Chapter 9
Sustainable Energy: Challenges and Perspectives

S. Prasad, K. R. Sheetal, V. Venkatramanan, S. Kumar, and S. Kannojia

Abstract Currently, energy security, sustainable development and wellbeing are the energy policy drivers throughout the world. India has made significant progress, far more rapidly in the past 2 years, increasing the installed capacity of sustainable energy, and potentially this upward drift is anticipated to persist. The innovation in new and advanced technologies, aggressive energy policies, action, and planning activities has enabled India to resolve the barriers of commercial production of sustainable energy. The domestic production and use of renewable energy, such as off-grid power sources, i.e., solar power, wind power, small hydropower, biofuels and bioenergy from new biomass will help to reduce the fossil fuel use and its imports from other countries.

Sustainable economic and industrial growth also requires safe and sustainable energy resources. The use of sustainable energy will help in strengthening low-carbon energy in India and providing a clean environment through reduction of pollutants and greenhouse gas emissions. Prospective attention to financial and development needs by the use of sustainable energy will also improve the living standards of society with equity and economic sustainability. There is a strong need to extensively adopt and use sustainable energy technologies to supply off-grid power, especially in the areas with difficulty in accessing the central grid power, such as un-electrified villages, remote areas, and hilly terrains. Finally, these sustainable energy sources offer massive benefits and can contribute significantly to ensuring a secure energy future for India.

S. Prasad (✉) · S. Kumar · S. Kannojia
Centre for Environment Science and Climate Resilient Agriculture,
Indian Agricultural Research Institute, New Delhi, India

K. R. Sheetal
Central Arid Zone Research Institute, Regional Research Station,
Bikaner, Rajasthan, India

V. Venkatramanan
School of Interdisciplinary and Transdisciplinary Studies,
Indira Gandhi National Open University, New Delhi, India

© Springer Nature Singapore Pte Ltd. 2019

S. Shah et al. (eds.), *Sustainable Green Technologies for Environmental Management*, https://doi.org/10.1007/978-981-13-2772-8_9

Keywords Renewable energy · Sustainable energy · Solar energy · Biomass energy · Fossil fuels

9.1 Introduction

Energy is a key driver for agriculture, industries, and service sectors that influence economic development, but today's rising concern over its sustainability has put India in a critical position. The burning of fossil fuels causes multiple environmental problems such as air pollution and global climate change (Zidanšek et al. 2009). Global change threatens the very existence of life. Transforming the present coal dominated energy mix to renewable and sustainable energy dominated energy use is one of the herculean tasks facing India (Institute for Energy Research 2014). A fine balance of environmental sustainability with necessary economic development is required. On the other hand, the transition to sustainable and renewable energy technologies provides an opportunity to address not only the environmental problems but also overall economic and developmental needs to improve the living standards of people with equity and economic sustainability (IAC 2007).

The global community is becoming increasingly clear that management of the considerable risks due to air pollution and climate change, necessitates reduction in fossil fuel utilization, as has been explained in several reports including the fifth assessment report released by IPCC. It is of utmost importance, urgency and priority that a policy objective of finding ways and methods to generate and use energy that helps to preserve the integrity of elementary natural systems, arrest environmental degradation and sustain development toward a more sustainable, fair and civilized world (IAC 2007). Solar, wind and water-based energy and biofuels are a few examples of sustainable energy (IAC 2007; Steven and Majumdar 2012). The innovation in new and advanced energy technologies has enabled India to resolve the barriers of commercial production of sustainable energy. Therefore, sustainable energy and low-carbon technologies could provide ways for development opportunities that result in a world that is healthy, viable and has a secure energy source (Steven and Majumdar 2012).

9.2 Energy Consumption Pattern: Global Scenario

According to 5th Assessment Report of IPCC, the world energy consumption is rising at the rate of 2.3% annually (IPCC 2014). The global energy mix in 2012 was dominated by coal, natural gas, and oil with 87%. However, the dominance changes between these three sources with year, although only marginally. In the same year, while the contribution of natural gas and coal increased 0.1% and 0.2%, that of oil reduced by 0.3%, in the global energy consumption. This trend was predicted to lead to replacement of oil by coal by the year 2017 by the International Energy Agency (IEA) (World Watch Institute 2015). The IEA also expects an increase in global energy requirement under the existing scenario, from 12 to approximately 17 billion tonne oil equivalents (t.o.e.) in the time period from 2009 to 2035 (WEO 2009).

9.3 Energy Consumption Pattern: Indian Scenario

India was the 3rd largest consumer of petroleum products and crude oil in 2015, and it was also the 3rd largest net importer of crude oil and petroleum products after the United States and China in 2016 (IBEF 2017). The Indian energy demand is rising at a rate of 6.5% year^{-1}. With energy consumption of 0.55 tonnes of oil equivalent per capita, India's consumption is far below the international average of 1.9 tonnes; but the consumption is expected to almost double by 2035 (The Hans India 2017). With a gap of more than four times between the demand (4 million barrels per day) and production (1 million barrels per day) of oil as of 2015, the gap between India's oil demand and supply is widening (Dunn 2016). India's consumption was nearly 194 million tonnes in 2016–2017 as against 148 million tonnes in 2012 fiscal. By 2040, the Indian oil production predicted to remain steady while the oil demand is predicted by IEA to increase up to 7.5 million barrels per day. Energy companies in India are hence turning to other energy sources to reduce the country's dependency on oil imports.

The net oil import dependency of India rose from 43% in 1990 to 75% in 2015 that resulted in a massive strain on the current account as well as the government exchequer (US EIA 2014; Dunn 2016). The transport sector accounts for the most significant share in terms of utilization of petroleum products in India, consuming nearly 70% of diesel and 99.6% petroleum, and the demand is anticipated to show a growth of 6–8% in the coming time in tandem with the rapidly growing vehicle ownership. This implies that imports will also rise to 92% by 2030 (WEO 2009). With domestic oil production providing only one-fourth of the national demand, energy security has emerged as a vital question for India. This situation necessitates the production of alternate energy from readily available resources (IEC 2015).

9.4 Energy and Environmental Quality

The advancements in scientific monitoring capabilities and increased awareness in recent past has shed more light on the more understated effects associated with energy production, conversion, and use, on ecology and environment like being the cause for pollution and climate (Levine 1991; World Watch Institute 2015).

9.4.1 Fossil Fuels and Air Pollution

Present energy and transportation systems, mainly based on fossil fuels, are the most significant contributor to air pollution throughout the world. The burning of fossil fuel releases carbon monoxide (CO), Volatile Organic Compounds (VOCs), nitrogen oxides (NOx) and particulate matter (PM). In the presence of sunlight, the VOC and NOx mixture results in ozone (O_3) formation in the troposphere, the leading constituent of photochemical smog (Levine 1991). Coal-based power plants are known to have higher CO_2 emissions and other pollutants per kWh electricity generation (IEA 2004).

The combustion of coal also severely affects local air quality by emitting sulfur dioxide (Institute for Energy Research 2014). Contributing about 40% and 38% of gross CO_2 and ozone, burning of biomass is also a grave source of gaseous emissions (Levine 1991). In addition, combustion of biomass as fuels in conventional systems also contribute to 1.4 million tonnes (MT) of methane (CH_4). The emissions are not the only points of ecological concern while using energy (Prasad et al. 2012). Hence, this energy system is turning out to be unsustainable, and sustainability is an essential criterion for energy in this century (Steven and Majumdar 2012).

9.4.2 Fossil Fuels and Global Climate Change

One of the significant threats facing the world today is climate change (Zidansek et al. 2009). According to IPCC 5th Assessment Report, the major anthropogenic contributor to climate change is the use of fossil fuels (coal, gas, oil) which came into practice at the dawn of the industrial era, which amplified the atmospheric concentration of heat-trapping greenhouse gases. Atmospheric greenhouse gas concentration since the pre-industrial revolution to the recent time and global warming potential is given in Table 9.1 (Blasing 2014). The report also reveals that of the 10 $GtCO_2eq$ increase in annual anthropogenic GHG emission that occurred in the last decade (2001–2010), energy supply was the major contributor with 47%, followed by industry, transport and building sectors with 30%, 11% and 3% respectively (IPCC 2014).

Table 9.1 Recent tropospheric greenhouse gas (GHG) concentrations

GHGs	Pre-1750 level	Recent level	GWP(100-year time horizon)	Increased radiative forcing (W/m^2)
CO_2	280	395.4 ppm	1	1.88
CH_4	722	1893/1762 ppb	28	0.49
N_2O	270	326/324 ppb	265	0.17
O_3	237	337 ppb	n.a.	0.40
CFC-11	zero	236/234 ppt	4660	0.061

Source: Blasing (2014)

According to IPCC 5th Assessment Report, more than three-fourth of the increase in greenhouse gas emissions in the 40 years since 1970 was mainly from industry and burning fossil fuels. CO_2 emissions from fossil fuel use have touched 32 (±2.7) $GtCO_2$/year, in 2010, and increased further by about 3% during the next year and approximately 1–2% in the year after (IPCC 2014). Global climate change is predicted to cause irreversible and irreparable adverse impacts on agriculture, health sector and on the earth and the ecosystem as a whole (IPCC 2014).

The herculean and insurmountable task of reducing GHG emissions by 60–80% by 2050 compared to 1990s, necessary to limit temperature rise to 2 °C above pre-industrial levels and to stabilize CO_2 concentrations below 550 ppm, requires a total shift to low-carbon emission technologies that can effectively tackle climate change (IPCC 2014). It was observed that global CO_2 emissions from fossil fuels and industry were almost stable in the years 2014 to 2016, increasing only 0.2%, against the 2.2% average rise during the previous decade. This decline was primarily due to decreasing in global coal use and improvement in efficiency of energy use and increased utilization of renewable alternative energy sources (REN21 2017). India is also developing its various renewable energy sources, especially power generation from solar, wind, biomass, and other viable alternative sources (Zidansek et al. 2009). From 2012 onwards, India has started reforms in oil and gas pricing to promote sustainable investment and to lower subsidy costs (Dani 2014), which could efficiently augment energy supply, at the same time improving energy efficiency in India (Prasad et al. 2014).

9.5 Renewable and Sustainable Energy

Solar energy, wind power, and biofuels are examples of renewable energy which refers to the energy obtained from natural resources that will not deplete over time (Farrel and Gopal 2008). Non-renewable energy sources like fossil fuels form over millions of years and hence do not regenerate easily. The technologies developed to exploit renewable energies are known as renewable energy technologies (RET) or clean technologies or green energy. Sustainable energy goes one step further in terms of energy efficiency than renewable energy. Optimizing energy supply and use leading to minimum wastage leads to higher energy efficiency (Beckett 2012). Renewable energy base and energy efficiency are the twin pillars of sustainable energy.

Sustainable energy systems, technologies or resources support economic and human development needs, at the same time conserving the environment, reducing climate change risks by reducing GHG emissions, giving equal chances for all people to access energy and also improving energy security (IAC 2007; Steven and Majumdar 2012; Beckett 2012).

9.6 Renewable Energy: Global Landscape

Today, the scope of renewable energy lies beyond providing the viable future energy sources (IAC 2007). It is a tool to deal with problems caused by fossil fuel use on environmental and human health and promote energy security, economic and social welfare (REN21 2014). The contribution of renewable energy to global energy production is increasing gradually. In 2015, renewable energy provided 19.3% of global energy production with modern renewables contributing around 10%, and rest by biomass (Fig. 9.1). Out of total energy use, heat energy from modern renewable sources contributed to 4.2%; hydropower accounted for about 3.6% and 2.4% from other renewable sources (REN21 2017).

As per International Renewable Energy Agency's (IRENA) estimate, the global share of renewable energy can exceed 30% by 2030 for which technologies are already on hand. This global share can be further enhanced by 6% by improving energy efficiency and upgrading energy access (MNRE 2009). This trend is visualized through the fast growth rate of renewable installed capacity and production during past years, predominantly in the power sector (Fig. 9.2). Renewables provided 24.5% of electric power worldwide by latter part of 2016. The highest improvement in renewable sector was found in solar energy which accounted for almost half of the newly installed power, followed by wind and hydropower (REN21 2017). Similarly, growth rate of biofuel production, mainly for transport sector, also picked up pace in 2013, after a slow pace from 2010 to 2012. Although biofuel blends remain the primary focus of the policy support for alternate energy in the

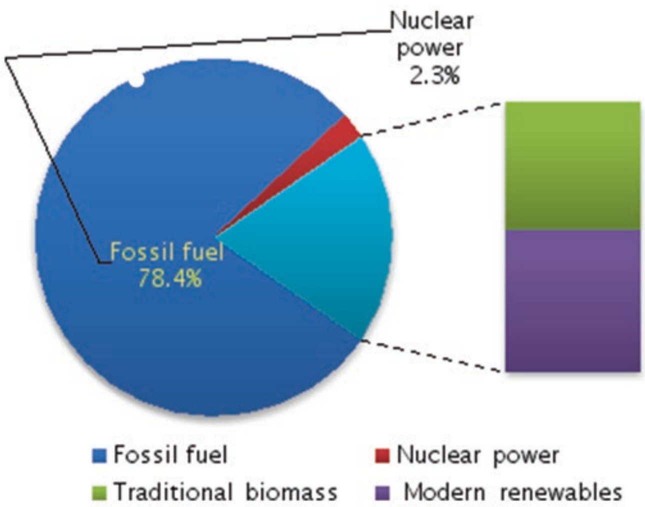

Fig. 9.1 Renewable energy share of global final energy consumption in 2016. (From REN21 2017)

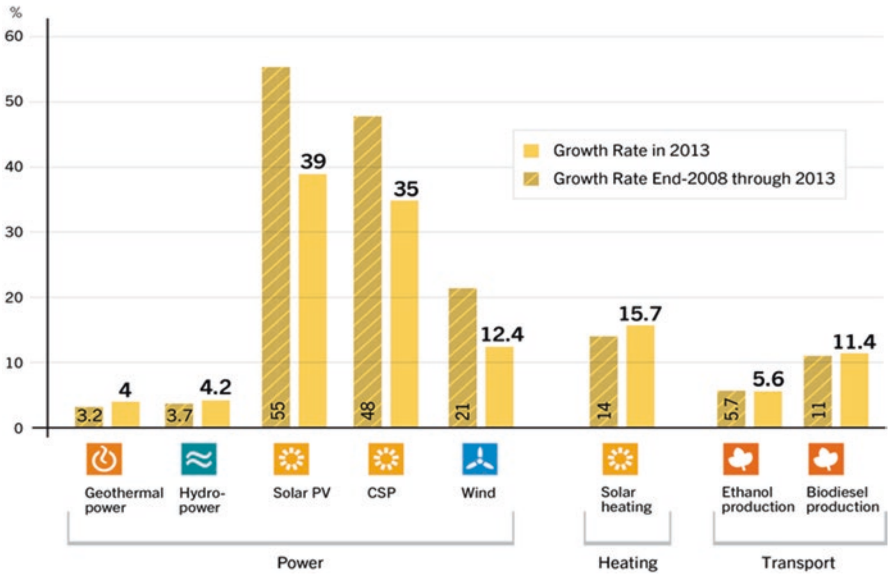

Fig. 9.2 Average annual growth rates of renewable energy capacity and biofuels production. (From REN21 2014)

transport segment, policies encouraging the exploitation of electric vehicles (EVs) are emerging (REN21 2017).

9.7 Sustainable Energy Policies, Institutions, and Programs in India

Global policy decisions are at present being greatly influenced by problems of environmental pollution, energy security and climate change (Planning Commission 2003). The Public Utilities Regulatory Policy Act, 1978 forced the purchase of electricity from independent power generators at reasonable rates in the US. As a result, by 1990s, similar rules were brought in other countries as biomass electricity production grew substantially (Larson and Kartha 2000).

India is one country to have a separate 'Ministry of New and Renewable Energy' to address issues of development of renewable energy sources along with biofuels. Of the total installed power, renewable power (14.8%) has secured the second position after thermal (69.4%) and is spreading its wings rapidly in India (MNRE 2017).

Numerous initiatives were taken up by the Government of India in the past few years including the idea of solar park and Green Energy Corridor concept, rooftop solar program initiation, increase in clean environment cess, solar pump scheme, making purchase of energy from waste to energy plants, etc. attempt has been made to create 50,000 people trained in solar photovoltaic systems under the Surya Mitra

Scheme by March 2020. Advancing towards improved cook-stoves initiatives; commencing coordinated R & D activities in solar thermal and photovoltaic systems; second-generation biofuels, hydrogen energy, and fuel cells, etc. are the other noteworthy schemes.

Since 1993, India has had a fixed purchase price for biomass-generated electricity to encourage expansion of biomass-generating capacity. A task force was constituted by MNRE leading to development of a National Programme on Biomass-based co-generation (Shukla 2000), which recognized bagasse waste as a potential energy resource and suggested initial thrust on bagasse co-generation in the sugar industry. The Government of India (GOI) is enthusiastic in increasing contributions of sustainable energy (resources as a low-carbon generation), undertaking necessary planning and policies to ensure the use of renewable energy in all sectors. The success of this goal is ensured by national-level institutes such as National Institute of Solar Energy (NISE), National Institute of Wind Energy (NIWE), and Alternate Hydro Energy Center (AHEC) (MNRE 2014), under the government's supervision.

Financial support for renewable energy development and improving energy efficiency projects is provided by the Indian Renewable Energy Development Agency (IREDA), also supervising the renewable energy incentive programs. Funding is also provided by GOI and multilateral lending agencies. Ministry of Power, Planning Commission and Prime Minister's Council on climate change are few other government institutions responsible for developing renewable energy (REN21 2014).

The GOI in 1981 launched a national project on biogas development. The National Biogas and Manure Management Program (NBMMP) is implemented by MNRE in the country. It is executed by the state nodal departments/state nodal agencies and Khadi and Village Industries Commission (KVIC), and Biogas Development and Training Centers (BDTCs). MNRE is also funding research projects on different aspects of hydrogen energy, geothermal energy technology development. These projects are assisting in the development of indigenous research and industrial base, proficiency, trained workforce and models/devices/systems in the country (MNRE 2014).

In a bid to decrease dependency on imported fuels, a notification was made by GOI in Sept 2003 making blending of petrol with 5% ethanol compulsory initially in 9 states and 3 union territories, which was to be extended to the whole of India later on. In the case of biodiesel also some steps were taken such as the identification of *Jatropha curcas* as the highly likely candidate for biodiesel production through the 'National Mission on Biodiesel, 2003' and emphasis on wasteland plantations of this tree-borne oilseed (MNRE 2009, 2014). Further, a 'biodiesel purchase policy' was brought into action in 2005 to enable oil companies to purchase biodiesel for 5% blending with diesel by the Ministry of Petroleum and Natural Gas (MOP&NG). In another step forward, the National Biofuels Policy (NBP), 2009 was launched to ensure prevention of debates between food and fuel and the use of only wastelands for biofuel crop cultivation (MNRE 2009). It also gave attention to issues like Minimum Support Prices (MSPs), subsidies for biofuel crops growers, marketing, subsidies for the biofuel industry, mandatory blending of with ethanol and biodiesel, testing and certification of biofuels (Planning Commission 2003; MNRE 2014).

9.8 Renewable Energy Installed Capacity of India

With a noteworthy growth in clean energy over the past years, our country is catching up fast on the determination to becoming a global leader in production of renewable energy (MNRE 2014; IRENA 2014). India has tremendous growth potential in the energy production from different renewable sources, with a potential of about 900 GW (Table 9.2). Table 9.3 shows India's total renewable energy installed capacity (in MW). As per MNRE reports, solar, wind, small hydropower and biomass together contribute to 16% of total electrical installed capacity by the end of 2016 (MNRE 2017), with wind energy contributing more than half of the installed capacity among renewable (GWEC 2017).

India has set a target of 16,660 MW of renewable installed energy for the year 2016–2017, including solar (12,000 MW), wind (4000 MW), SHP (250 MW), bioenergy (400 MW) and energy from waste (10 MW). Other than this, solar photovoltaic energy, cogeneration from non-bagasse biomass, energy from waste, gasification of biomass, small wind/hybrid systems, micro hydel systems are also targeted to produce about 100, 60, 15, 10, 1, 1 MW eq. of renewable energy as off-grid energy, along with large number of biogas plants for the same financial year 2016–2017 (MNRE 2017). For the future, GOI also hopes to achieve establishment 100, 60, 10 and 5 MW of solar, wind, biomass and small hydropower leading to reaching the target of 175 GW of clean energy by 2022, through the work of several organizations and provisions dedicated towards this goal. Advancing the national goal of the creation of renewable energy systems not only benefits ecology and environment in the long term, but also helps to secure energy requirements, employment creation, achieve financial development and reduce dependency upon the exhaustible energy resources (IRENA 2014; Kumar et al. 2015).

Table 9.2 Total renewable energy potential from various sources in India

Sectors	Potential (in MW)
Wind Energy	102,788
Solar Energy	748,990
Small Hydro Power (SHP)	19,749
Biomass	17,538
Bagasse Cogeneration	5000
Waste to Energy	2556
Total	896,621

Source: Energy Statistics (2017), Govt. of India

9.9 Renewable and Sustainable Energy Technologies: The Path Forward

The challenge of sustainable development can be realized through development of renewable energy technologies (RETs) (Make in India 2015). Many scientific and technological obstacles need to be overcome in the next 5–10 years to meet the ambitious RETs capacity addition goal and biofuel mandates for sustainable energy supply. However, the current innovations in RETs are capable of resolving the barriers of commercial production.

9.9.1 Wind Power

Among renewable energy sources, wind energy is becoming one of the essential sources of power generation. In India, wind turbines are generally used for off-grid mechanical power or electricity generation. The wind energy plants comprise of a wind turbine and an electrical generator connected using a gearbox. The wind turbine converts wind kinetic energy into mechanical power. It can be used for specific tasks such as grinding grain or pumping water, or an electrical generator can convert this mechanical power into electrical energy (Ahmad et al. 2014). The rate of wind energy is now waning due to noteworthy advancements in wind mill technology, as well as raise in the height of the wind towers.

Industry associations of India emphasize the high potential for wind energy from 65 to 242 GW, if tower heights are kept more than 50 m, energy conversion efficiencies are improved and necessary policy initiatives are adopted (Ramasamy et al. 2015). At a hub height of 100 m, India's wind power potential is approximated to be 302 GW as per NIWE. Presently, with 31 GW installed capacity in the first quarter of 2017 and contributing to 57% of total renewable energy, India is at the 4th position globally, with respect to wind power (Table 9.3) (MNRE 2014; GWEC 2017). This energy is mainly generated in the states of Tamil Nadu, Maharashtra, Gujarat, Rajasthan, and Karnataka, together supplying 94% of total wind energy generated. The Wind Resource Assessment is led by the coastal state of Gujarat with 84.4 GW estimated potential, followed by the other states mentioned earlier (GWEC 2017).

Table 9.3 Total renewable energy installed capacity (as on 31 Dec 2016)

Renewable energy (RE) sources	Power (MW)	% Contribution to Installed energy
Wind Power	28700.44	57.3
Solar Power	9012.66	18.0
Small Hydro Power	4333.85	8.6
Biomass energy	7907.34	15.8
Waste to Power	114.08	0.2
Total	50068.37	

Source: MNRE (2017)

Table 9.4 Installed capacity of wind power in various states of India (as on 31 Dec 2016)

S. No.	States of India	Installed capacity of wind power (in MW)	% Wind power potential used
1.	Tamil Nadu	7613.86	22.53
2.	Karnataka	2869.15	5.14
3.	Maharashtra	4653.83	10.25
4.	Rajasthan	3993.95	21.28
5.	Andhra Pradesh	1431.45	3.24
6.	Madhya Pradesh	2141.1	20.42
7.	Gujarat	3948.61	4.68
8.	Kerala	43.5	2.56
9.	Telangana	77.7	1.83
10.	Others	4.3	0.13

Source: MNRE (2017)

To fulfill the rising demand for energy, other states are also following in the footsteps to increase wind power production (Ahmad et al. 2014).

Installed wind power capacity of various Indian states till March 2016 is shown in Table 9.4. Tamil Nadu, the state with maximum wind energy installed, increased its capacity from over a period of 5 years from 2009, with a result of 69% increase (Make in India 2015). Apart from the on-shore potential, India also has high off-shore wind power potential owing to its long coastline (7600 km) and wind patterns. The states of Tamil Nadu and Gujarat will play a major role in this addition of energy production capacity with proper planning and estimation (Ramasamy et al. 2015). Increasing the energy conversion efficiencies can help elevate Indian power position to that of the global wind energy leaders, which requires technological and market interventions (Ramasamy et al. 2015).

9.9.2 *Solar Energy*

There are two techniques of using solar energy: thermal and photovoltaic way. The thermal route employs the heat from solar energy for cooking, water heating and purification, drying, etc. The solar photovoltaic (SPV) method transforms the light in solar energy into electricity via the use of solar cell installed in a solar panel, which can then be used for lighting, pumping, communications, and off-grid power supply in un-electrified areas (Indian Renewable Energy Status Report 2010). Being a tropical country, India is bestowed with abundant number of clear sunny days, obtaining 4–7 kilowatt-hour per square meter per day radiation on an average and as a result, shows good potential for development of solar power (Ramasamy et al. 2015). The desert state of Rajasthan receives the highest annual solar radiation in India.

The solar energy plans are executed by the MNRE, considered one of the most extensive programs globally. India has an assessed solar power potential of around 748,990 MW, out of which the solar grid had a cumulative capacity as of October 2017 of 15.60 GW (Energy statistics 2017; MNRE 2017). Increase in solar capacity has led to decline in solar electricity rates, which has gone below that of coal based electricity. Out of the total commissioned solar power capacity in the country as of March 2017, the share of Andhra Pradesh is maximum, closely followed by Rajasthan Tamil Nadu, Telangana, and Gujarat (Bridge to India 2017).

The state and central governments combined initiation of the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010, is a momentous stride towards the support of sustainable energy in India. The objectives of the mission are (i) to establish 20,000 MW of grid-connected solar power (ii) to develop 20 million solar lights which will meet the target of 2000 MW of off-grid power (iii) to cover an area of 20 million meter squares with the solar thermal collector; by the year 2022. The tie-up of the MNRE with IREDA aims to encourage use of solar energy and in general, increase clean energy capacity in India, through location-specific and need-based research, demonstrations, financial support and in league with private sector projects (MNRE 2014; Ramasamy et al. 2015).

9.9.3 Small Hydropower (Less than 25 MW)

When economic feasibility is taken into consideration, small hydro projects were found better than other sources (Balachandar 2014). However, presently only 5% of this source's capacity has been exploited on a global scale, out of 150–200 GW potential as per the International Energy Agency. Another advantage is the lower and comparable rates of this small hydropower to traditional thermal power of around Rs 2–3/kWh, without the addition of any associated variable fuel cost (i.e. natural gas or coal) as in thermal power (World Bank 2010). In India also, this source can play a major role in supplying energy to remote and inaccessible regions, carving its niche in the Indian energy sector. Small hydropower plants are categorized in the following segments presented in Table 9.5.

India has an estimated small hydropower (less than 25 MW) potential of approximately 20,000 MW out of which the collective installed capacity as of 31st December, 2016 was 4333.85 MW counting both off-grid and grid-connected

Table 9.5 Classification of Small Hydro Power Project (SHP)

S. No.	Category	Station capacity in kW
1.	Micro Hydro	Up to 100
2.	Mini Hydro	101–2000
3.	Small Hydro	2001–25,000

Source: MNRE (2014), Annual Report, Govt. of India sources (MNRE 2017). Irrigation channels in plains and rivers in hilly areas are the areas with high potential to generate this power. To successfully tap into this power, the government has set subsidies for new installations as well as to maintain existing hydropower plants (Indian Renewable Energy Status Report 2010). Further incentives for establishment of this source is provided through loans at low interest rates and income tax exemptions, all of which has culminated in its significant share in India's electrification efforts in rural areas without access to electricity from the central grid (Ramasamy et al. 2015; World Bank 2010).

9.9.4 Geothermal Energy

Thermal springs have drawn consideration, being the surface manifestation of the vast resources of energy at depth in the form of geothermal reservoirs (Mittra 2011). The geothermal energy is now better known for electricity generation. It is derived from the Earth's core, mantle, and crust heat, and has been helping meet both industrial as well as household energy needs with great success. Geothermal energy holds the key to solve the power problem of India. It is an ideal alternative energy resource meeting all requirements as a clean, non-exhaustive energy (Razdan et al. 2008). The global leader in this sector is the United States with 3.6 GW installed capacity followed by Philippines and Indonesia in 2016, with global production being a projected 78 terawatt-hours (REN21 2017).

India is at the budding stages of development of geothermal energy, chiefly due to the lower rates of coal. Reports from the Geological Survey of India (GSI) reveal the existence of about 340 hot springs, which are distributed in seven geothermal provinces of the country (Aggarwal 2016), i.e. Himalayan (Puga, Chhumathang), Sahara Valley, Cambay Basin, Son-Narmada-Tapi (SONATA) lineament belt, West Coast, Godavari and Mahanadi basin. Most of them are in the low surface temperature range from 37 to 90 °C, which is suitable for direct heat and power applications (Kakkar et al. 2012). At present, the geothermal resource is tiny, but the GOI has an ambitious plan to produce 10,000 MW of geothermal energy by 2030 (Aggarwal 2016). According to International Sustainable Energy Agency, geothermal solutions can provide not only sustainable but also economical and safe energy for all by 2050.

9.9.5 Biomass-Derived Bioenergy and Biofuels

Plants capture sunlight and carbon dioxide from the atmosphere for growth, and this basic mechanism leads to the classification of biomass as a renewable source (Larson and Kartha 2000). Tropical countries, like India have enormous potential for energy generation through biomass and its residues. It is available in plenty in the form of agricultural waste (crop residue and cattle dung, etc.), urban waste (municipal solid waste, etc.) and industrial waste. India has about 500 million metric tons of biomass availability annually, which can be converted to bioenergy (by the thermo-chemical and biochemical process) or directly used as a heat and power source (IRENA 2014).

Deploying bioenergy with carbon capture and sequestration results in a net decline in atmospheric carbon. The vast potential of biofuels becomes more noticeable as an alternative to the depleting fossil fuels. Moreover, they can be locally produced, requiring very less modification before final-use. Biomass energy also supports rural economy, requires lesser capital investment than other renewable, leading to lesser unit cost (Sharma and Trikha 2013).

9.9.5.1 Biomass to Bioenergy by Thermo-chemical Process

The conversion of biomass to an alternative form of modern bio-energy can be achieved primarily through thermo-chemical conversion of biomass. The end-products of the thermo-chemical processes such as combustion, pyrolysis, and gasification, include heat, electricity, or gaseous or liquid precursors which may be modified into biofuels. With biomass serving as an energy source for more than three-fourth of the country and producing 32% of the total primary energy use, biomass occupies a central position in our energy security (Biomass Knowledge Portal 2017), with over 30,000 MW estimated power production of which only a meager 8% has been exploited as yet (Schroder et al. 2008). Currently, India has over 5940 MW power capacity from biomass based plants of which only 4946 MW is grid-connected (mainly from bagasse cogeneration and waste to energy plants) and 994 MW off-grid power plants (mainly from non-bagasse cogeneration and biomass gasifier systems) (Biomass Knowledge Portal 2017).

Biomass energy along with other renewable, can play a major role in the planned electrification of about 24,500 remote identified villages of India where the extension of grid electricity is not possible or very expensive (EAI report 2012; Thomas et al. 2015). The uniform availability of biomass throughout India, particularly in the rural areas, increases the importance of biomass as an energy source for electrification. This abundant resource worth annual investments of crores of rupees with >700 billion electricity units production and also employing several people, has the potential to form a significant element of India’s energy mix in upcoming future (Thomas et al. 2015).

9.9.5.1.1 Direct Combustion of Biomass

The direct combustion of biomass has been carried out worldwide since ancient times. Since ancient times, firewood, field level residues and cow dung, have been a crucial segment of energy supply and these traditional biomass still has its followers particularly in rural areas and remote location. In complete combustion, biomass is oxidized giving out carbon dioxide, water and heat energy (Farrell and Gopal 2008). A popular ‘biomass combustion technology’ or the traditional cooking method in developing countries involves burning biomass under a pot supported by three stones. Despite its huge popularity, energy efficiency of this method is very less (15%), simultaneously exposing users to air pollutants such as methane (CH_4) carbon monoxide (CO), particulates (PM), nitrogen oxides (NO_X), and tars (Farrell and Gopal 2008).

9.9.5.1.2 Biomass Pyrolysis

Pyrolysis is essentially the thermal breakdown of organic components in waste to energy under inert atmospheric conditions or in limited air supply, at temperatures ranging from 350–550 °C up to 700–800 °C (EAI report 2012). During the process, the long carbon, hydrogen and oxygen compound chains break down into smaller molecules in the form of highly heterogeneous gaseous, liquid, and solid by-products (Jahirul et al. 2012). The pyrolysis oil, a liquid product is a heterogeneous blend constituted of high oxygen content and resembling a very viscous tar, from which fuels or chemicals may be produced (Fisher et al. 2002). Char is the intermediate solid residue which is formed in reactors during pyrolysis processes. This residual char finds use as a fuel or soil amendment (Jahirul et al. 2012).

9.9.5.1.3 Biomass Gasification

Gasification is the efficient means of producing green power. It is incomplete oxidation of biomass under controlled conditions aimed at getting peak yields of gaseous compounds rich in carbon and hydrogen compounds such as CO, CH_4, H_2, CO_2 and heat (Fisher et al. 2002). These by-products are referred to as syngas or producer gas can be used with minor changes in air inlet, to operate a diesel engine in dual fuel mode. A drawback of this process is due to one of its condensate product ‘tar’, an environmental pollutant, formed from high molecular weight volatiles (EAI report 2012; Fisher et al. 2002).

The gas can be put into use directly for electricity generation via a spark-ignited gas engine incorporated with an alternator (Tanger et al. 2013). This electricity can be used locally or off-grid or can be made on-grid, providing enough flexibility for small or large scale production for remote and difficult areas. These features also ensure the sustainability and feasibility of biomass gasification in India.

9.9.5.2 Biomass to Liquid Biofuels by Biochemical Process

Liquid biofuels like ethanol and biodiesel are the most feasible green alternatives to fossil fuel-based transportation fuels. Molasses, a waste product of sugar industry is the main feedstock for bioethanol production in India, while biodiesel is made by the transesterification of non-edible oilseeds. Indian government has brought forth several missions and policies in support of biofuels, along with loans at lower interest rates for establishing ethanol production plants, encouraging cultivation of non-edible and tree-borne oilseeds and tax exemptions for biodiesel use.

9.9.5.2.1 Ethanol as Biofuel

Production of energy efficient technologies offers the world the safest and the most environmentally benign way to sustainability. In the past few decades, great attention has been focused on the development of alternative fuel sources with particular reference to ethanol. Raw materials containing sugars, or resources which can be converted into sugars, can be used as fermentation feedstocks for ethanol production (Meshram and Mohan 2007). The fermentable raw materials can be grouped into three (a) directly fermentable sugar containing materials such as starch (b) lignocellulosic biomass (c) urban/industrial organic residues. Reports are also available on direct fermentation of sugarcane, sugar beet and sweet sorghum to ethanol (Prasad et al. 2009), which require the least costly pretreatment, where starchy, lignocellulosic resources and other wastes need expensive pretreatment, to change into fermentable substrates (Rao et al. 2013). However, since maintaining the food security is given higher priority in our agrarian economy faced with rising population pressure, it is not possible to divert a fraction of the sugary or starchy food sources towards biofuel production.

Recently, lignocellulosic biomass, as the most abundant renewable resource has been widely considered for ethanol production. It gives us an opportunity to look forward to the day when all fuel needs can be met from the utilization of agricultural residues, as it has been reported that use of currently available 74 Tg of agricultural residues across the earth could produce 16 times higher ethanol production over present level (Prasad et al. 2007). The ethanol production potential from biomass is high enough to replace 32% of the global petrol consumption (Meshram and Mohan 2007). With respect to India, the entire annual petrol consumption can be met by utilizing jut one-third of available surplus biomass (Ramasamy et al. 2015).

Ethanol from biological systems is considered of particular importance because it can be readily used as a fuel for spark ignition engines without necessitating any modifications. Ethanol contains high oxygen percent of 34.7% by weight, aiding complete fuel burning and a marked drop in emissions. It is usually used as an additive in petrol to increase octane number, and improve the type of emissions. Ethanol, being the low-carbon fuel, appears to have enormous potential benefits to minimize the risk of greenhouse gas emissions. It also reduces carbon monoxide emissions and smog; usually caused due to sulfur deposits in gasoline (Kim and Dale 2004).

9.9.5.2.2 Biodiesel as Biofuel

Biodiesel is defined as ‘monoalkyl esters of long chain fatty acids obtained from renewable lipid feedstock, such as vegetable oil or animal fat’ by the American Society for Testing and Materials (ASTM) (Prasad et al. 2012). As the best diesel alternate, it may be used directly or after blending. The 'B20' blend which consists of biodiesel and diesel in 1:4 ratio by volume is most common. Biodiesel fuel blends cut down emissions of particulate matter (PM), carbon monoxide (CO), hydrocarbon (HC) and sulfur oxides (SOx), thus less toxic to humans and environment. Also with 80–95% lesser carbon dioxide emissions over its life cycle, biodiesel has very little share in climate change, as compared to fossil fuels (Karmakar et al. 2010).

Substantial developmental actions have been done regarding the production and use of biodiesel. A 1000 liters/day capacity biodiesel production plant was established by the Aatmiya Biofuels Pvt. Ltd. at Por-Vadodara, Gujarat, using *jatropha* seeds as feedstock (Marina et al. 2002). Another commercial level plant with an expandable daily biodiesel production capacity up to 100 tonnes was proposed by Southern Online Biotechnologies (P) Ltd., in Andhra Pradesh. Lurgi Life Science Engineering, Germany is providing the technology for this unit, along with their Delhi-based associates (Biswas et al. 2006).

9.9.6 Hydrogen Energy

Hydrogen (H_2) is a sustainable energy, which is produced from available sources and used in every application where fossil fuels are being used. H_2 is the fuel of the future, largely due to its high conversion efficiency, non-polluting nature, and recyclability, yielding only water after combustion (Francis et al. 2005). There are many hydrogen production processes, including electrolysis of water, biomass gasification, and biological processes. Currently, steam reformation of methane or electrolysis of water is employed almost exclusively to produce H_2. Currently, H_2 is produced, almost exclusively, by steam reformation of methane or by water electrolysis. Supercritical water partial oxidation, steam reforming, and gasification are the thermo-catalytic processes employed for H_2 production (Gupta et al. 2013). In the last decade, the important problems associated with H_2 economics have changed dramatically. Nevertheless, refineries now have turned into net consumers of H_2 to cut pollution and meet environmental rules and regulations.

In India, hydrogen production from renewable resources is at the dawn of development. The Many research projects focusing on the development of different aspects of hydrogen production technology is being undertaken, funded by Government of India. The Indian Institute of Science, Bangalore, is researching on employing an open top downdraft gasification system to enhance the performance of the oxy-steam gasification unit for hydrogen production at a rate of about 0.1 kg/kg biomass at various steam-to-biomass ratios. The National Institute of Technology, Rourkela is working on the development of a 5 kW capacity bench scale fluidized bed gasifier for hydrogen production rate of about 0.09 kg/kg of feedstock (Sherif et al. 2003). The roadmap envisions initiating research and development activities in various sectors and aspects of hydrogen energy technologies and envisaged goals of aggregate hydrogen-based power generation capacity of 1000 MW and one million hydrogen-fuelled vehicles in the country by 2020 (Nouni 2012).

9.9.7 Biogas

Biogas production is a sustainable energy technology which not only efficiently manages and converts organic wastes into clean bioenergy but also allows the best possibilities to cut tropospheric emissions of greenhouse gases (Kumar et al. 2010). Biogas is produced via the anaerobic digestion of organic and bio-degradable resources such as agricultural waste, food waste, municipal waste, sewage etc. The slurry produced after digestion is rich in macro and micronutrients and can be used directly as valuable organic fertilizer. Biogas is a mixture of different gases primarily methane (CH_4) and carbon dioxide (CO_2) and may have small quantities of hydrogen sulphide (H_2S) and moisture. Methane is the only combustible constituent of biogas (Pathak et al. 2009).On account of methane's low specific gravity, methane biogas will rise on escaping, thus dissipating from the site of a leak which makes it safer than other fuels like petrol and Liquefied Petroleum Gas. One cubic meter of biogas generates 1.5 kWh which is equivalent to 1 lb of LPG, 0.54 L of petrol, 0.52 L of diesel and 4 kWh of electricity in terms of calorific value.

Biogas finds its use both as a source of heat for cooking by direct combustion and for mechanical or electrical power applications with internal combustion engines (Pathak et al. 2009; Rao et al. 2010). Biogas plant helps to attain self- sufficiency for cooking gas and highly nutrient- rich organic fertilizer for households having feed material (Horst 2000). Further, this technology can solve the problems of indoor air pollution in households and while saving on the cost of refilling of LPG cylinders. The Government of India offers a subsidy for family type biogas plants as per the rates are given in Table 9.6.

Table 9.6 Subsidy for setting up of biogas plants under national biogas and manure management programme

	Particulars of central financial assistance	Family type biogas plants size cubic meter (M^3) capacity day^{-1}	
S. No.	Central subsidy rates applicable (In Rs.)	1 M^3	2–6 M^3
1.	North Eastern Region States, Sikkim (except plain areas of Assam) and including SC & ST Categories of NE Region States	15,000	17,000
2.	Plain areas of Assam	10,000	11,000
3.	Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Niligiri of Tamil Nadu, Sadar Kurseong & Kalimpong Sub-Divisions of Darjeeling, Sunderbans (West Bengal) and Andaman & Nicobar Islands	7000	11,000
4.	Scheduled Castes/Scheduled Tribes of all other States except North Eastern Region States (including Sikkim)	7000	11,000
5.	All Others	5500	9000

Source: MNRE (2014), Annual Report, India

9.10 Contribution of Sustainable Energy to CDM

Despite all challenges, the clean development mechanism (CDM) saw rapid growth in the past decade, quickly becoming the most significant carbon offsetting mechanism in the world. Currently, India accounts for approximately 4% of global greenhouse gases emissions. However, on per capita basis, its emissions are only one-fourth of the global average and less than 10% of those of most developed nations. India has committed to reduce its economy's emission intensity to 20–25% below 2005 levels by 2020 and has pledged that per capita GHG emissions will not surpass those of industrialized countries (Ngumah et al. 2013).

In 2008, NAPCC (National Action Plan on Climate Change) was launched to promote development goals while addressing GHG mitigation and climate change adaptation. As per NAPCC, renewable sources have the potential to meet 15% of India's energy demand by 2020 (Ramasamy et al. 2015). The NAPCC includes eight dedicated missions, out of which one is devoted to solar energy (Sood et al. 2014). India is observed to be one of the most attractive Non-annexe-I countries for CDM project development.

The Clean Development Mechanism (CDM) of the Kyoto Protocol extends supporting hands for the development of renewable energy projects in India. The fundamental economic hurdle is the relatively higher costs of electricity generation through Renewable Energy Technology (RET), although the scale of difference varies with each technology. This price difference can be compensated to some extent by the revenues attained from selling CERs from a CDM project (Sood et al. 2014).

9.11 Conclusion

Sustainable energy is the need of the time and it is gaining currency due to its low–carbon generation potential, often accompanied by its co–benefits. The transition of the fossil fuel based conventional energy to sustainable energy will help in effective management of air pollution, climate change mitigation, and spur sustainable economic growth and improve living standards of people with equity and environmental quality. The IPCC Fifth Assessment Report validates the promising role of bioenergy in encouraging economic development by increasing and diversifying farm incomes and providing rural employment and in offering cheap alternatives for mitigating climate change. There is a need to adopt and use renewable and sustainable energy technologies for mitigating of environmental challenges across all sectors.

Acknowledgment Authors wish to thank Indian Agricultural Research Institute, New Delhi, India for providing financial support.