, incorporation into the soil, composting, and CA-based residue management. The most effective and remunerative method is mulching; incorporation into soil requires heavy use of implements for chopping and mixing in the soil which inversely increases the energy demand (Jat et al. 2020). Crop residue could be also used for biochar, biofuel, and energy production. Crop residue has a potential of about 128 MW per Mt. per year energy production (Chauhan 2011, 2012). On the other hand, CA-based residue management required heavy machineries thus, energy input and output is more however, net energy could be higher (Jat et al. 2020). Crop residues contain about 12.5 MJ t^{-1} energy equivalent (Choudhary et al. 2017; Parihar et al. 2013); quantity of residue used for mulching significantly enhance the energy cost in agriculture (Parihar et al. 2018). It is well-known fact that residue retention or incorporation enhances the input use efficiency of crop and use a reduced quantity of inputs like fertilizers, water, pesticides, etc. Therefore, it indirectly contributes in the reducing total input energy demand of the crop (Parihar et al. 2018; Tomar et al. 2006). Total energy demands pattern of various components differs in CA-and CT-based residue management. In a five-year study, Jat et al. (2020) recorded the highest share of residue (79%) in total energy requirement in CA-based crop production if 80–100% stubbles of crop retained in the field (Fig. 7.4). Energy indices directly depend upon the quantity of residue retained on soil (Choudhary et al. 2017; Saad et al. 2016). CA-based residue management enhanced 23% energy input with only 44% increment in energy productivity over the conventional system because of higher productivity in CT-based residue management (Jat et al. 2020). However, in both systems, residue cover of about 4 t ha^{-1} significantly enhance the energy output but EUE and net energy return recorded higher in no-residue treatment (Choudhary et al. 2017). Mulching enhances energy output by 5–18% over no-mulching on the other hand, residue retention in conservational agriculture significantly lower down (12.7%) the total CO_2 emission as compared to residue incorporation in conventional agriculture (Yadav et al. 2018). Therefore, it is cleared that mulching is a highly important practice and has multiple roles in terms of weed management, soil moisture conservation, and ultimately reduce energy demand if used appropriately with management practices.

7.2.5 Weed Management

Weeds are the common obstacle in crop production resulting in 20–80% yield loss (Deike et al. 2008). Weed management implies different approaches in chemicals, degree of mechanization, machineries, human labor demand, etc. thus affecting the energy input. Effective weed management upshots the crop yield and enhances total energy output (Klingauf and Pallutt 2002; Deike et al. 2006, 2008). Use of herbicides nowadays gaining popularity in Indian agriculture; but the herbicides formation, its transport and formulation process indirectly use energy. Some of the popular herbicides used in Indian agriculture and their energy equivalents as shown in Table 7.3.

Though energy use of different weeds management practices in crop production accounted very low share (2–5%) in total energy demand (Jat et al. 2020; Deike et al. 2008). However, adopting a conservational tillage system facilitates large dependency on herbicide use; thus, may increase its share in total crop energy demand. On the other hand, CA-based tillage may itself curtail total energy input in agriculture by reducing tillage and diesel demand (Clement et al. 1995; Lu and Lu 2017; Singh et al. 2020a). Therefore, herbicidal usage in conservational tillage reduced energy input and enhances output on the whole.

Other weed management approaches like mechanical and manual need more energy. Conventional methods of seedbed preparation for reduction of weed pressure required 15–23% more energy than stale seedbed (Chaudary et al. 2006). Hand weeding is the labor consuming practice in contrast to mechanical methods, thus needs more renewable energy but less nonrenewable energy (Wood et al. 2006; Deike et al. 2008). Mechanical weeding on the other hand required more total energy input (Devi et al. 2018). Similarly, herbicidal use significantly reduced energy

Table 7.3 Energy equivalent of some popular herbicides use in India (Source: Green and McCulloch 1976; Audsley et al. 2009)

Sr. No.	Herbicides	Energy equivalent (MJ kg^{-1}a.i.)	Sr. No.	Herbicides	Energy equivalent (MJ kg^{-1}a.i.)
1.	2–4 D	107	8.	Linuron	310
2.	Atrazine	208	9.	Mesosulfuron-methyl	659
3.	Bromoxynil	302	10.	Metsulfuron-methyl	518
4.	Diquat	420	11.	Pendimethalin	421
5.	Glyphosate	474	12.	Simazine	226
6.	Isoproturon	378	13.	Trifluralin	171
7.	Iodosulfuron-methyl sodium	691	14.	Paraquat	460

demand in agriculture with a higher output/input ratio as reported by Franzluebbers and Francis (1995) and Deike et al. (2008) in maize, sorghum and other crops.

Herbicidal sequence, dose, time, and method of application affect the energy budgeting not only in terms of energy input but also energy output by enhancing herbicidal efficacy and crop yield in a cropping system. Herbicidal use now became an integral part of Indian agriculture due to scarce and costly labor availability. Manual weeding in wheat is energy-intensive practice and demand 4–5% higher input energy. Adopting less labor requiring approaches in weed management has great importance. Herbicidal efficacy improved the energy budgeting of crop production. Continuous use of a single herbicide in a particular cropping system is not so effective whereas mixing and sequential use of different herbicides broaden the spectrum of weed control. Tank mix application of pinoxaden, carfentrazon, and metsulfuron-methyl in wheat resulted in higher EUE, energy profitability and crop productivity in Haryana (Devi et al. 2018). Sequential application of pendimethalin followed by pyrithiobac-sodium in cotton required 4–8% less input energy than pendimethalin *fb* glyphosate directed spray and Pyrithiobac-sodium + quizalofop -p-ethyl *fb* directed spray of glyphosate (Rani et al. 2016). Application of adjuvant in herbicides enhance its efficacy and reduce the dose required; lower dose of the verdict (0.3 kg ai ha^{-1}) with bio-agent significantly enhanced the energy output and EUE in wheat (Zargar et al. 2016). Weed management strategies differ in energy use and its efficiency. Methods that suit best for effective weeds control with a higher yield of crops and cropping system significantly enhance the energy use efficiency. However, energy input of different herbicide did not vary much to the total energy input in crop, than methods and approaches of weed management. Continuous use of herbicide is not good for ecosystem health at all. Therefore, integrated use of herbicides with cultural, mechanical, and manual practices needs to be adopted for energy use also.

7.2.6 Energy Efficient Irrigation Techniques

India ranked highest among other countries on freshwater consumption; 80–90% of which are used for irrigation purposes in crops (Hoekstra and Chapagain 2007; Green et al. 2018; FAO 2016). About 160 Mha agricultural lands in India are covered by groundwater irrigation and 22 million by canals (Dhawan 2017). Irrigation has a direct role in energy demand. Largest proportion in-ground irrigation systems required huge energy quenching for pumping/extracting, distribution, and application. Current irrigation practices are consuming enormous water and their WUE are low (30–40%). For increase water use efficiency, scientific and modern techniques like micro-irrigation and crop management techniques also impose additional energy demand (Pinmental et al. 2004; Khan and Hanjra 2009). Seeking the present scenario, irrigation, and energy efficiency together needs to be improved through (1) efficient pumping techniques and (2) smart water use at the farm level.

7.2.6.1 Energy Efficient Pumping

India extracts about 230 billion m^3 of water every year for different purposes through pumping (Shah 2009) that impose direct energy demand in the form of fuel and electricity. The number of electric operated pumps in India is more than diesel operated therefore about 70% of groundwater extraction system uses the electricity (Mishra et al. 2018). Over an estimation pumping of 1000 cubic meter water from one-meter depth emitted 4–13 kg CO_2 (Karimi et al. 2012; Patle et al. 2016a, b) therefore groundwater extraction costs 222.38 billion m^3 CO_2 every year that contributed to global GHG emission (Mishra et al. 2018). It is therefore urgent need to adopt alternative strategies including use of nonrenewable energy sources like wind and solar energy as well as efficient pumping and water distribution techniques.

Energy requirement for irrigation and CO_2 emission together could be reduced by adopting renewable energy sources. India has a wide potential of solar energy of about five thousand trillion units annually (Muneer et al. 2005; Mukherjee and Sengupta 2020). Replacing diesel and electricity-based pumps with solar based could save huge nonrenewable energy. Though irrigation hours are limited (6–10 h in day time only) for solar-based pumping thus scheduling in the proper way matters (Picazo et al. 2018). However, the use of batteries in automated irrigation system suits best and reducing the nonrenewable energy uses.

Most of the Indian farmers on the one hand using nonstandardized, under and oversized electric pumps while on the other hand subsidized electricity to agriculture is provided by the government under its policies (BEE 2009). This resulted in overuse of electricity and other nonrenewable resources. Pump sets in India consuming about 25% of total electricity (Singh 2009). Energy efficiency could also be improved by avoiding under and oversized, inefficient local pumps (Tyagi and Joshi 2019). Use of efficient pumps and their timely maintenance could be able to save 30% (27.9 BU) electricity annually (NPC 2009). For the sake of this, several efforts have been made by the Government in times to provide financial assistance for replacing local pumps with BEE labeled pumps (BEE 2009). Further government is planning to reduce the energy consumption by 46 billion KWh power annually in the next few years by facilitating assistance to farmers for adopting energy efficient pump sets (WISE 2017). Proper maintenance of pump sets and pumping efficiency could save 40% energy use based on the current scenario (Tyagi and Joshi 2019).

After the ground irrigation, canals also contributed a major proportion of net irrigated area (23%) in India. Unlined canals and poor infrastructures at the farm level resulted in poor (38%) irrigation efficiency. Lining of canals, their maintenance, reducing water loss at farm gates and are able to reduce water loss (22.5%) thereby reducing energy use in agriculture (Arshad et al. 2009).

7.2.6.2 Smart Water Use Techniques

Surface irrigation method through flooding required a large amount of water. Water flows freely under the force of gravity and therefore gravity-fed irrigation system has negligible energy demand. However, over and uneven irrigation in flood and furrow methods reduces WUE. Drip and sprinkler method could replace gravity-fed irrigation and offer a significant reduction in water use (Playan and Mateos 2006; Zehnder et al. 2003). These highly pressurized irrigation systems consume much direct and nonrenewable energy; about 23–48% of the total energy of crop production used in pumping and operating the above said irrigation system (Singh et al. 2002; Khatri et al. 2013). Energy demand in the pressurized system depends upon the amount of water used by crop, depth of water table, flow rate, and efficiency (Lal 2004). Use of electricity and diesel as energy source directly contributed in carbon and ecological footprints. Pressurized irrigation systems produced 1.75 times more GHG (Patle et al. 2016a, b). For achieving better WUE along with lesser environmental impact, a smart balance between water use and energy consumption is needed.

Surface irrigation method is mostly practiced by the Indian farmers through pumping groundwater. In this method of irrigation water demand is high ultimately requires more time for pumping. Adopting laser land leveling and zero tillage in spite of conventional practices where gravity-fed irrigation systems are prominent, resulting in enhancing irrigation efficiency (70%) and reducing energy use by 15–20% (Naresh et al. 2016; Tyagi and Joshi 2017). Seeking future water demand and scarcity, shifting from pressurized free flow to micro-irrigation including sprinkler provides opportunity for efficient energy use. Micro-irrigation is able to save about 30% energy than traditional method due to overall reduction in water use (Tyagi and Joshi 2019). In spite of better WUE (70–75%), sprinkler system functioned under a high-pressure range of 98–294 kPa (Singh et al. 2009) and requires more energy for maintenance of pressure. This demand could be reduced by adopting low energy water application devices (LEWA). LEWA required lesser operating pressure (39–98 kPa) and facilitates a direct energy saving over pressured irrigation systems (Singh et al. 2010). Irrigation scheduling in rice under pressurized irrigation (sprinkler and LEWA) at two days intervals resulted in saving of 20–30% water use over surface method of irrigation. These twin systems required more nonrenewable energy but LEWA found 5% more efficient than sprinkler (Singh et al. 2016). The LEWA resulted in more energy productivity (1.64) followed by sprinkler (1.17) over surface (1.06) irrigation (Singh et al. 2018a). This difference is attributed to lesser fuel/electricity demand, amount of water used, and operating pressure. The amount of water use in crops also affects nutrient and energy use. Water guzzling crops required more water and nutrients thereby more energy`. This holds true in case of rice, sugarcane, and root crops. Water requirement of rice is more; intermittent and alternate wetting and drying in rice is a good practice in improving WUE and EUE (Tyson et al. 2012). Direct sowing and CA-based rice cultivation significantly reduced water, nutrients and energy demand (Jat et al. 2014). Similarly, sugar beet required more irrigation than bean and winter wheat therefore required 60 to 164% higher direct energy (Topak et al. 2005). Clearly, the efficient irrigation methods, irrigation scheduling, and the use of smart irrigation techniques not only reduces the energy demand but also reduces water wastage and increases nutrient use efficiency in crops.

7.2.7 Nutrient Management

The substantial growth in food production is achieved due to heavy use of fertilizers after the green revolution and ultimately leads to food security. Indian agriculture is consuming 265.91 LMT of fertilizers for the production of 2848.3 LMT foodgrains (GOI 2019). Scenario of fertilizers consumption is likely to increase which will require a huge amount of energy in its production process. It has been estimated that about 9.63–10.77 MTOE of energy will be required to meet increasing fertilizers demand by 2030 (BEE 2018). A large share in energy input is constituted by inorganic fertilizers in crop production (Nabavi-Pelesaraei et al. 2014; Singh and Benbi 2020). Therefore, achieving high fertilizers use efficiency with minimized energy consumption in crop production is the major challenge to be fulfilled now. Application of fertilizers in the right quantity at right time and advanced technologies could be helpful in improving resource use efficiency.

7.2.7.1 Amount of Fertilizer Use

Energy consumption in a cropping system varied with fertilizers use. It has a direct relationship; higher the fertilizer uses higher the input energy required. Nutrient management contributed 24–54% of total energy used in a cropping system (Amenumey and Capel 2013; Yadav et al. 2017; Singh et al. 2020c; Singh et al. 2019b). Crops require a huge quantity of N rates. Root crops generally need more input energy due to heavy fertilizers demand (Hulsbergen et al. 2002). Similarly, cotton required 7.3 and 14.2% less amount of fertilizers than maize and rice thereby reducing energy demand of about 6.9 and 12% along with more energy output/input ratio in Punjab (Singh and Benbi 2020). Most of the cereals and oilseeds demanded the huge amount of nitrogenous fertilizers. Indirect energy evaluation of different fertilizers indicated that urea formation is the high energy-requiring process. Higher nitrogen requirement of crops along with its higher energy equivalent (60.6 MJ kg^{-1} N) force to achieve better nitrogen and energy use efficiency at farm level (Esengun et al. 2007; Singh et al. 2019b).

Lower nutrient use efficiency is one of the reasons for higher fertilizer and energy use in Indian agriculture (Wassmann et al. 2009; Singh et al. 2020c). Balanced application of primary nutrients (NPK) in rice significantly raise the agronomical and physiological N use efficiency by 39.8% and 22.3% respectively, thereby higher net energy (6.03%) and energy productivity (8.0%) with 7.5% lesser GHG intensity (Singh et al. 2020c) over N application alone.

Rice seedlings in nurseries put additional fertilizers demand and energy. Direct seeding of rice required lesser N fertilizer (6–10%) application rate along with better use efficiency than conventional transplanting and was found efficient in terms of input energy (Mandal et al. 2015a, b). Fertilizers demand could be supplemented by FYM use. Reducing the N fertilizer dependency by 25% replacement through FYM in rice significantly enhance the energy output (87.6%) and productivity (102.5%) of yellow mustard grown in rice–mustard cropping sequence (Mallikarjun and Maity 2017). Higher energy productivity in sequential cropping is mainly attributed to lessen fertilizer demand by successive crops which is fulfilled by mineralized nitrogen. While, in situ residue covering resulted in higher fertilizer claim in main crops especially N. It is reported that soil surface covering in zero-tilled wheat put ~5% higher energy demand due to more nitrogen application rate needed by microbes during decomposition process (Singh et al. 2020c). Hulsbergen et al. (2002) advocated demand of much higher N fertilizer rates for better energy output than the amount required for maximum energy ratio and minimize intensity. Higher fertilization sustains the crop yield and food security of livelihood. It is almost impossible to minimize energy intensity in crop demand but a harmonious combination must be achieved.

7.2.7.2 Nutrient Source

Continuous intensifying GHG and energy needs due to fertilizers consumption along with the deterioration of soil health puzzled the agricultural researchers, farmers, and policymakers (Smith et al. 2004; Hoeppner et al. 2006; Rautaray et al. 2020). Rebuilding soil, water, and environmental health in agroecology is an opportunistic approach nowadays. Organic manure, green manuring, integrated nutrient management, use of bio-agents for nutrient fixation and remobilization curtailing fertilizers demand in several ways (Robertson 2015). Achieving nutrient use efficiency at farmer's field could save 32–38% total energy saving through various practices (Chauhan et al. 2006; Nabavi-Pelesaraei et al. 2014).

The INM helped in reducing energy input (24%) and improving energy efficiency (35%) over inorganic fertilizers (Rautaray et al. 2020). Integrated use of nitrogen in crop production not only enhance its use efficiency but also advocated to improve productivity, ecosystem health, and energy use efficiency. Farmyard manure is the easily available option to farmers for INM in India without much scientific knowledge but the high quantity is needed to replace the nutrient demand owing to less nutrient content (Dhar et al. 2017; Rautaray et al. 2020). Besides high C:N ratio, energy requirement for FYM application at the farm level in paddy is 60–65% of total crop energy demand (Ramchandra and Nagarathna 2001). Green manures in that condition may be feasible; it is reported that green manure had an annual potential of 14–15% primary nutrients saving (Rautaray et al. 2020). Use of sesbania green manure reduced 23.5% energy use in paddy over inorganic nutrient management. It substantially added 54 kg NPK ha^{-1} with only 317.5 MJ ha^{-1} energy use grown by using 20 kg seed ha^{-1} in situ before paddy cultivation (Rautaray et al. 2020). Additional application of FYM (10 t ha^{-1}) with inorganic fertilizers obviously enhanced the energy input as reported by Mandal et al. (2009) but 22.4% higher energy output and 20.8% net energy over NPK alone in soybean cultivation at Bhopal, India.

Energy efficacy could be realized by lessening the dependency on fertilizers nutrient through the use of organic manure and inclusion of legumes in a system (Metzidakis et al. 2008; Nabavi-Pelesaraei et al. 2014). Legume-based cropping system required relatively lesser nitrogen demand and hence energy use. Similarly, Yadav et al. (2017) reported least fertilizer energy demand (10,451 MJ ha^{-1}) in rice–legume cropping system than rice–toria and rice–maize cropping in rainfed area of India with better resource use efficiency.

7.2.7.3 Time of Fertilizer Application

Fertilizer manufacturing is energy-guzzling process. A unit quantity of nutrients production, packaging, and transportation consume direct and nonrenewable energy sources. Energy equivalent for fertilizers nutrients is 60.6, 11.1, 6.7, and 20.9 MJ kg^{-1} of N, P_2O_5, K_2O, $ZnSO_4$, respectively (Mobtaker et al. 2012; Unakitan et al. 2010; Pahlavan et al. 2011; Nabavi-Pelesaraei et al. 2014; Mandal et al. 2015a, b). Time of fertilizers application imposed negligible/low impact on energy input but affects its utilization during the crop production process (EUE). Higher nutrient use efficiency and crop yield likely to enhance the energy output and use efficiency (Yadav et al. 2017; Wassmann et al. 2009; Mandal et al. 2015a, b; Singh et al. 2020c). Synchronizing nutrient application especially N with crop demand, growth stage is key for improving N use efficiency (Giller et al. 2004; Singh et al. 2018b). It reduces fertilizer demand by eliminating nutrient loss from crop ecosystem (Pampolino et al. 2012). As indicated in earlier sections that diminishing nutrients demand through applying fertilizers at the right time of crop reduce the energy input and upshot output. Application of N fertilizers in more splits synchronizes its supply with crop demand. Phosphorus, potassium, and zinc at basal application are more helpful in improving crop yield vis-à-vis nutrient use efficiency. However, much research needs to be conducted to know the best time of nutrient application and its energy use pattern for achieving energy self-sufficiency.

7.2.7.4 New Approaches

It is reported that crops effectively utilizing only 17% of total N applied; rest costs the environmental problems (Erisman et al. 2008; Jat et al. 2012). This low NUE demanded more energy consumption with lesser EUE in agriculture (Shaviv 2005; Jat et al. 2012). Only 30–45% of recovery efficiency in major crops like rice, wheat, and maize was reported (Ladha et al. 2005). Therefore, researchers focused on many approaches like site-specific nutrient management, coated urea, leaf color chart (LCC), remote sensing and geographical, nano-fertilizers, slow-released, and coated fertilizers, etc. to improve NUE and declining its loss in the environment.

Inherent nutrient supply of soil never remains the same across the field. This large variability could be managed by applying nutrients as per soil testing and crop response calculations. This reduces the nutrient application rate and enhances its use efficiency. Various researchers reported 20–30% saving of nutrients following site-specific nutrient management approach with a higher nutrient recovery by crop (Gill et al. 2009; Khurana et al. 2008; Hach and Tan 2007; Jat et al. 2012). Leaf color guided nitrogen application through LCC or SPAD meter are able to save 12.5–25% fertilizer N over blanket recommendation (Bijay-Singh et al. 2002). Normalized Difference Vegetative Index (NDVI)-based N management is the most efficient approach for enhancing NUE (Gill et al. 2008; Gupta 2006). Controlled released and coated fertilizers reduced crop N requirement by 20–40% with higher NUE (Balkcom et al. 2003; Zvomuya et al. 2003). All these approaches are able to enhance NUE vis-à-vis reduced fertilizer application rate. Enhancing NUE is the most feasible way to reduce crop energy demand. Relationship of NUE with energy use pattern of major crops of India is shown in Fig. 7.5. It is advocated that

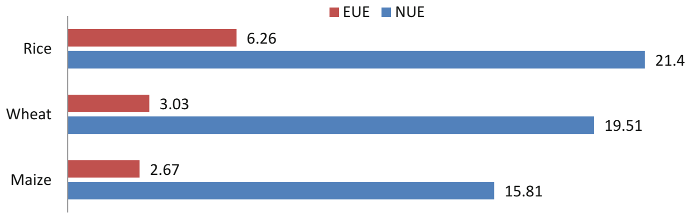

Fig. 7.5 Relationship of agronomic NUE of crops vis-à-vis Energy input and EUE (Source: Yousefi et al. 2015; Singh and Benbi 2020; Yadav et al. 2017)

enhancement of NUE resulted in better input energy utilization with greater EUE. Similarly, Yousefi et al. (2015) found a positive correlation with NUE and energy use efficiency. Though only few reports are available indicating energy use pattern of advanced nutrients management technology therefore, some researches are going on to curtail the energy demand in agriculture through efficient management technologies and its further demand in harvesting and postharvesting techniques.

7.2.8 Harvesting Techniques

Harvesting is the labor, cost, energy-consuming practice shared about 20–25% labor and total cost incurred in agriculture (Sahoo and Rehman 2020). Our agricultural system facing a huge shortage of labor and same time abnormal weather conditions like frequent rain and cyclones during harvesting, drying and threshing causes greater loss. Losses due to weather as well during manual harvesting operations along with high labor demand collectively responsible for inefficient energy use and efficiency in agricultural system. Canakci et al. (2005) reported high (9–22%) energy consumption in manual harvesting of maize, wheat and sesame due to high labor requirements. Mechanical harvesting and combining harvesting, threshing, and winnowing could reduce labor demand but at the same time increases energy use in agriculture. However, no doubt pressure of utilizing nonrenewable energy sources in agricultural system will enhance significantly the environmental costs due to CO_2 emissions. Therefore, renewable energy-based harvester and combiner needs to be developed.

Mechanization in agriculture solved many problems in agriculture but at the same time the Indian agriculture is currently facing challenges of nonrenewable energy crisis. Promotion of renewable energy use in agriculture needs to implement and is a need of time. Common machined-based harvesting operations consume a large amount of nonrenewable energy. Kiran et al. (2017) and Sahoo and Rehman (2020) advocated the use of electric-and battery-operated reaper with 35–60 cm cutting width in rice instead of diesel-based harvester. Average energy consumption of diesel-based combine harvester is 4500–6000 MJ ha^{-1} (Chaichan et al. 2014) which is much higher than labor-based (700–1100 MJ ha^{-1}) manual harvesting, threshing, and winnowing using more proportion of non-renewable energy (Yadav et al. 2017; Canakci et al. 2005). However, semi-automated solar-based mini paddy harvester is more efficient than conventional diesel based that completely relied on the renewable energy sources (Pathak et al. 2017). Therefore, seeking labor shortage in commercial farming, solar-based power reaper needs to be adopted which reduces dependency on non-renewable energy sources. This is also feasible for small and marginal farm land-holding farmers.

7.2.9 Postharvest Management

Postharvest management and value addition of crops beyond farm gate is an important agricultural practice. Globally, food production and supply chain consume about the world's 30% of total energy. Out of which, about 70% energy is consumed in postharvest processing, transportation, and value addition (FAO 2011; Vourdoubas and Dubois 2016). Postharvest losses of food have sizable proportion (30–35%) which imposed a great threat to most of food production, value addition and nonrenewable energy utilization. As far as pulses are concerned, postharvest losses are to the tune of 25–50% (Birewar 1984; Jeswani and Baldev 1990; Pratap et al. 2016); and most of losses are during value addition (15–20% in milling) and improper storage (5–10%). Though postharvest value addition itself is the big concern in energy use and management.

The foremost postharvest operation after threshing is the drying of grains to obtain proper moisture content. Rice, generally, harvested and threshed at 20–25% moisture but it needs 12–14% grain moisture content for safe storage (Van-Hung et al. 2016; Gummert et al. 2020). An average traditional dryer consumes about 4–6 MJ of energy for kg^{-1} grain; sun drying is the least nonrenewable energy-consuming practice but need more space, time, and human labor (Jittanit et al. 2010; Sims et al. 2015). In rice processing and milling, parboiling process requires huge amount of thermal energy whereas the traditional parboiling process needs 240 to 1600 MJ t^{-1} thermal energy (Ahiduzzaman and Islam 2009). Modern rice milling processes are less energy consuming but need nonrenewable energy (105 MJ t^{-1}) in the form of electricity (Ahiduzzaman and Islam 2009). Out of total electricity consumed in rice milling in India (Fig. 7.6); 82% shared by drying and milling process and 4% by parboiling (Sims et al. 2015).

Energy quenching in postharvest processing and management is a diverse challenging situation. High energy requirement owing to improved and modernized processing and milling processes over farmers practice; but energy output may be higher. Gummert et al. (2020) reported more energy output (34.44 GJ ha^{-1}) and input (16.88 GJ ha^{-1}) in improved postharvest processing and milling using a combine harvester, flatbed dryer, and hermetic storage (IPR) over farmer's practice. However, energy use efficiency is reported higher (2.04) in IPR owing to lesser harvesting loss (3–7%) due to grain loss in shattering, grain damage and labor demand over farmer's practice (1.95). Efficient processing techniques save 30–35% losses during value addition and are able to upshot efficient energy utilization in food-supply chain.

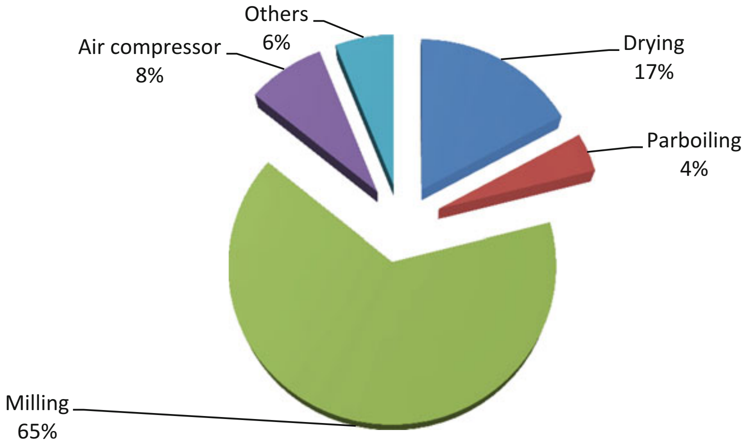

Fig. 7.6 Proportion of electricity used in various practices of rice milling in India (Source: REEEP 2010; Sims et al. 2015)

7.3 Protected Cultivation and Energy Use Pattern

Protected cultivation in India covers about 1.5 lakh ha of area, out of which 20% comes under greenhouses (NHB 2017). Protected cultivation alters micro-climate of crops partial/fully that facilitate and accelerate the crop productivity. Alteration in microclimate consumes 2.5 times higher input energy compared to open field (Pandey et al. 2020). Energy utilization pattern in greenhouses differ. Most of the input energy in greenhouse is required for crop protection measures (28.9–55.7%), while in open field more energy is consumed in tillage and soil management.

Electricity is the main source of direct energy supply for maintaining temperature, humidity, and irrigation. Share of electricity in some greenhouses may be higher due to heavy use in heating and drip irrigation systems (Kuswardhani et al. 2013). However, fertilizers energy input is more or less equal in both the conditions (Hedau et al. 2013); plant stacking, training, and pruning consumed the bulk of energy (16.3–21.9%) in greenhouses. According to Djevic and Dimitrijevic (2009) fertilizer is the third-largest energy input practice, after energy consumption for heating and that embodied in boxes. In general, fertilizers shared 21–27% energy input source for tomato, chili, and lettuce production in greenhouses (Kuswardhani et al. 2013) and uses more direct energy. Ozkan et al. (2007) reported 60% share of direct energy in greenhouse grape production in Turkey with lesser nonrenewable energy (81.30%) in greenhouse than open field (93.16%). Greenhouses use electricity as direct energy sources for maintenance of temperature to some extent, humidity and light depending upon its type, crop, and management. Under certain climatic condition and cropping pattern electricity used for heating or cooling contributed about 60–80% of total energy consumption (Gruda et al. 2009; Gruda and Tanny

Table 7.4 Potential energy conservation techniques in green/poly houses (Source: Gruda and Tanny 2014)

S. no.	Type of saving	Saving potential (%)
1.	Thermal screen	20–40
2.	Sealing of vents and windows	10–20
3.	Heating system	10–18
4.	Optimization of boiler	10–15
5.	Climate control	10–20
6.	Better use of cultivation area/crop planning	10
7.	Special insulation and glazing	7–10
8.	Sensors	5–10
9.	Irrigation	5–10
10.	CO_2-fertilization	5

2014). Greenhouse development and installation itself consumes huge energy; about 400–500 MJ m^{-2} ground area energy embodied for typical greenhouse construction (Canakci and Akinci 2006). This puts additional burden on energy demand.

Pandey et al. (2020) reported 64% higher output/input energy ratio and energy productivity (62.5%) in poly-house cucumber production over open land. Similarly, Kuswardhani et al. (2013) reported energy ratio of 0.85, 0.45, and 0.49 in greenhouse production which is much higher than open field vegetable production (0.52, 0.17, and 0.18) for tomato, medium land chili, and highland chili, respectively. Crop cultivation in greenhouses, plastic mulches, poly houses, tunnels efficiently utilize solar energy. Broadly speaking, solar energy is the main source (65%) in terms of benefits for greenhouses. Besides its high energy consumption, EUE in greenhouse is always high. Elings et al. (2005) further suggested some important measure for improved total energy utilization and efficiency in greenhouse production. Increased insulation had potential of 23% energy saving while lowering temperature set point had 16% saving potential. Some practices like elevated relative humidity, screen gap control, and temperature integration had saving potential of about 5%. Some other practices are able to reduce energy consumption in green/poly houses that are listed in Table 7.4.

7.4 Alternative Land Use Management

About one fourth (205 million acres) of India's geographical area is under community forest, pastures, and water bodies. These serve as vital ecological functions, global energy balance and, contribute to carbon sequestration, biodiversity conservation, hydrological supplies and have social, cultural significance to rural communities. They further engage the critical livelihood requirements of more than 350 million of India's rural population (Dhyani et al. 2013). Alternate land-use systems, technologies and agroforestry include planting woody perennials (trees, shrubs, palms, bamboos, etc.) on the same land-management units with agricultural crops and/or animals, in any sort of spatial or temporal sequence. In agroforestry systems, both ecological and economical interactions between the different components prevailed (Kavargiris et al. 2009). Nutrient cycling is much more efficient in agroforestry than any other agricultural systems due to presence of woody perennials. It includes endless alteration of nutrients within different components of the ecosystem and involves processes, such as weathering of minerals, activities of soil microfauna and flora. The conversions occurring in the biosphere, atmosphere, lithosphere, and hydrosphere also include in nutrient cycling (Michos et al. 2017, 2018). In agroforestry, more nutrients in the system are reused by plants (compared to agricultural systems) before being lost from the system. The two significant differences between agroforestry and other land-use systems are (a) the transfer or turnover of nutrients within the system from one component to the other; (b) the feasibility of maintaining the system or its components to promote increased rates of turnover without influencing the overall productivity of the system. The input demand in agroforestry is less with better efficiency; therefore, consumption of nonrenewable energy and greenhouse gas emissions are also lower (Platis et al. 2019).

Higher productivity along with lesser nutrient demand due to efficient cycling and integrated biological cycles made agroforestry less energy consuming practice. Lin et al. (2013) reported the better energy balance of agricultural subsystem, forestry subsystem, and agroforestry system as shown in Table 7.5. Forestry subsystem and agroforestry system had higher EUE (23.0 and 12.8, respectively) than some of the other agricultural subsystem viz. potato and wheat. The lower EUE of agroforestry system might be due to lesser yield in comparison to forestry system. Jianbo (2006) reported 9.45% higher EUE of Paulownia-based wheat–peanut intercropping than traditional non-agro-forestry cropping system (wheat–peanut). Similarly, Pragya

Table 7.5 Energy balance of agricultural subsystem, forestry subsystem, and agroforestry system (Source: Lin et al. 2013)

	Input energy (GJ ha^{-1})			Yield (Mg-DM ha^{-1})	Energy output (GJ ha^{-1})	EUE
	Direct	Indirect	Total			
1. Agricultural subsystem						
Potato	5.0	5.2	10.2	6.0	104.0	10.2
Wheat	3.3	1.4	4.7	2.5	46.0	9.7
Sunflower	3.7	1.7	5.4	2.6	70.0	13.0
Crop rotation	3.0	1.8	4.8	2.5	47.9	10.0
2. Forestry subsystem						
Forestry	2.5	2.4	4.9	5.4	111.3	23.0
Poplar				6.4	128.7	
Willow				4.0	75.4	
Alder				4.7	88.7	
Black locust				6.6	152.6	
3. Agroforestry	2.9	1.9	4.8	4.8	61.6	12.8

et al. (2017) advocated better net energy ratio of agroforestry-based biofuels system (4.2–6.44) over soybean-and corn-based cropping system (0.88–1.35).

Agroforestry system could minimize nonrenewable energy inputs in agricultural production and reduce GHG emission (like CO_2, CH_4, N_2O, etc.). On the other hand, it also increases EUE of crop production along with vegetative carbon and soil organic carbon stocks of the soil. Renowned scientist and research analyst during conference of parties (COP21), i.e., Paris agreement suggested agroforestry as a measure in adapting the ill consequences of climate change and reducing GHG (Baah-Acheamfour et al. 2017). Agro-forestry ecosystems, such as intercropping with best management practices, could enhance both EUE of the production system and the added-value of the agricultural products.

7.5 Efficient Livestock Production and Management

Global chain of livestock production and management provides services to 1.3 billion people and contributed 40% of the value of agricultural output (FAO 2009; Rota 2012). India has about 512 million livestock; mainly buffalo (37%), goats (26%), and Cattle (21%). Livestock is the integral part of agriculture which acts as both source and sinks for the energy. Mostly dairy animals, buffalos, cows, and crossbreeds of cattle are integrated with agriculture and are gaining popularity. Livestock consumes energy in terms of green fodder, feed, and concentrates. Daily energy requirement of cattle is 17–33 GJ per unit; but the crossbreeds require highest among other breeds (Saini et al. 1998). Energy intake for feed depends upon the daily feed intake and body size; buffalo has more bodyweight therefore required more energy. However, some crossbreeds of cows like Jersey, Holstein Friesians, etc. also required similar energy intake.

Despite higher energy demand of crossbreeds of cow and buffalo, energy output of buffalo, in general, is higher than cross-breeds of cow. Indian local cow (*desi*) yielded very less milk owing to low-energy output (12 GJ day^{-1} unit^{-1}). Energy output of buffalo and crossbreeds of cow ranged 45 to 50 GJ day^{-1}. Howbeit energy use efficiency is more in the case of crossbreed cow due to higher milk yield with lesser feed requirement. Manures of cattle and buffalo serve as energy for humans and crops-nutrient sources in rural India. Livestock production and their waste have great potential for renewable energy sources. Crop waste is mainly straw used for feeding material for livestock and manures used as nutrient sources for crop; a synergism in crop-livestock system prevails. Integrated farming system model comprising crop with mushroom, poultry and goat rearing consumes about 2.98 GJ and 24.53 GJ direct and indirect energy, respectively for one acre land in Bihar; highest proportion used by goatry (Kumar et al. 2019). Integration of livestock with agriculture enhances the energy use in agricultural system. Woods et al. (2010) reported more energy use efficiency (0.11–0.5) in integrated cultivation with crop over isolated rearing of poultry and animal husbandry (0.7–1.7). Therefore, integrated farming system were found more efficient in terms of energy productivity and utilization.

Livestock waste in general is used as energy source by combusting in India; dried cow-dung cake has a calorific value of 14 MJ kg^{-1} (Kaur et al. 2017). About 60 million tons cow-dung used as a direct energy source in India. Direct combusting of cow-dung produces a huge amount of CO_2 and is a concern for major environmental issues. Cow-dung has much potential for biogas production—a direct energy source. Biogas contains 60–70% methane which could be used for direct combusting in kitchen or electricity production (Chasnyk et al. 2015; Sun et al. 2015). Biogas contains 16–25 MJ m^{-3} energy equivalents and could produce 5–7 kWh m^{-3} electricity (Kaur et al. 2017). Indian cattle waste had a potential of 263,702 million m^3 of biogas generation along with 477 TWh of electrical energy. The increasing demand for both direct and indirect energy in different sectors of agricultural systems need to be managed through the efficient use of these energy sources at the farm level. In this context, various policies or strategies need to be enacted by lawmakers and stakeholders in contribution with various institutional supports for the sake of the environment, human welfare, and ecological safety. Some of the laws and policies are already undertaken by the government of India to split the energy demand in each demanding sectors.

7.6 Policy and Institutional Support

Agricultural production demands about 203 BU approximately 18% of total available energy in India (BEE 2019). The foregoing data about demands of energy consumption globally as well as in India showed marked effects of rapid growth in energy demand and carbon footprints. Continuous power supply results in carbon emissions and is not cost-efficient. On the other hand, rely on renewable energy for pumping and irrigation can make the situation better and ultimately reduce GHG emissions and are cost-effective for large-and small-scale farmers. Electrification without decarbonization is the main slogan in developed and developing countries. But to decarbonize the power sector in agriculture, each country should utterly develop awareness on efficient strategies and sustainable approaches that offset the growth of carbon footprints. Some important approaches have been undertaken by the government of India to ensure reduced augmentation in CO_2 emissions and to split the energy demand of each sector in a sustainable manner are as follows;

- Shift toward the use of renewable energies in an efficient way.
- Formation of innovative policy measures in coordination with private institutions already working in that path.
- To increase the access of energy technologies and practices.
- Policies for energy-smart food production.
- Increase in output per unit of energy use.
- Technological change in energy efficient farm machinery and irrigation system.
- Reduction in petroleum as well as fertilizer consumptions.

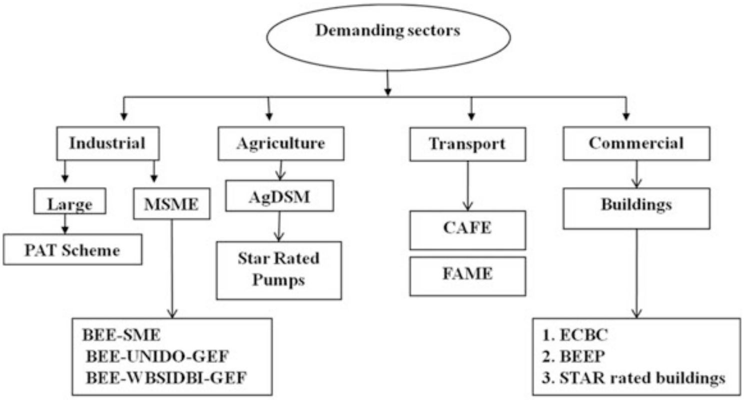

Fig. 7.7 Energy efficiency schemes in demanding sectors

Broadly speaking, each service sector indirectly contributes a fine share in energy consumption for agriculture sector. So, importance was given by the government of India to agriculture sector and several steps were taken to combat the energy consumption in a sustainable manner. The approach to promote technologies, institutions, and policy measures for alternative renewable sources of energy is a win–win approach for small-and largescale farmers. To monitor, review progress, and enforcing the implementation of energy policies availability of good quality and timely energy data are important.

Bureau of Energy Efficiency (BEE) initiated many national, state, and sector levels energy efficiency programs in coordination with several agencies and institutions that ultimately results in crosscutting the trend of India's energy consumption of the economy. The Fig. 7.7 represents prominent schemes in different demanding sectors (BPSRWE 2019). The estimated overall energy savings of about 23.728 MTOE in the year 2018–2019 was observed with the adoption of the aforesaid energy efficiency schemes. The PAT scheme saves 7.064 BU of electricity energy and together with other energy savings resulted in 25.529 Mt. CO_2 emission reductions. The agriculture sector (including Star Rated pumps) accounts for 7.051 BU of electrical savings. The overall total energy saving in this sector was 0.61 MTOE that also results in 5.78 Tone of CO_2 year^{-1} reduction emissions. Whereas, Corporate Average Fuel Economy (CAFE) and FAME schemes accounts for 0.848 and 0.038 MTOE of total energy savings with reduced emissions to the account of 2.650 and 0.070 Mt. CO_2 in 2018–19 (BPSRWE 2019). As far as the commercial sector is concerned which also includes farm infrastructure and buildings STAR-rated buildings and other Green Building Programme accounts for total savings of 0.007 and 0.006 MTOE and reduction in emissions to the tune of 0.068 and 0.057 Mt. CO_2 respectively. in the year 2018–2019.

Since, we are discussing agriculture sector as our major concern we will continue with the major policies undertaken under this sector. Agriculture to industrial sectors encompasses growth in power demand. Two approaches in these sectors mainly focus on first, gradual shift toward Renewable Energy (RE) and second, integration into the grid and systems approach on engendering Energy Efficiency (EE) practices. The amended Energy Conservation Act in 2010 directed its policies to focus specifically on energy efficiency programs and schemes like by setting of BEE and National Mission for Enhanced Energy Efficiency (NMEEE). Besides BEE doing commendable jobs in energy efficiency, initiatives were also proposed to other organizations, such as EESL, SIDBI, PCRA, SDAs, etc. EESL stakeholders take initiatives on SLNP, UJALA, BEEP, AgDSM, National EV Mission schemes, SIDBI worked on BEE-WB-GEF, PRSF schemes, PCRA organization is involved in Fuel Efficiency Programme, whereas TERI involved in GRIHA Rating System and so on.

7.6.1 National Action Plan on Climate Change (NAPCC)

The plan was enacted in 2008 and released by the government of India, and the main objectives of the plan were to combat energy consumption and related carbon emissions. National Mission on Enhanced Energy Efficiency (NMEEE) was one of the parts of NAPCC having four initiatives

- Perform Achieve and Trade (PAT),
- Market Transformation for Energy Efficiency (MTEE),
- Energy Efficiency Financing Platform (EEFP).
- Framework for Energy Efficient Economic Development (FEEED).

Among these, PAT is related to energy demand reduction of fertilizer sector also (BEE 2018). This is the one of the important program for large-scale industries mainly targeted to reduce their Specific Energy Consumption (SEC) over a period of 3 years. The fertilizer industries that maintain their Specific Energy Consumption would be issued Energy Saving Certificates (ESCerts) and those industries who could not achieve the target have to either pay penalties or have to buy ESCerts. The energy savings under fertilizer production was to the tune of 0.78 MTOE with reduction in CO_2 Emissions by 0.93 Mt. CO_2 $year^{-1}$. So far, the fuel-saving in fertilizer production is concerned about 2.0% of electricity saving and 90.0% of gas-saving was observed. PAT Cycle-I started in 2012 to 2015 whereas PAT Cycle-II started in 2016 to 2019. These cycles were formed to identify “Designated Consumers” (DCs) in cycle-1 and to identify new DCs in existing sectors in cycle-2.

7.6.2 Energy Saving Through Micro-Irrigation

The government of India undertaken to formulate a task force on micro-irrigation in 2004 to enhance saving of water use along energy through adoption of micro-irrigation. National mission on micro-irrigation (NMMI) is successful in 30% saving of direct energy consumption by covering >7Mha additional land under micro-irrigation (Global AgriSystem 2017).

7.6.3 Efficient Pumping Techniques

Indian farmer's using inefficient local pumps for groundwater extraction at their farm. The government made efforts to replace these with high energy efficient BEE labeled pumps (Tyagi and Joshi 2019; BEE 2009). This has about 40% total electricity saving potential (Patle 2016a, b) with average 40–50% energy efficiency of labeled pumps compared to non-BEE labeled pumps (25–30%). To combat the problem, the government of India has launched AgDSM programme. About 5109 to 63,615 BEE five-star rated 5 HP pumps were installed from 2016 to 2019 that ultimately results in saving of 0.18 BU electricity and 0.148 million ton reductions in the emission of CO_2.

7.6.4 Policies for Improved Water and Energy Efficiencies

To promote climate-resilient agriculture government of India had put forward some other programme like:

- National Innovations on Climate-Resilient Agriculture (NICRA) in 2011 (ICAR 2011).
- Accelerated Irrigation Benefits Program (AIBP),
- Pradhan Mantri Krishi Sinchai Yojana (PMKSY),
- Rashtriya Krishi Vikas Yojana (RKVY),
- National Mission on Micro-Irrigation (NMMI), or promoting water-use efficiency (GOI 2017).

7.7 Conclusions

Besides foodgrain self-sufficiency, higher use of mechanization, fertilizers, irrigation, and changed cropping patterns drastically enhanced the energy consumption in Indian and global agriculture. Changing global climatic scenarios and energy demand is serious threat for sustainable green future. Energy demand of India stands third after China and the USA; where agriculture consumes about 5% (29,311 MTOE) of total direct and indirect available energy sources. Tillage (10–30%), fertilizers (24–50%) and irrigation are mainly energy-intensive agricultural practices. Highest proportion of direct energy consumption attains by electricity used in agriculture. Since, we are on verge of energy crisis, achieving energy efficiency in agricultural practices are win–win strategy. Diversified and legume-based cropping is most energy-efficient cropping pattern. CA-based tillage including zero-or reduced tillage with residue covering could reduce 50–70% fossil fuel demand with better EUE and productivity. Problem of 37 Mt. CO_2 emissions in environment from residue burning in India could also be solved by in situ residue management. Achieving higher WUE along with reduced energy demand are major challenges in India. LEWA and drip irrigation is prominent technology of many field and horticultural crops. Weed management shares very less (2–5%) in energy consumption pattern. Herbicides bypass the indirect energy demand of labor. Crop rotation with legumes, INM, site-specific nutrient management with advanced technology reduces demand of fertilizers. Effort for enhancing NUE through modern approaches indirectly upshot the EUE. Renewable energy-based machineries like harvester, dryer, and milling could reduce 10–15% energy used in agriculture. Protected cultivation using greenhouses efficiently harness renewable energy sources, i.e., solar energy. Integrated farming and agroforestry-based land-use management with animal components are the best energy efficient practices which need to be adopted now for sustainable green future.

7.8 Future Prospectus

As per the present growth rate, we are on verge of an energy crisis; triple energy will be required for sustaining food security by 2040. Indian agriculture mainly uses subsidized electricity and fossil fuel which are energy inefficient and a threat for green future. Reducing nonrenewable energy demand in agriculture is the talk of the town and challenges researchers, policymakers and farmers. Reducing direct energy consumption and promoting renewable energy in agriculture through policies and institutional support must be undertaken. Energy and food security are twin challenges in agriculture. Our efforts should be energy-oriented; only reducing energy demand is not a solution as food security might be on a threat. Our goals should be enhancing EUE rather than reducing energy consumption. However; many agricultural practices are able to reduce energy demand by enhancing input use efficiency but more needs to be evaluated. Energy budgeting of many modern technologies for higher NUE and WUE is still lagging behind. Most of the researchers focus on curtailing direct energy demand while indirect energy must also be curtailed down. Obviously, modern tools and implements are effective in equilibrated use of natural resources; but information on their energetic are meager. Our green future will depend upon energy availability and climate scenario. Reducing GHG emission by better energy use pattern is need of hours.

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