Biomass and Solar: Emerging Energy Resources for India

Yogesh Shinde, Deepak Dwivedi, Poonam Khatri and Jitendra S. Sangwai

Abstract The role of energy has been central in day to day life. Non-renewables sources such as fossil fuels have been exploited to an extent that unless we find new reserves, it will be difficult to sustain the energy demand for future. Conversely, renewable forms of energy, such as biomass and solar, have shown to provide alternatives. India houses around 17% of the world's population and is bound to play a deterministic role in driving the global energy demands in near future. Responsible usage of fossil fuels while compounding the role of renewable energy sources would pave the pathway to sustainable growth without burdening the environment. In this direction, the present chapter has deliberated the potential of two important renewable energy sources, i.e., biomass and solar. The authors have discussed the current state of technology development for converting the energy from these renewable sources to usable forms such as electricity, fuels, etc. Further, a detailed account of different policy initiatives taken up by the Government of India towards the promotion of their usage has been provided. In addition, the life cycle assessment (LCA) following a systems approach have been highlighted in the chapter as a mean to ensure the sustainable energy systems meeting the requirements of future. Lastly, the chapter has given insights on likely paths to optimize the usage of renewable energy sources.

Keywords Biomass · Solar · Life cycle assessment · Policies
Sustainable energy

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1 Introduction

Climate change has emerged as a global problem of the century having impacts on environment and health. Global temperature rise is around 0.17 °C per decade starting from 1950 and this trend is expected to continue due to our heavy reliance on fossils for fulfilling energy demand [18]. The researchers from Oxford in their recent publication estimated that the climate change will be responsible for 529,000 deaths by 2050 [51]. This consequences have lead researchers and policy makers to set up a financial institution to bring the issue under high priority area. Paris agreement and Green Climate Fund (proposed in 2009 at conference of the parties (COP) 15, in operation from 2014) are among the few initiatives which were taken at world level to reduce green house gases (GHG) emission. In order to keep the earths' temperature rise below 1.5 °C [39, 42], around 90% reserves of coal, 50% of gas, and two-thirds of oil reserves need to be kept intact by 2050 which appears practically infeasible without slowing down the world's economic growth. Therefore, the current trends of unsustainable consumption of fossil fuels and concomitant pollution levels have brought attention to the renewable energy sources in both developing and industrialized countries. Technological advancements in past few decades have brought the contribution of renewable energy sector to around 14% in meeting global energy demands [53]. Increasing renewable energy share would not only minimize the pressure on fossil fuels but also has environmental benefits. European union (EU) has set a target of increasing the share of renewable energy to 20% by 2020 [15]. Developing countries also have taken several policy initiatives in this direction.

As delineated in the report published by Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat recently it is expected that India's population would be the largest by 2024. In view of the rising population and growing economy, India is expected to play a deterministic role in driving the global energy demands in near future. There are plans of one trillion dollar investment to ensure access to the clean energy for every Indian [56]. Indian economy is the third largest economy after USA and China, and is expected to grow more than five times to its current size by 2040. In order to further strengthen economy, government has announced various schemes to improve industrialization, such as 'make in India'. Energy demand of India is expected to grow from 775 million tons of oil equivalent (Mtoe) to 1133 Mtoe by 2040, with an average growth rate of 3.4% per annum [21]. Industrialization along with urbanization will further affect the energy usage pattern. Figure 1 depict the contribution of various energy sources to primary energy demand along with energy consumption by various sectors such as transport, residential, industry, etc. In current scenario, there is an urgent pressure on energy systems to grow and meet the growing energy demand in India, pushing it towards becoming dominant user of fossils [19]. In view of the limited reserves and extravagant dependence on fossil fuels, India has resorted to importing the energy resources. According to the Ministry of Petroleum and Natural Gas, India is the third largest importer of crude oil after USA and China; which has

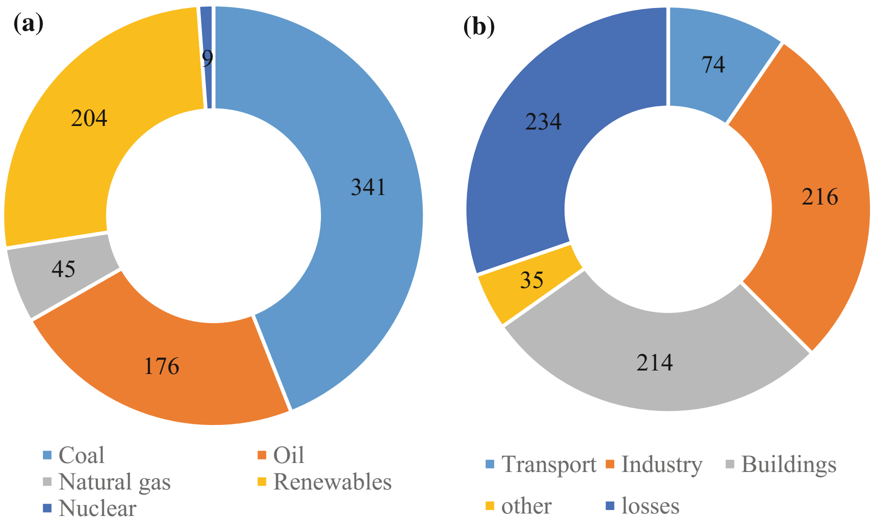

Fig. 1 Contribution of various energy sources **a** towards total energy demand and **b** consumption by different sectors of India for year 2013 in Million tons of oil equivalent (*Source* IEA [21])

imported 213 million ton worth of 70 billion USD during April 2016–2017 [57]. In addition to the economic burden, the exceeding use of fossil fuels is responsible for various environmental and health impacts which generally remained unaccounted. Achieving the optimum potential of renewable energy sources have been reckoned as an engine to bring about the transition to a future of sustainable energy [50]. India has a rich source of renewable energy available in various forms. Presently, the contribution of fossil fuels in the total primary energy demand is ~75% and rest comes from renewable sources (Fig. 1). Primarily, the growing energy demands and geopolitical pressures accompanied by limited reserves of fossils have driven the progressively increasing interest of India in renewable energy alternatives [19]. Renewable energy sources have potential for replacing the fossil fuels without further affecting the environment. Vast availability of renewable energy sources has reinforced the interest in promoting growth in the renewable energy sector in India. However, increased production of renewable energy to minimize the dependence on fossil fuels sets multiple challenges to be addressed in coherence. India's Intended Nationally Determined Contributions (INDCs) committed at COP 21 in 2015 has reinforces the attention to renewable energy industry. India targets to have 175 GW of installed capacity of renewable energy by 2030. Both biomass and solar would play major role in shaping the energy market in India. In order to accomplish its INDCs, multitude of efforts have been initiated at various levels, for an example draft report of third National Electricity Plan have specified that all renewable energy alternative together would account for 56% in the India's total installed power capacity by 2027. Here, an effort is made to highlight the importance of biomass and solar based renewable energy systems in India. Different schemes, action plans, challenges and emerging technologies in biomass and solar are discussed. It has also emphasized on taking a holistic approach for growing the renewable energy share in India incorporating the aspects of economic feasibility, environmental friendliness and societal welfare into account [45].

Although lot of research have been done already in biomass and solar energy, but some questions are still remained unanswered. These are primarily impact of biomass in carbon emission reduction, impact of solar energy in improving India's rural economy and large scale applicability of solar energy in transportation, etc. Considering these facts, the importance of biomass and solar energy in regards to India's future and described the policies related to these energy sources. A brief discussion has also been presented on the renewable energy sources. This chapter also includes the information about the lapses in the existing policies and thorough analysis of earlier conducted research and published reports which will lead to pave the way for the future policy design. It is worth to note that bioenergy has been emerging energy technology despite being some earlier evinced failures, and this has been explained in the life cycle assessment (LCA) analysis. LCA also confirmed about the complexities involved in the assessment process.

This book chapter is uniquely designed for the readers to provide information about the current state of the Government of India's policies in biomass and solar energy which is useful to understand the sequential progress made in these areas. Authors also discussed about various barriers in implementation of policies, impact of current socio-economic conditions on these energy sources and recent development made in these areas.

2 Biomass Based Energy Sources

Biomass is generally a plant material available abundantly in varied forms including dedicated energy crops and trees, agriculture food and feed crop residue, aquatic plants, microalgae, wood and wood residue, animal waste and other waste material [30]. While there are different renewable sources of energy such as wind, solar, hydropower, only agricultural biomass is the renewable carbon source [14]. Though biomass consumption has been continuing since ancient time, the advanced use of biomass for a variety of energy needs such as biofuel and power generation is relatively recent. Its use for biofuel and power generation does not add to the carbon dioxide emission. Theoretically the process is cyclic and sustainable use of biomass is expected to emit carbon almost equal to the amount sequestered during photosynthesis [49]. This new development has instigated further research and development in the biomass based energy systems. The substitution of fossil based carbon such as coal and crude oil with renewable biomass carbon has been recognized as a new platform of opportunities such as biofuels, electricity, heat, and biomaterials [14]. In view of the continuing energy demands and finite availability of fossil fuels, India has emerged as a strong promoter of renewable energy sources.

Several studies have estimated the biomass energy potential for India [19, 47, 49, 50] and some studies have provided descriptions for different biomass conversion routes [14, 27, 30, 33, 34, 49]. In an assessment of bioenergy potential from crop residues in India, it has been estimated that India produces 686 MT gross biomass annually of which 234 MT (34% of gross) has been estimated as surplus for bioenergy application which is equivalent to 17% of India's total primary energy consumption [19]. Among the states, Uttar Pradesh ranked at the top and sugarcane topped amongst all the crops. Singh and Gu [49] provided a critique on the scope, potential and implementation of biomass conversion to energy in Indian scenario. Though various studies have given estimates of biomass energy potential, accurate estimates for regional levels are still scarce [30]. Maity [30, 31] assimilated different estimates provided by government bodies (Ministry of Petroleum and Natural Gas, Ministry of New and Renewable Energy) for the potential generation of renewable energy sources. The surplus biomass can produce about 18 GW of power annually. The petroleum consumption for the year 2010–11 was 14.18×10^7 metric tons with major share accounted by transportation fuels, high speed diesel oil (42.2%), motor gasoline (10%) and aviation turbine fuel (3.6%). If all surplus biomass can be processed sustainably, it would substitute ~10% petroleum, ~90% petrol or ~22% diesel. The estimations for biomass in the form of non-edible oilseeds during 2010–11 amounted to ~20 MT with substitution equivalent of 2.5% for petroleum consumption. Similarly, the microalgae has been identified as rich triglycerides feedstocks which can be processed to produce petroleum diesel. The microalgae exhibit high productivity of ~20–22 g/m^2/d which if cultivated on a hectare land would produce biodiesel equivalent to 18.8–20.7 t (with 30% oil content by weight). Considering such high productivity, the estimations for microbial biomass have showed that diverting only 3% of arable land and 12–18% jatropha cultivation area to microalgae can produce biodiesel sufficient to meet transportation fuel demands. Though all the crop residues cannot be used for power generation, ~15–20% can be used without impacting the present usage for cooking and animal feeds. Additional improvement in biomass energy potential has been foreseen through technical improvements in cookstoves. Traditional cookstoves exhibit poor fuel use efficiency, ~10%, which if raised to, say 20%, can add 100 MT of the surplus biomass [9]. However, actual realization of bioenergy potential in India has been much lower than the estimated potential. This indicates huge scope of research advancements in the area in order to ensure complete utilization of the biomass potential.

There are three driving forces for attracting the progressively increasing interest in biomass based energy systems, namely reduced environmental emissions, more energy, and employment [10]. Several studies reported that developing countries have sizeable potential for large biomass production capacity in the longer term, thereby creating more income sources and employment [19]. Biomass based energy systems are generally located near their production site to be economical and the technological developments regarding the biomass conversion routes gives them a competitive advantage. The advanced technological options has showed cost-effective use of energy crops, e.g., gasification processes producing methanol and hydrogen which can be used as transportation fuels. Though the biomass energy market in India has not yet reached its optimum potential, developed nations including Europe and US have established biomass markets through the use of non-agricultural lands [49] and policy regulations.

Direct combustion of biomass has been the oldest way of producing energy. Other most commonly used conversion pathways to convert biomass into energy include: thermal (gasification and pyrolysis), biochemical (anaerobic digestion and fermentation) and chemical (transesterification). Thermochemical conversion involving thermal decay and chemical reformation of biomass in the presence of different oxygen levels has been proved to be advantageous over biochemical conversion since it can convert all the organic components [34]. The thermo-chemical conversion of biomass takes place through different processes such as pyrolysis, gasification and combustion for converting it into useful forms of energy. Anex et al. [3] have compared the biochemical and thermochemical pathways for converting biomass into fuel, and based on their economic analysis they concluded that the pyrolysis is the cheapest route for such conversion. Liu et al. 2014 found that, the stand-alone biomass-to-liquid fuel plants are anticipated to yield fuels in the range of $2.00–5.50 per gallon gasoline equivalent with pyrolysis the lowest and with biochemical the highest.

The biomass unlike any other renewable energy source is capable of producing multilayered outputs including all forms of energy, chemicals and polymers through integration of different conversion routes in a biorefinery. Though the research in this area is still underdeveloped, the concept of processing biomass to produce biofuels and large number of biochemicals has been considered analogous to a petroleum refinery and petrochemical industry termed as biorefinery [14, 30, 31].

2.1 *Biorefinery: Going Beyond Generation of Power and Fuel*

Crude oil is the feedstock in a petroleum refinery, which is refined into fuels and chemicals for petrochemical industry. For instance, naphtha is raw material for production of several building block chemicals (synthetic gas, olefins and aromatics) in petrochemical industry. Currently, more than 90% of the organic chemicals are derived from the fossils based building blocks [30]. Another important raw material other than naphtha is natural gas. It has been estimated that petrochemical industry consume around 10% of petroleum refinery output in form of naphtha and ~30% of natural gas to produce these building block chemicals. Strong dependence of mankind on intensive consumption of limited fossil reserves causing environmental and health impacts has compelled the development of renewable energy alternatives. Among all renewable energy sources, biomass has shown to be most favoured fossil fuel alternative for producing transportation fuels and other chemicals, as it is the only carbon rich renewable energy source. Several studies reported that biomass can be processed to produce alternatives of these fossil fuel derived building block chemicals. However, the predominant use of biomass, so far, has remained limited to fuels and energy.

This quest for making biomass systems analogous to petroleum based systems has given attention to the concept of biorefinery. International Energy Agency (IEA) defines biorefinery as "Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy" [13]. Biomass refinery analogous to a petroleum refinery uses biomass as a feedstock to produce biofuels and a variety of biobased products through the integration of various conversion routes [14, 30, 31]. Criterion for classifying different existing and emerging biorefinery systems is heterogeneous in nature. Cherubini [14] attempted to provide a common classification approach based on four key aspects of a biorefinery, i.e., platforms, products, feedstocks and processes. Major classification type for biorefinery systems has been the type of conversion routes used in a biorefinery which classify them into three phases: I, II and III [23]. Phase I biorefineries generally has fixed processing capacities and use grain as feedstock. A dry mill ethanol plant is an example of phase I biorefinery. Phase II biorefineries allow processing flexibility. They also use grains as feedstock to produce an amalgam of products depending on the demands and market price. They employ a wet milling technology. Example of products include starch, ethanol, high fructose corn syrup and corn oil. The phase III biorefineries are considered most advanced as they use a mixture of biomass (whole crop, green biomass, lignocellulose feedstock) and combination of technologies to produce a multitude of products.

The biomass based fuels are characterized as first and second generation biofuels. The first generation biofuels are produced from seed or grain part of the plant (e.g., sugarcane, starch crops, rapeseed). It is the first generation biofuels which has actually showed competition with food industry and raised environmental concerns [14]. Their extended use is further influenced by the impacts on soil fertility along with the consumption of energy in production and conversion of the crop. The limitation identified in the use of first generation biofuels can be overcome in a biorefinery through production of second generation biofuels along with a variety of platform chemicals [27]. Further, the nature of biomass is heterogenous similar to conventional fossil fuels and producing only energy from biomass limits the complete utilization of their potential. Therefore, to become a true alternative to fossil fuels, biomass needs to also provide the alternatives of both fuels and platform chemicals. Cherubini [14] identified three main drivers, namely climate change, energy security and rural development for using biomass to produce bioenergy, biofuels and biomaterials and chemicals. In a biorefinery, the plant metabolites (primary and secondary) produced through photosynthesis can be processed to create industrially important platform chemicals as in petroleum refineries [34]. The primary metabolites are carbohydrates (sugars, cellulose, hemicellulose) and lignins termed as lignocellulosic biomass which can be converted into biofuels. These biofuels are called second generation biofuels avoiding the competition with food industry. The secondary metabolites, present in low amount, include biochemicals (gums, rubber, resins, waxes, terpenes, tannin, alkaloids, etc.) of high value. These secondary metabolites can be processed in a biorefinery to produce high value chemicals such as bioplastics, food flavours, pharmaceuticals and nutraceuticals. Based on the model of a petroleum refinery, Pacific Northwest National Laboratory (PNNL) and National Renewable Energy Laboratory (NREL) identified 12 building block chemicals that can be derived from biomass in birefinery [55]. An increasing interest in the development of biorefinery systems of both researchers and policy makers has also been acknowledged through various policy initiatives [15] founded on research attempts aiming at minimizing the dependence on fossil fuels.

Further, the second generation biofuelshave produced as truly carbon negative energy source. However, the progressively increasing use of biomass for producing a spectrum of products (materials as well as energy security) need to be examined for their overall sustainability [14]. Overall sustainability here means considering the environmental trade-offs of entire life cycle starting from cultivation of biomass crops to its conversion process and use stage. Consideration of all upstream and downstream processes while incorporating all the environmental trade-offs/impacts would provide an unbiased picture of their sustainability in comparison with fossil based systems. LCA is an appropriate tool for such comparisons.

2.2 *Biofuel Policies in India*

The energy crisis of 1970 compelled the policy makers worldwide to set up policies for development and evolution of renewable energy sources including biomass [50]. India is the third largest importer of crude oils,industry and transport sectors together account for half of the total energy consumed (Fig. 1). The high energy demand is predominantly constituted by coal (in industry), petroleum (in transport), and electricity (in buildings, industry, and agriculture). Considering a 10% annual growth in number of vehicles, petroleum use will continue to expand, particularly in road transport, which account for significant share of passenger (90%) and freight movement (60%). Currently, the transportation fuel demand is mainly shared by diesel (46%) and gasoline (24%). The average demand for transport fuels is estimated to rise from 134 billion liters in 2015 to 225 billion liters in 2026. The current growth in transportation and consequent increase in petroleum consumption aggravate the environmental concerns. Government of India (GoI) is targeting EURO-III and IV as reference emission norms for vehicles, which in turn necessitate fuels to be clean and green [4]. The biomass based fuels have shown to be a promising alternative to curb the crude oil dependency and thus biomass based policies have received great attention in recent years.

In India, the major policy development in the area of biomass energy started in 1980s with small scale technologies when focus was to improve the efficiency and quality of traditional biomass in form of improved cook stoves and biogas. A medium-scale focused policy development referred to biomass gasification technology. It was aimed at providing the conventional energy sources from biomass, i.e. electricity. The evolution of long term policy goals started in 1990s with aim of creating institutional support for the formulation and implementation of biomass energy technologies at both micro and macro levels. Department of Non-conventional Energy Sources (DNES) was upgraded to Ministry of Non-conventional Energy Sources (MNES). This new institution set up provided more financial support to the widening scope of renewable energy promotion activities as well as the research and development. The reformation of MNES as Ministry of New and Renewable Energy in 2006 speeded up the progress and became highest institution in the renewable energy sector formulating and implementing policy strategies in all sectors including biomass.

An important point of policy evolution related to biomass energy was the setting up National Policy on Biofuels in 2009. The overarching goal of the policy was to ensure biofuels (bioethanol and biodiesel) availability in the market to meet the demands of transport fuels at any given time. The policy indicated a target of replacing 20% of petroleum fuel consumption with blending biofuels by the year 2017. Biofuels are viewed as a means to reducing dependence on imported fossil fuels and meeting energy needs through the use of non-food feedstocks. With the aim of increasing biofuels production GoI is promoting and encouraging: (a) ethanol derived from sugar molasses/juice for blending with gasoline, (b) biodiesel derived from non-edible oils and oil waste for blending with diesel, and (c) bio-methanol and biosynthetic fuels [4].

To meet the policy objectives, blending level of 5% ethanol in petrol was made mandatory by GoI in 2003 under the Ethanol Blending Programme (EBP). Ethanol is mainly produced from sugarcane molasses, a by-product of sugar production. The supply of ethanol has been controlled by cyclic production of sugarcane. Low availability of sugarcane molasses raise their price and therefore impacts the cost of ethanol production which in turn interrupt the supply of ethanol for EBP. Although the GoI has taken multidimensional steps to promote the biofuels production, the targets of achieving 20% blending appear far away [7]. India's current ethanol production in the year 2017 allow blending of only 2% [4].

GoI started National Mission on Biodiesel in 2003 to reduce the burden on ethanol production and to address the environmental concerns. Two phases were proposed in the mission: first, a demonstration project in Phase 1 by 2006–2007 and second, a self-sustaining expansion in phase 2 by 2011–2012. Jatropha was identified a most suitable tree borne non-edible oilseed for biodiesel production. The central government and several state governments provided incentives for supporting jatropha cultivation. Biodiesel purchase policy was also launched in 2006 as a potential tool to achieve socio-economic and environmental benefits. However, the ambitious target of achieving 20% blending remained unattainable due to insufficient feedstock (jatropha seeds) and lack of high-yielding drought-tolerant crop cultivars. Ultimately, a solution for reducing the dependence on imported fuels with associated socio-economic and environmental benefits can be seen in the promotion of second and third generation biofuels production. Government's support, subsidies, and fuel blending mandates would be crucial for the improving the competitiveness and scale of economies in the biofuels industry [7].

2.3 Challenges to Biofuel

Biofuel production has received huge attention of policy makers as well as scientific community to combat the challenges of limited supply of fossil fuels and growing deficit of energy. The strong commitment has been made visible in the policy initiatives, institutional set-ups and articulated via persuasive research efforts in this direction. Government's subsidies, fuel mandates and targets have been supportive to great extent in protecting the biofuels industry. However, the biofuels production in India has not yet achieved the desired targets in term of techno-economics as well as social aspects. The biofuel policies being promoted with assertion have failed in execution. In addition, the environmental sustainability of biofuels (first-generation) has often been misleadingly presented as carbon neutral. This section give description of different challenges to biofuels that needs to be tackled for meeting the goals of reduced dependence on fossil fuels.

Biofuels in India are mostly first-generation fuels and sugarcane being the most common feed stock followed by initially successful jatropha. The rising renewable energy market and ambitious ethanol blending goals (20% by 2020) seek increased production of sugarcane which in turn require more water, agriculture land and has competition with food industry. Jatropha based first generation biofuel production has also been hindered by the lack of availability in from of inadequate infrastructure for seed collection, transport and treatment [7]. Second generation biofuels from biomass have been identified as an answer to the challenges of first generation biofuels as biomass is anyway produced as a by-product of food production. The quantity of biomass produced in India is sufficient to meet the target of 20% biodiesel blending by 2030. However, lack of proper mechanisms for collection, storage and transport of biomass are important barriers preventing to achieve the desired levels of bioenergy production. Thus, management of the biomass supplies and transport for industrial operation makes an important hotspot of improving the bioenergy production. Providing incentives and infrastructure support for collection of biomass feedstocks can be considered as a first step by the policy makers [38]. Another hindrance in the second generation biofuels is high capital investment associated with large risks. According to an estimate, achieving the targets of national policy on biofuels would require an investment of US$ 32 billion by 2020 [38]. The required investment is blocked by different barriers in form of immature technology, uncertainty in market and policy support for second generation biofuels [20]. The advanced biofuel technology for producing second generation biofuels is very young and it need large scale demonstration of projects to attract the large investments. Besides the government support, there is an immediate need of investment from private companies like petroleum companies. Hindustan Petroleum Corporation Limited (HPCL) in 2016 has set India's first second generation ethanol based biorefinery in Punjab. As Punjab is rich source of biomass feedstock, the biorefinery anticipates to meet 26% requirement of ethanol blending for Punjab, reduce GHG emissions while creating around 1200 jobs throughout the supply chain. The successful implementation of second generation biofuel based refinery can reduce GHG emissions as compare to the first generation biofuels. In achieving the goals of national policy on biofuels employing second generation biofuels would save 53 million tons of CO_2 eq. by 2020 [38].

2.4 *Biomass to Power Policies in India*

India has been able to achieve a great progress in advancing the access to energy in recent years. Electric form of energy has become an integral part of the socio-economic and infrastructural development of the country in agriculture and industry. India's power generation capacity has shown a significant rise while grappling with the risky financial situation of local distribution companies and transmission and distribution losses. The total installed capacity of power generation (as on 31 March 2017) is 329.23 GW. Of the total power generation capacity, ~67% is contributed by fossil fuel based sources, 17.4% by renewable energy sources (solar, biomass and wind) and 13.6% by hydro sources (Fig. 2). GoI in its Intended Nationally Determined Contribution (INDC) towards United Nations Framework Convention on Climate Change (UNFCC) has aimed higher by setting a target of reaching 175 GW (40%) of renewable energy capacity by 2030 (MNRE, 2017). This appears very ambitious goal in perspective of today's level of 37 GW.

Though 240 million people still remains without access to electricity, this number is almost half of that in year 2000. Most of population without access to electricity reside in rural areas and the demand for electricity in rural areas is increasing at 7% growth rate [9]. The key factor which restrict the electrification of remote villages is localization of fossil energy based generation of electricity, necessitating huge transmission network. Further, the transmission and distribution losses would reduce the efficacy of capacity addition. Therefore, using the locally

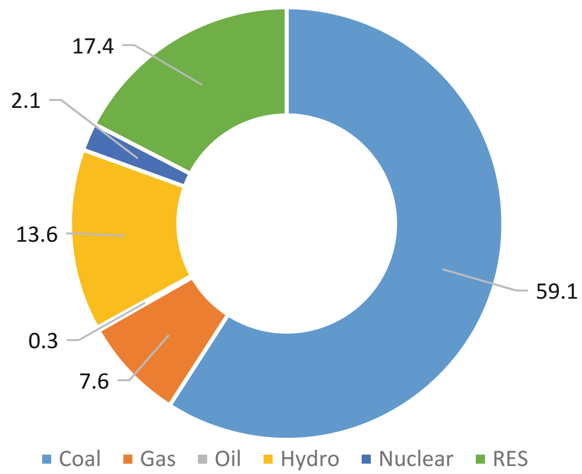

Fig. 2 Power generation capacity in India through various sources, 2017 (*Source* Ministry of power, GoI)

available renewable energy sources for decentralized electricity generation is apparently viable option for electrifying the remote villages [9]. The National Electricity Policy (NEP) announced by Government of India along with other rural electrification programmes such as Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) have been centred around improvement of rural electrification. The RGGVY launched in 2005aimed at providing electricity to villages with 100 or more residents and free electricity to people from economically weak section (below the poverty line). After the difficulties in implementation, the program was resumed in 2015 within a new scheme of Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) [21].

The NEP emphasize on using renewable energy sources in all the villages including those having grid connectivity. This intends to reduce the load of grid provided the decentralized electricity generation is economically viable. Sustainable energy supply can be foreseen through energy conservation and increased use of renewable energy [27]. Potential renewable energy sources for decentralized electrification include solar photovoltaics, wind mills, small-scale hydropower plants and biomass gasifiers. The selection of optimal renewable energy source is dependent on the geography and the source available. Biomass, more than any other renewable energy source, has uniform and abundant availability at low rates. The desired potential of biomass for meeting the energy demands can be validated through the estimations of potential of surplus biomass for power production in India which is about 18 GW [9]. Many other advantages that come into sight from the substitution of fossil fuels with biomass for power generation include low cost, low environmental emissions, improved security of supply and employment opportunities.

Even though large potential estimates for biomass to power conversion indicate a win-win situation by curbing fossil fuel consumption and using renewable sources, the actual conversion of biomass to power is limited by inadequate collection, handling and transport. The lack of proper collection and transport mechanisms and incentives often leave farmers with the option of burning the crop residues. Further, the biomass produced at manufacturing industries are mostly found with high moisture levels which require drying before conversion. Lack of a functional market for biomass render farmers and several small to medium industries discard their biomass as waste. Both open biomass burning in farms and industrial biomass wastes cause environment pollution. There is an urgent need of proper collection and transport systems for economic and environment friendly operation of decentralized biomass conversion plants. The need appropriate collection mechanism and incentives calls for an action from policy makers in increasing the share of biomass resources in India's energy mix. Optimizing the biomass feedstock's supply would become a turning point in aspect of energy security and combating the climate change.

Buragohain et al. [9] indicated two possible technologies for electricity production from biomass: (1) biomass gasification coupled with an IC engine operating on producer gas, and (2) boiler-steam turbine route or cogeneration. GoI has undertaken several programs to realize the biomass potential through two major schemes: (1) grid interactive and off-grid, and (2) distributed renewable power. Under the grid interactive and off-grid scheme MNRE implemented Biomass Power/Cogeneration Program in the mid 1990s with a macro level focus on sugar mills. It was aimed at promotion of large-scale technologies and provided incentives (financial and fiscal) to the participating sugar mills for power generation and cogeneration. In the scheme of distributed renewable power, MNRE implemented a sector oriented program named Biomass Energy and Cogeneration (Non-Bagasse) in 2005. The program promoted medium- to large-scale biomass technologies such as biomass gasifier and biomass co-generation (non-bagasse). The focus of the program was broad covering pulp and paper, textiles, fertilizers, petroleum, petrochemicals, and food processing industries. It had twin objectives i.e. to supply heat and electricity for industrial operations and to feed the surplus power in the main grid, therby reducing its load. Ultimately, it was aimed at reducing the GHG emissions from industrial operations and the overall sector. The Biomass Gasifier Program, another program in distributed biomass power scheme, was implemented through collective efforts of government and non-government bodies. The program focused on both micro and macro levels. At micro level, this program aimed at promoting and increasing the biogas power generation capacity at small scale such as meeting the electricity demands of households and small-scale industries. At the macro level, it aimed at promoting distribution projects for engines running on biogas, paired with biomass gasifier for off-grid and grid power operation. In addition to these programs, several other initiatives have been taken by central and state government bodies to harness the biomass energy potential. Biomass power generation sector is expanding day by day, with annual investment of 600 crores INR and generation of 5000 million kWh of electricity along with total employment of 10 million man-days in rural sector [1, 9].

Overall, the biomass energy policies adopted and implemented by the GoI have led to significant outputs in the form of energy infrastructure. With the support of various enabling mechanisms, India's bioenergy sector is expected to contribute 10 GW in its INDC targets of 175 GW from renewable energy sector. Several ongoing efforts have resulted in enhancing the biomass based installed capacity from 3 GW in the year 2012 to about 5 GW in year 2015. Presently, 5 GW of total installed capacity of power has been reached from 500 biomass (power and cogeneration) projects which is used for feeding to grid (as on December 2015). In addition, around 30 biomass power projects and 70 biomass cogeneration projects aggregating to 350 and 800 MW capacity, respectively are under various stages of implementation [48]. These achievements have contributed in increasing the energy supply and usage at both micro and macro levels. Furthermore, the policy implementation has resulted in capacity building of biomass based plants [50]. The government through its policies and strategies, therefore, has been an important factor for reaching so far in tapping the biomass energy potential and there is much more to capture. Capacity building programs and commercialization activities have contributed in human resource and knowledge development. Establishment of Sardar Swaran Singh National Institute of Renewable Energy (SSS-NIRE) by MNRE is an important achievement in the perspective of capacity building. It is an autonomous institute focussed on carrying out state of the art research and development and activities oriented on commercialization of renewable energy technologies in India. An example of latest initiative taken by MNRE in this direction is SSS-NIRE Bioenergy Promotion Fellowship convened by institute.

3 Solar Enrgy in India

The government of India (GoI) is aiming at increasing the access to clean and affordable energy through renewable energy sources. Considering the topography of Indian states, solar based energy technologies can be effectively utilized for meeting the demands of per capita energy consumption by harnessing the solar energy. Solar based energy technologies would save the transmission and transportation cost, thereby making it an economic and versatile energy alternative for developing countries including India. Government is actively participating to make the solar alliance partner where around 121 countries participating to share technology and finance for achieving the aim of poverty elimination [58]. Promoting the solar energy technologies has contributed in socio-economic development and poverty elimination by providing jobs and cheap electricity [59]. For example, recently 12,000 solar pumps were distributed to farmers in Chhattisgarh with subsidized rate under the scheme called "Ujjwala Yojna" [60]. Another identified area of potential application of solar energy is in public transportation as highlighted by the Indian Railway's interest in installing solar panels at the top of 250 trains in order to reduce the fuel cost [61, 62].

Solar energy can be utilized either in direct or indirect manner: Direct application of solar energy includes utilization of solar radiations for photovoltaic devices and indirect application includes utilization of solar energy in apparent form such as wind, mini hydro, biomass etc. Direct application of solar energy involves utilization of thermal component of solar radiation through solar water heaters, solar cookers etc. whereas the energy component of solar radiation gets utilized in solar photovoltaics (PV). Solar PV devices convert solar energy into electricity and later this energy can be utilized for various application in industrial and residential sectors. The solar insolation received in the form of $\sim$3000 h (equivalent to 5000 trillion kWh) of sun light supports industry and service sector to utilize this technique [46]. Geographical coordinates of India ensures maximum availability of solar radiation for different application. Most of the Indian states' received typically 1500–2500 kWh solar radiation/m^2 with significant bright illuminating sunny days (Fig. 3). It is worth to mention that western Indian region receives greater amount of solar radiation compared to eastern parts, which justifies the higher attention given by solar companies to the western India, potentially in Rajasthan and Gujarat. Ministry of New and Renewable Energy (MNRE), Department of Science and Technology (DST) along with their associated partners and stakeholders, such as Indian Renewable Energy Development Agency (IREDA) etc., are diligently promoting research and development (R&D) and commercialization in solar energy

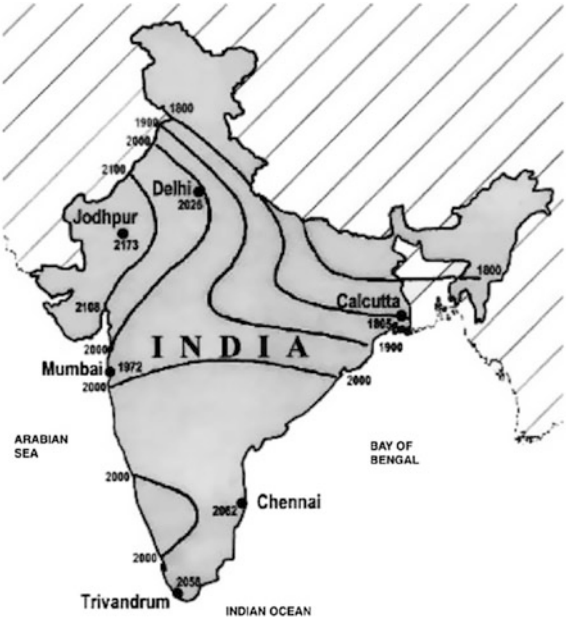

Fig. 3 The distribution of annual solar irradiation, kWh/m^2 (*Source* Muneer et al. [32]) (Reprinted from Publication "Muneer et al. [32]" with permission from Elsevier)

technologies in India. The scheme launched by GoI called-"National Solar Mission" is specifically designed for promotion of solar energy in India aiming to accelerate the solar cell manufacturing with indigenous technology. This mission also aims to develop a skilled manpower for promoting solar energy application. For example, programme called, "Surya Mitra" is one of the scheme of Indian government operated under the flagship of National Institute of Solar Energy (NISE) who runs this scheme with the collaboration of various states' nodal agencies and other partners which comes under MNRE support [63]. This scheme indirectly supports National Solar Mission by developing skilled manpower for promotion and growth of solar PV market in India. Expansion of job market in solar energy and maintaining job opportunities is essential to make the scheme sustainable in long term. There are various provisions and action plans has been designed under the National Solar Mission which needs to be explored to get a clear understanding about the India's solar action plan, therefore in the next section, we will be discussing about the National Solar Mission plan of India in detail.

3.1 National Solar Mission

In India, about 20% population living without electricity access because of the large energy deficit, which was around 11% in 2009 and dropped down up-to 2.9% during 2015–16 [64]. It should be highlighted that per capita energy consumption of India is less than one third of that of world and it is lowest as compared to other BRICS countries. Figure 4 depicts the current status of power generation and surplus for Indian states.

As discussed earlier, being a growing economy power demand in all the sectors is increasing continuously. Thus, to meet growing demand of power, GoI has aimed high in solar power due to its supportive geographical positioning of India, which supports in getting significant solar radiation. In November 2009, GoI launched Jawaharlal Nehru Solar Mission, which was designed to support National Action Plan for Climate Change and supports the other schemes which are currently being operated simultaneously. Under the solar mission, India aims to increase its grid connected solar power capacity up to 100 GW by 2022 whereas earlier the target was to increase the capacity up to 20 GW [64]. The mission was designed in 3 phases, currently transiting from phase two to phase three. The first phase of solar mission was finished in 2013 which was considered as shortest phase in the mission. The phase 3 would run from 2017 to 2022. It is worth to highlight that

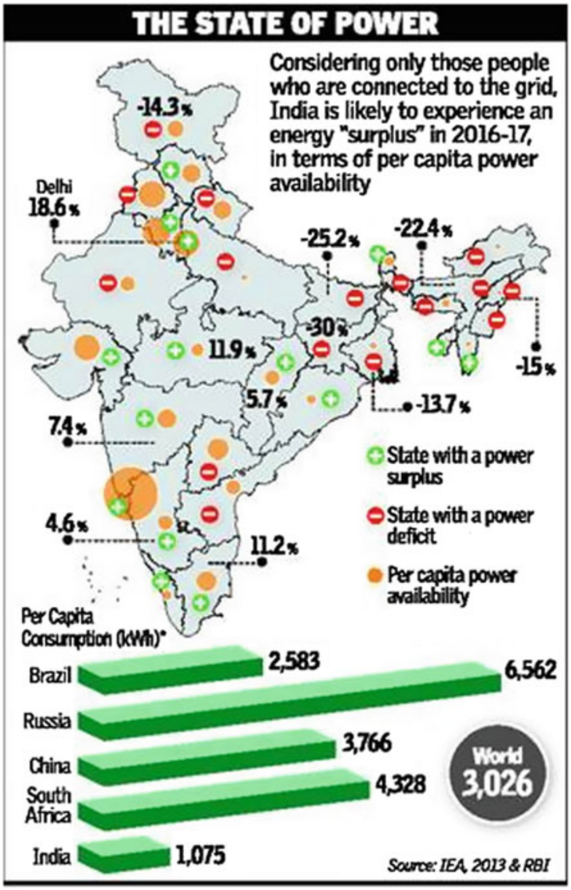

Fig. 4 Indian states position (2013) for power surplus condition (*Source* IEA and RBI) [64]

readjustment in pre-decided target is possible under this scheme and can be done based on the various operating situations. Each phase in solar mission has specific targets and provides flexibility to renew or update the new or existing targets based on the progress made in earlier phases. As delineated earlier, important component of the program is to encourage indigenous manufacturing and production of solar energy appliances. Here in this section, we will briefly discuss about some of the targets set up for all three phases of the 'National Solar Mission'.

Phase one of solar mission was devoted to the solar roof top and grid connected small solar plant installation cum power generation. Government has allocated around 4337 crores to achieve the target. Precisely it was decided to achieve 1000 MW power generation from grid connected solar power plant [65] [26]. The first phase of solar mission promoted roof top and small grid connected power sources and was designed in a way that these power generating devices get efficient power from distribution system. Provision of low interest rate and subsidy was affirmed by regulating body of national solar mission. No specific plan was designed for specific type of solar cell modules such as crystalline solar cell, amorphous solar cell and thin film solar cell. Also, manufacturing of solar cell modules contained less attention in the 1st phase, whose impact was clearly shown in the upcoming stages of the mission. Now the scheme called "Surya Mitra" etc. is compensating the damages.

The phase two aimed to achieve 10 GW power generation. Unlike phase one, the responsibilities of state and central government were divided in this phase. The central and state governments was assigned to achieve 4 GW and 6 GW of power generation target [66, 67]. Development of solar cities, skilled human resource development, solar parks, promotion of solar cookers and solar water pumps including solar water heating system are other promising characteristics of the second phase of the scheme. In the summary, phase two was fully devoted in designing a program which affects the common people of India through providing low cost energy service and generating jobs. Although the jobs were not created as it was expected because of global economic slowdown. Further, uncertain market condition and unestablished tax policies made the scenario worst for solar energy [68]. Readers should note that jobs creation was not among the priority in the first stage of the solar mission, therefore the skilled labors were not developed at the initial stages of the mission. This made an adverse effect on installation of solar power plants because investors were lagging with the supply of labors [69]. The solar mission of India is implemented through various mechanism which is described schematically in Fig. 5, which can be divided in 4 parts.

3.2 Implementation of National Solar Mission

The long term policy explains the use of step by step designing of policy which provides flexibility to correct the errors (that were occurred in earlier stages). The step by step policy designing also provided the time to examine the existing

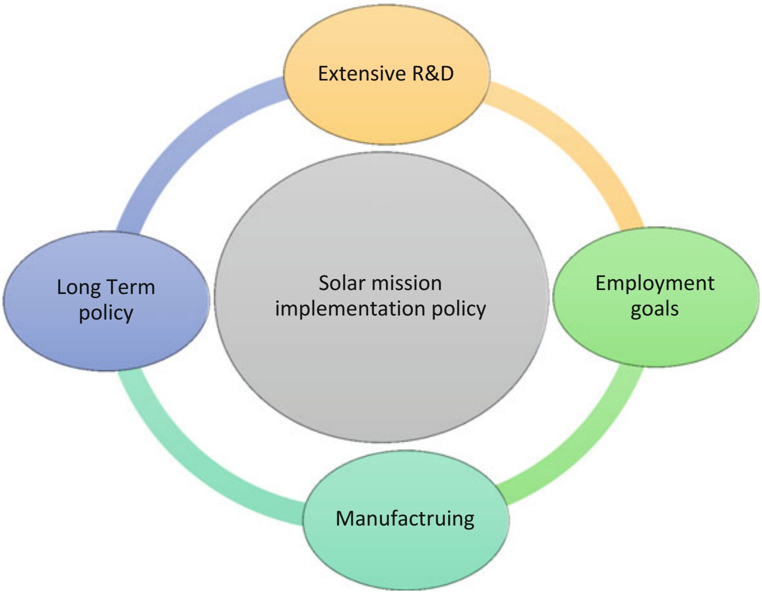

Fig. 5 Schematic of implementation mechanism of National solar mission in India

policies' results and to understand the flaws in each stages. Readers should be cautious that flaws could have been occurred either due to the policy failure or due to the unavoidable circumstances generated due to the global economic conditions. Policy paralysis may also include the human error such as improper human resources etc. could be a prominent factors for failures.

The analysis of each step would tell about the time period where maximum and minimum efficiency of implemented policy has been achieved and the factors responsible for it. The component of R&D involved research fund allocation under the flagship of MNRE and DST. The government aims to support research in solar PV for promoting new developments and innovation in this area and to make those innovations accessible for the common and poor people. The academic institutes are encouraged to participate in the existing program. This strategy will support in the knowledge and database generation and also encourage students and university to develop sound research infrastructure for conducting research. These fellowships are also supporting National Solar Mission policy indirectly because if researchers availing these government supported fellowships may get involved with PV based research. These fellowships encourage them to choose their area of interest which could be range of fields such as Si solar cells, thin film solar cell, policy design etc. Bhaskara advanced solar energy fellowship program has also been launched which allows Indian students and scientists to get exposed to USA based labs, working in solar energies [70].

Solar PV module manufacturing is another area which needs sound policy design. The manufacturing sector's policy must be designed in a way that it promotes solar PV manufacturing and installations in India. This can be done through supporting the development of solar parks across India. As delineated earlier, employment generation is an important component of the solar policy of India and that is interlinked with policies designed for manufacturing sectors. Figure 6 elucidates the types of jobs which will be generated by 2022 in solar energy sector but still sufficient job creation remain a challenge for India's solar mission.

Therefore government of India has decided to develop various solar parks which are designed to support in job creation and to enhance the existing manufacturing capacity in solar energy sector. Government of India has sanctioned 34 solar parks across the country to achieve the power generation capacity of about 20,000 MW. It should be noted that the notification issued by MNRE on 16.06.2016 [72] sanctioned the highest capacity solar park in Karnataka (2000 MW) whereas the lowest capacity solar park was allocated to Meghalaya (20 MW).

3.3 Challenges in National Solar Mission

The initiatives taken by Indian govenrment have received great applaud by national [73] and international media [74, 75]. The article published in New York Times articulated that solar energy prices per kWh electricity generation in India would go down up to 2.44 INR from the current price of 7 INR approximately. Such great fall in price would be worthy enough for the poor people in a developing country like India. Therefore, the application of solar energy would be advanced if solar power

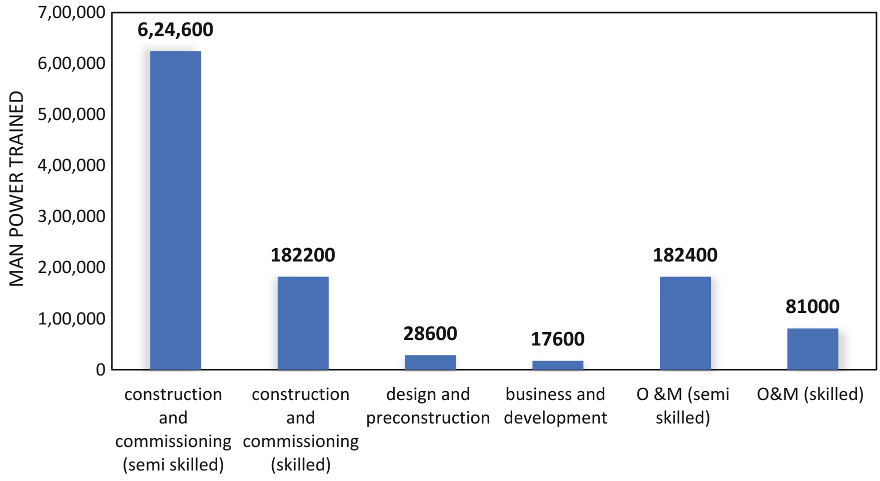

Fig. 6 Number and types of job creation in solar sector by 2022 [71]. [Reprinted from "CEEW and NRDC [11]" with permission from Council on Energy, Environment and Water (www.ceew.in)]

price gets cheaper than those of coal based power. The price reduction will bring down the cost to grid supply and will attract investors to invest in grid connected solar PV plant, an opportunity for more job creation. However, there are several challenges which would come across during the policy implementation and also in designing the future policy. The next sectionis illustrating these challenges briefly.

3.3.1 Awareness and Encouragement Among People

Illiteracy rate in India is a major hurdle for the National Solar Mission. The majority of population lives in the villages and without motivating farmers, children and youth to indulge themselves with solar appliances in their life, it will be difficult to achieve the real goal of the mission. Therefore it becomes essential to educate them about the benefits of solar power and solar energies role in their daily life application. For example, heavy farming states such as Punjab and Chhattisgarh are currently facing a problem of disturbance in rain fall pattern as a result of global warming. It is worth to mention that India has been recognized as 3rd largest GHG emitter [42]. The strategies elucidated in Table 1 could be adopted for the purpose of awareness and encouragement among people. However, it cannot be denied that in a developing economy like India it is hard for the consumers to afford roof top PV, solar cookers etc. due to high cost.

The only way which would enable people to get indulge with solar based devices is through bringing public awareness about the benefits of solar energy application and the government support in form of subsidies. Though, solar energy prices are coming down but initial cost of installation is still very high and making solar technology less attractive specifically for farmers and below poverty line families. It is worth to note that less efficient (cheaply available) solar panels make the energy output less effective than the application of costly and efficient panels and therefore poverty is an important factor for India's solar energy policy [35]. The only way which would enable people to get indulge with solar based devices is through bringing public awareness about the benefits of solar energy application and the government support is in form of subsidies. Apart from these circumstances, few other factors such as illiteracy and inadequate understanding in pay back process have also been identified as barriers for India's solar energy sector. Illiteracy is the biggest threat for India's solar growth plan including the growth of solar mission and other development programs. UNESCO's report has pointed out the illiteracy problem in Indian adults which postulated about the illiteracy of one out of four Indian adult [52]. Therefore, educating the adults about solar power becomes essential to achieve the desired goals of India's solar mission. Other important components include education and training [8]. Higher education may not be required in this regards whereas basic secondary education including vocational training about solar energy may serve the purpose in efficient manner. Solar mitra (described later in this chapter) is an exclusive example and success of this program may lead to significantly positive results. Lack of understanding about the pay back process including accelerated depreciation, unavailability of unified electricity

Table 1 Possible strategies suggested for solar PV promotion

Youth	Farmers	Children
• Help them to get skilled. "Surya MItra" program is currently helping in this regards. Launching more community based programs would help youth to get involved with the solar mission. (specifically rural youth who do not have much access to good education institutes near the vicinity of their villages) • Design of higher education program which are entirely focused on solar energy science and policy. That can be either a degree program or a post graduate diploma program which will support youths to acquire knowledge about the basics of solar PV. By providing scholarship etc., one can attract bright young minds in this field • Involvement of universities (state and central) to promote research and development (lab based). Most of the universities are currently promoting research in solar PV but the institutions such as polytechniques and ITIs etc. should not be remained untouchable and therefore course development plan should be decided for them • Promote industry to offer internship etc.	• Organizing a program which is specifically designed for the farmers, must aim to provide an introduce the benefits for solar energy to the farmers • Helping them to get fund with minimal interest rate either from Govt or from public private partnership agencies. List must be made available to the farmers easily about the possible loan grant agencies and NGOs who can support them with the funding • Encourage farmers through various schemes. For an example offering subsidy in seeds etc. if they use renewable energy sources in their farming activity would be a promising method to promote solar energy • Encourage agricultural based research activities where solar energy could play a vital role • Allocate an award money for farmers who promotes renewable energy in their farms and glorify them	• Through organizing the slogan, essay, speech etc. which is being currently organizing by Govt. on various occasion such as on national renewable energy day • Organizing an event to visit solar station for school children, organizing a forum to explore their ideas about renewable energy and provide help them to understand and explore it more • Renewing the current education curricular and incorporating major sections of renewable energy in science where the need and the principles of solar devices and Govt's mission needs to be discussed. The social aspect of policies which are made for different solar agencies needs to be discussed in social science subjects • Encourage students to participate in solar based projects during their school practicals

regulatory committee, etc., are few other hurdles in making solar mission vibrant. Accelerated depreciation benefit has become prominent after demonetization and assumed that it has led to increased investments in solar energy (effects of other factors may not be neglected at the same time). Analysis of recent studies have indicated that the researchers are aiming to achieve 6–8 KWh/day/KWp, for both grid and off grid photonic energy based system. It is realized that capital expenditure of 1–5 KWp scale grade's solar unit requires about 1 lakhs/ KWp and this cost should bring down for the developing countries like India [36].

3.3.2 Indigenous Manufacturing of Solar Appliances

Goel [16] illustrated about the contribution of India in manufacturing of solar appliances and also delineated its role in the global scenario. Study praised "Make in India" policy and speculated that it would bring investors in solar appliance manufacturing sector. The biggest obstacles identified for the investors include land acquisition, foreign investment policy and skilled employee cum leadership. Although government is boosting them through providing various subsidies and loans with low interest rates but still foreign investors are yet to come with significant investment amount. "Start-up India" is another program which motivate people to set-up their own firm. This scheme may support solar appliance manufacturing strategy of government of India but the lack of education and training about solar energy based device manufacturing and knowledge related to policy making could be assigned as hurdle. These hurdles could be sorted out through offering a degree or diploma courses as described in detail in earlier section of this chapter. There must also be a management course on solar policy making which must cover the thorough analysis of different countries' solar energy policies. Courses can be designed for various lengths such as either 6 month diploma or a year (or two) depending on the institutions' governing body and academic councils' decision. It is easy for the institutes such as IITs, NITs and IIMs to introduce these courses as most of the IITs are currently consisting energy oriented research centre and offering related courses too. Surya Mitra, launched in 2015 has targeted to trained 0.05 million workers for solar energy during the 2015–2020 time period. RBI has also revised the guidelines and kept renewable energy under the category of priority sector, which provides a luxury of accessing easy loans approval for roof top system with significant tax reduction [76].

3.3.3 Research and Development

Global research and development expenditure in renewable energy was around 9.66 billion USD in 2012 with 51% share allocated to solar based research. USA, Japan and China are the biggest research and development hubs in this area. It is worth to mention that china is currently investing large amount of public money in solar based research and development activities. There are lot of solar based research activities are currently being carried out which are not only concentrated on improving the efficiency of existing solar based PV materials but also focused on the development and innovation of new materials for future application, Device fabrication techniques, cost reduction through design engineering and solar grid based research including solar energy policy based research etc. India is lagging behind in research and development expenditure as also reported by Goel [16]. Figure 7 gives a comparison of R&D expenditure in India and other parts of the world.

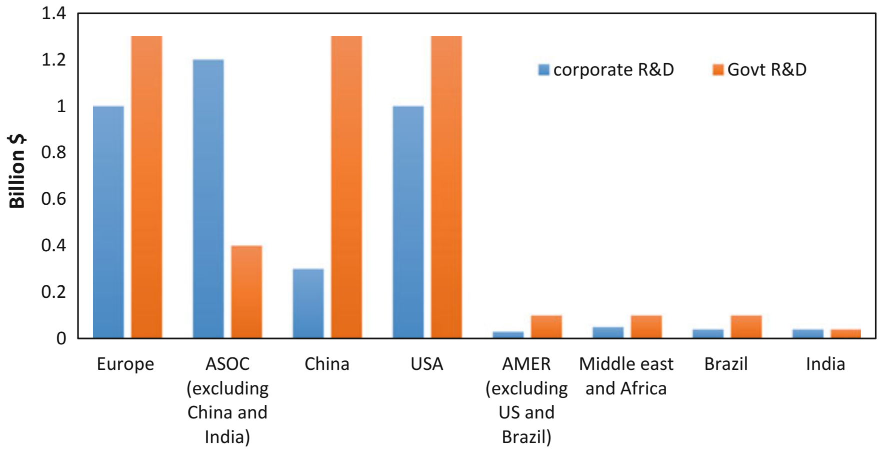

Fig. 7 Comparison of R&D investment of India with other countries [16]

It is essential for government to provide financial support for solar energy based research to public, private and deemed universities and encourage skilled people to get involved with the research activities. A positive sign in this direction can be seen in the government's call for researchers to develop international collaboration in solar based research. International collaboration allowed Indian researchers to get an access of international labs. UKIERI (UK India Education and Research Initiative) is one of the program which is currently being operated with the support of UK and India governments [77]. Bhaskara program (as discussed earlier), DST clean energy research initiative [78] are some other examples of initiatives/schemes which supports solar India mission directly or indirectly.

3.3.4 Human Resource Development

Study conducted by National Resources Defence Council (NRDC) and Council on Energy Environment and Water (CEEW) has highlighted various important skills which are required in Indian solar industries such as solar PV manufacturing, Solar based research and development etc. Study also suggested about the possible number of skilled workers required by the end of 2022 for the success of National Solar Mission and solar PV plant installation cum operation. Findings are illustrated in Tables 2 and 3.

Under the flagship of MNRE, various human resource development focused programs are currently required. For instance, villagers' centred program with provision of stipend in solar based short term courses would enable villagers to indulge themselves with solar energy based activities.

Design of bachelor courses: modification in current bachelor programs (such as BSc or BTech) is another efficient way where interdisciplinary engineering program

Table 2 Key skills required for different respective sections of solar PV industry

Manufacturing	Business development	Design and preconstruction	Construction and commissioning	Operation and maintenance
• Research and product development (patents) • Machine operating • Sales and marketing	• Market and opportunity tracking • Bid drafting and pricing • Site selection and leasing	• Plant design engg and architecture • Procurement and EPC planning • Project management	• Site engg (civil, electrical and mechanical) • Project management • Logistic management	• Performance and data monitoring • Equipment management • Technical management for grid integration

Source CEEW and NRDC [11]

Table 3 Number of skilled labour and employee required by 2022 in solar sector

Function	Skill	Key skill	Number of trained persons to achieve 40GW of solar rooftop (by2022)	Degree required
Manufacturing	Highly skilled	Research and product development	–	Photovoltaic engineering
Business development	Highly skilled	Market analysis, project finance	15,200	Business administration
Design and preconstruction	Highly skilled	Plant design	18,400	Civil, mechanical or electrical engineering
Construction and commissioning	Highly skilled	Site engineering	154,000	Civil, mechanical or electrical engineering
	Semi-skilled	Electrical and PV installation	338,400	–
Operation and maintenance	Highly skilled	Performance data monitoring	48,000	Electrical engineering
	Semi-skilled	–	92,400	

Source CEEW and NRDC [11]

focused on photovoltaic engineering can be designed. Photovoltaic has been proved to be a field which involves various engineering and science based approach such as electrical, electronics, materials science, mechanical, physics and chemistry, etc.

Counselling centre: Solar and PV technology is still new to most of the Indian and therefore it is worth to set up a counselling centre which would lead a common man to the best possible option related to their careers.

3.3.5 Policy Barrier

Development of effective PV growth model either through involving private sector or through public private partnership is a need currently. Efficient solar policy must incorporate certain essential elements such as R&D, commercialization, manufacturing, promotion, government support either through tax reduction, making installation policy flexible or through providing subsidy in terms of excluding GST charges. The policy must be open for international collaboration Involvement of many nodal, state and central agencies would often demoralize PV companies and foreign investors and therefore making this system (for all necessary legal clearance) centralized (removing multi step clearance process) would help in fast processing of applications. Govt. has initiated the plan by encouraging the solar park development to mitigate and overcome these policy barriers as mentioned earlier in this chapter, whereas its outcomes must be regularly examined. Solar park area would become the easily accessible option for the investors to invest comfortably.

3.3.6 Accessibility of Manufacturing Hub

There are various solar PV technologies currently being used (crystalline Si, amorphous Si, thin film solar cell, perovskite and dye sensitized solar cell) and offer different efficiencies. Table 4 gives compares the pros and cons of all solar PV technologies. Recently announced “make in India” policy may provide desired atmosphere for the manufacturing units to start solar PV manufacturing in India. Establishing India as solar PV equipment manufacturing hub would made the nation an emerging exporter and can help us to capture the market of SAARC countries such as Bangladesh etc. where manufacturing of solar PV is not well organized as also highlighted by Rahman [40, 41].

3.3.7 Randomness in Energy Generation Capacity

An expansion of safe transmission network is sought for in the states which does not get enough solar radiation flux throughout the year such as Sikkim, Meghalaya and other North-Eastern states. These transmission lines must get connected through each states of India. Grid connectivity and stability are major problems for power generating units [17]. Considering the importance of inter-regional transmission capacity, the green corridor project has been implemented from 2012. ‘Green energy corridor’ (GEC) program involves about 7 billion $ investment to make the renewable energy linked up with national grid network [6]. The report of power grid corporation of India limited, Gurgaon (July 2012) described the attention paid in this perspective during the 12th plan [79]. The high capacity transmission corridor plan (under 12th plan scheme) decided for India, is portrayed in Fig. 8. Power grid selected by MNRE for green corridor development help in regulating transmission line infrastructure and paving the strategic future pathways

Table 4 Current and future options of solar technology for India

Technology	Advantages	Disadvantages
Amorphous Si Technology	• Simple technology • As compare to crystalline Si technology, amorphous Si absorbs more solar energy than the crystalline (provided both are having the similar layer thickness and size) • Less expensive, low weight, less material required • Flexible in terms of deposition, variety of substrates can be used such as curved, rolled etc.	• Prone to degradation • Increased light soaking or illumination time because introducing a light, the association of hydrogen with 4th Si breaks and causes creation of dangling bond which is nothing but a defect, this effect is known as Staebler Wronski effect and can be assigned as a function of manufacturing technology • Fluorinated—amorphous Si cell is another possible option which could be adopted.
Mono crystalline Si technology	• Comes among the highly efficient technology • This technology is space efficient and requires least space Efficient life time with less degradation • Effectively suitable for warm whether	Most expensive technology
Poly crystalline Si solar cell	• Processing of polycrystalline Si is less expensive than the monocrystalline Si • Higher temperature coefficient than the monocrystalline modules and therefore increment in heat outputs is lesser than the monocrystalline cell.	• Not as efficient as monocrystalline due to the involvement of impurity • As compare to monocrystalline, large space is required to achieve the electricity generated from monocrystalline
Thin film technology	• Large Scale production is effective and simple • Flexible technology and therefore can be deposited in any substrate, made them available for emerging application such as space mobiles etc. • Lesser impact of temperature than the other technology • Cheap technology	• Although, they are cheap but needs lot of space and therefore do not convenient for roof top • As illustrated, large space is required but poor efficiency • Requirement of support structures such as cables etc. increases the overall cost apart from thee land cost • Their degradation rate is faster than others. As illustrated earlier in this chapter, problems of appearance of cracks at the interfaces between transparent conducting oxide and absorber layer material degraded the quality and efficiency

(continued)

Table 4 (continued)

Technology	Advantages	Disadvantages
Bio hybrid solar cell	• Economic and easily accessibility of materials whereas some of the solar PV technology such as thin film, involves the application of rare earth metals [82]	• Structural and functional degradation of bio material involved in making bio-hybrid material is a serious threat (Ravi and Tan [43]) • Specifically life span of bio hybrid solar cell is less
CdTe	• Low cost thin film technology • In 2013, CdTe shared half of the thin film market worldwide [83]	• Use of rare earth element is preventing this technology to get commercialized • Toxicity of Cd is another major disadvantage
Dye Sensitized (3rd generation)	• Flexible, simple in construction and low cost • Price to performance ratio is good	• Practically it involves application of expensive material, such as platinum and ruthenium which can be eliminated
Hybrid-solar cell (organic-inorganic solar cell)	• Potential to get used in commercial manner • Possible to make it low cost (through roll by roll processing)	
Perovskite solar cell	• Processing of this cell is simpler than the conventional Si solar cell which requires multi step processing at high temperature • Can be synthesized through wet chemical method even at lab scale • Process cost is cheaper and wide varieties of techniques such as vapour deposition, spin coating etc. can be adopted	• Degradation with time is the major drawback as organic compound used to get decomposed in the presence of sunlight • Involvement of toxic elements such as Pb is a major problem to get it scale up

for promoting renewable energies such as solar energy etc. The report proposed certain future mechanism to promote renewable energy sources such as application of flexible generators which would help in submitting a bid during low frequency during the surplus capacity. It was suggested that power system security and reliability must be maintained. The actions undertaken during the 12th action plan are expected to add 41,000 MW of renewable energy and therefore energy evacuation is required through developing grid infrastructure which can be sufficient enough to transport renewable energy to load centres. In future, states would not be able to purchase and consume the entire amount of produced renewable power and it would require them to transfer energy to another state in need. Therefore power evacuation system through grid connected transmission is necessary and development of this system would not only empower solar energy based power generation but would also help empowering other renewable energy sources.

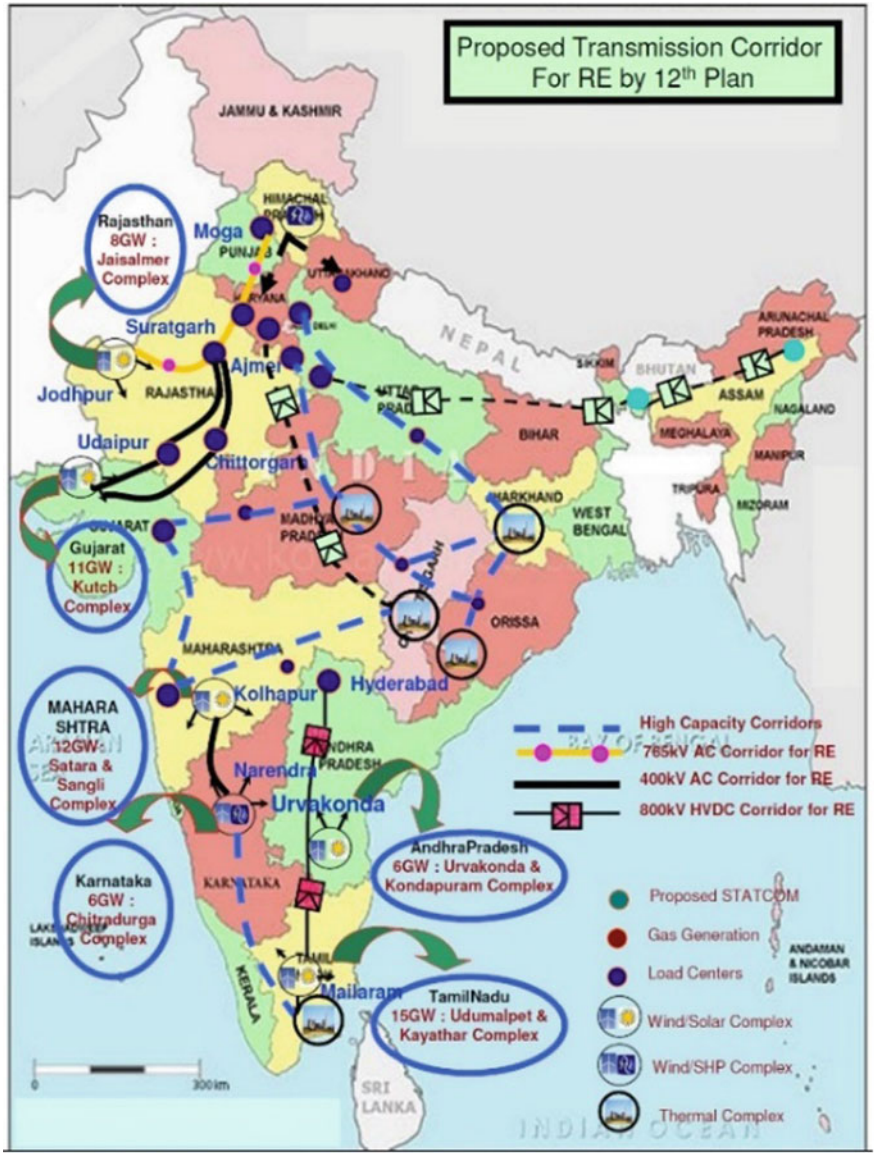

Fig. 8 Proposed green energy corridor for 12th plan (*Source* Bana [6]) (Reprinted from Publication "Bana [6]" with permission from Elsevier)

3.3.8 Strong Innovative Policy

Succinct government policies on harnessing the potential of renewable energies, have showed the results in increasing share of renewable energy capacity being reached up to 12% from 2% (9th plan) but solar mission is one of the few areas where policy could have been more dynamic and supportive. For an example, the data up to year 2012 suggests the grid interactive capacity for solar power was 45% whereas 70% grid interactive capacity was alone for wind energy. The growth pattern for solar energy was significantly higher from 3 to 941 MW during 10th to 11th action plan which certainly was an inclusive result of strong policy implementation and clear vision of introducing the solar mission. Though it was way below the maximum capacity expected (100 GW), but it paved a path to structure the mission. MNRE document titled—"Renewable energy in India Progress, vision and strategy" describing the government vision for 13th plan and aimed to achieve the capacity of solar power up to 20,000 MW (for 2022, 13th plan). Currently India has third largest installed capacity of concentrated solar power and therefore government aims to promote solar power by achieving a target of 175 GW renewable energy power (where 100 GW would be from solar energy). This document established the solar energy and PV technology as emerging source of energy in India as compare to wind and other renewable energies [79]. GoI has decided to connect solar power by grid and therefore annual solar installations growth will be 4 times by the end of 2017 with 10–50 GW power capacity (Including roof top and utility scale). Foreign Direct Investment (FDI) is another way of promoting the solar energy to reach its optimum potential. The electricity act 2003, allows 100% FDI in renewable energy sector [24] and according to commerce and industry department's statement, India has received 1.77 billion USD as FDI during April-2014 to September 2016 [80]. Although it would be interesting to observe and analyze the effect of newly launched Goods and Services Tax (GST) on FDI in renewable energy sector as different opinions have been floated in recent past. It is likely that GST implementation would change the indirect tax slab and may affect adversely in foreign investment [81].

Certain amount of monetary support has been provided by government of India under the budget of 2016–17 which includes the exemption of excise duty tax on copper wire and alloys used in solar PV manufacturing. The other supports include the concession on PV equipments, guaranteed market for solar PV manufactures, and special support under the renewable energy special economic zone and loans etc. Various state specific supports are also available, for example, Government of Rajasthan is willing to set up solar manufacturing facility at their solar park. GoI has also created an institution known as National institute of Solar Energy which aims to support research and development activity in solar energy and contributing in the solar energy progress in India. The current example is the setting up a 1 MW solar thermal research and development power project with their collaborator, IIT Bombay. It is worth to mention over here that NISE is an autonomous body under the flagship of MNRE and it has been established in September 2013. The state governments have also setup their state solar policy and established solar agencies at state level such as CREDA for Chhattisgarh is such agency.

3.3.9 Biased Policy in National Solar Mission

The policy about thin film under the national solar mission was little biased. 1st stage and 2nd stage policy implementation include the promoting the application of crystalline Si technology (cells and modules manufactured in India). But the case for thin film PV technology was different as the efficiency of thin film solar cells are lesser than the Si technology. Although researchers (from India and abroad) are working in this area to make this technology efficient. Si technology can generate power with less space requirement whereas the same equivalent power generation with thin film would need much larger space (area) which means that more labour cost would be associated with thin film solar PV station installation. Also low cost of Si PV made thin film technology not so appealing to investors. Reliability and degradation of thin film solar cell over the period of time, are also major concern for the investors to install PV station with this technology [29] whereas recent views and news article published in Nature [12] expressed the importance of thin film technology. Conventional Si solar panels are rigid and bulky whereas thin film technology can be used in various fields such as mobiles, watches, indoors etc. Therefore it is required to find solution to the problems associated with thin film PV technology and promote research and development activities specifically towards new efficient material development, effective manufacturing technology development and technology commercialization. Arent et al. [5] cautioned that outsourcing thin film PV technology could be a risky job because the chances of supply of degraded materials are huge as also highlighted by various researchers [44].

As already highlighted, succinct and innovative policies are required in solar component manufacturing. Government has provided various dividends on excise duty and taxes as illustrated earlier, lag behind in bringing desired attention of investors in manufacturing. Around 80% of our solar panels comes from abroad and it costs huge burden on nation's economy. Some of our Indian solar panel manufactures are Vikram solar (https://www.vikramsolar.com/), Moserbaer (http://moserbaer.com/products/solar/), Tata power (http://www.tatapowersolar.com/) and Lanco solar (http://www.lancosolar.com/).

Currently world has a large dependency in thin film technology where majority of elements used in thin film module manufacturing are rare earth elements. China's mining policy for rare earth has great influence on thin film PV technology market price. It is also worth to mention that thin film technology largely involves hazardous elements, therefore while promoting and deciding our policy towards thin film PV technology, one must take care about this important facts. Therefore, addressing the concerns of underdeveloped policy in context to thin film PV technology is an important attention seeking area. Recent article published by Johnson [22] highlighted various drawbacks in policy. For an example, biased policy towards foreign thin film technology manufactures as reported earlier in this chapter, caused a huge loss to our local manufactures. The interviews conducted by Johnson [22] with the manufactures suggested that the modules produced by local manufactures between 2011 and 2012 was 10–15% (in terms of operating capacity) but 0% in terms of cells. Around 50% of work force lost their job because of the severe conditions of companies such as Indo solar who stopped manufacturing completely though Moserbaer successfully restructured themselves. Similarly Tata BP became reluctant towards solar manufacturing. The article also highlighted about the lack of research and development activities. Although it was highlighted that solar manufactures were optimistic towards government policies and believed that policies could support them during stormy market conditions. However the threat of China's manufacturing capabilities was clearly highlighted in the study. As illustrated earlier in this chapter, extensive rely on thin film technology could be a dangerous steps (considering lack of rare earth mining sources within India). CEEW and NRDC [11] report suggested about the generation of about 23,884 jobs in solar market between 2011–2014 but the study done by Johnson [22] suggested nominal impact on the existing solar PV manufacturing in India during the stormy market conditions. It is also worth to mention that the data were taken during 2011–2014 where the 1st phase of National Solar Mission was being carried out and was extremely successful in terms of achieving targets as illustrated earlier but this remain a question that how can we provide maximum support to indigenous solar PV component manufacturing which should be sustainable enough even during the stormy market condition?

Lack of transparency in the ongoing policies [22] and needs for an extra attention were highlighted in various studies [44]. Therefore, based on the analysis, we can design a probability/possibility chart for future policy implementation strategies (Fig. 9), although policy designing is a complex phenomenon for a diverse field like solar energy and technology.

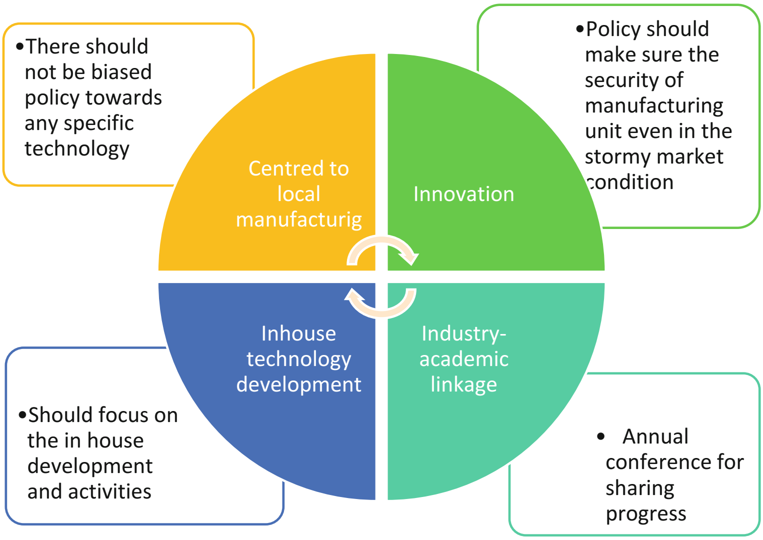

Fig. 9 Recommended future policy design and implementation policy

4 Sustainability Assessment of Renewable Energy Sources

The centralized energy systems based on fossil fuels represent the prevalent energy paradigm globally. The fossil fuels based energy systems have been regarded as damaging to environment and health [2]. The limited availability of fossil fuels, increasing energy demands and concerns of environmental and health impacts associated with their use have compelled the search for alternative energy sources. Renewable energy sources have been identified as an optimal solution for making transition to sustainable energy supply [37]. Renewable energy systems provide twin benefits in the form of reduced load on conventional energy sources and saved environmental emissions. Several governments including GoI have promoted the development and commercialization of renewable energy systems. The selection of renewable energy sources and conversion routes has been mostly dependent on techno-economic feasibility of the renewable energy systems [10]. Choosing one technology over the other has associated subjectivity because it often consider the use stage and overlook the trade-offs related to the entire life cycle [45, 53, 54]. For instance, the biomass based energy systems are mostly advocated for being as carbon neutral [27]. However, this is mostly so when only the use stage of renewable energy is taken into account. A major driving force for the political support to biomass substituting the fossil fuels comes from their environmental benefits [47, 49]. There are several studies supporting biomass based fuels over fossil fuels in terms of greenhouse gas (GHG) emissions. Similarly, solar PV based systems are viewed as environmentally clean in converting the solar energy directly into electricity but there are material and energy inputs as well as environmental emissions related to manufacturing and decommissioning of PV module. Therefore, the increasing use of renewable energy systems need to be assessed for entire life cycle and not only for the use stage [7]. The long term viability of renewable energy systems as a mean to provide sustainable energy supply have been questioned by several studies [13, 53, 54].

Life cycle assessment (LCA) is an internationally recognized methodology able to uncover the environmental performance of any product or process [25]. In biomass based energy systems, since the characteristics and conversion routes are biomass specific, an LCA based evaluation requires a reference system which can be used for comparison. Further, the second generation bioenergy systems have been promoted by several governments through technological advancements, but questions are raised on their accurate comparison with fossil based energy systems. Santoyo-Castelazo and Azapagic [45] used integration of all three sustainability dimensions using life cycle approach for identifying the most sustainable energy alternative for future electricity supply in Mexico. The study framework comprised scenario analysis, life cycle assessment, life cycle costing, social sustainability and multi-criteria decision analysis. 11 scenarios were assessed considering different technologies, electricity mixes and climate change targets up to the year 2050. The results showed a trade-off depending on the preference given to a sustainability criteria, particularly for social impacts. However, all the scenarios having renewable energy component were found sustainable as compare with business-as-usual scenario. Kumar et al. [28] carried out an LCA for assessing the GHG emissions and energy balance for 1 ton of jatropha based biodiesel system. The results were compared with petroleum based diesel system. The functional unit for GHG balance was 1 ton of jatropha. The results clearly indicated a strong influence of the criteria used for allocation the inputs-outputs between multiple products and irrigation in the agriculture stage. Therefore, decision making through sustainability assessments of renewable energy systems would require addressing the methodological complexities using tools like LCA.

5 Conclusions

Renewable energy systems with environmental benefits can significantly reduce the dependence on fossil fuels. Wide-ranging adoption of renewable energy sources and technologies in developing countries has been recognized as an essential solution to climate change challenges. India has emerged as potential market for renewable energy systems. With increasing support from government initiatives, public private partnerships and research the renewable energy sector has something to offer to every stakeholder. The estimations of fall in price for renewable energy are likely to give a setback to fossil fuel reliance.

India is responsible for 4.5% of global GHG emissions. In order to achieve "Intended Nationally Determined Contribution" of India in Paris agreement, India is expected to increase share of renewables in meeting total primary energy demand up to 40% by 2027. As highlighted in the chapter, transportation fuels along with electricity are the major forms in which energy is consumed. Growing demand of transportation fuels can be fulfilled by employing biorefinery concept, using biomass as a precursor in its various forms and electricity can be generated in decentralised as well as centralised manner using solar PV technology. GoI is also promoting the application of renewables by providing subsidies and making appropriate policies.

This chapter is an effort to highlight the importance of biomass and solar based renewable energy systems in India. The chapter attempted to provide account of present settings in policy and research perspectives for both. It has also emphasized on taking a holistic approach for growing the renewable energy share in India incorporating the aspects of economic feasibility, environmental friendliness and societal welfare into account.

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