Energy Footprint of India: Scope for Improvements in End-Use Energy Efficiency and Renewable Energy

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Abstract Energy plays a pivotal role in the development of a region. Increasing dependency on fossil fuels has caused serious concerns at the local (energy dependency, pollution, etc.) and global (global warming, GHG emission, etc.) levels. Harvesting of energy depends on the availability of resources apart from the economic viability and technical feasibility of meeting the demand. The energy requirement of India is mainly supplied by coal and lignite (19378.24 PJ), followed by crude oil and petroleum products (18432.96 PJ) and electricity (7562.24 PJ). However, energy consumption in rural India is largely dependent on non-conventional energy sources due to the availability, possibility of rapid extraction, and appropriate technologies. Globalization and consequent opening up of Indian markets has led to urbanization with the enhanced energy demand in the industrial and infrastructure sectors. The perishing stock of fossil fuel coupled with the growing concerns of climate change has necessitated the exploration of cost effective, environment friendly, and sustainable energy alternatives. Renewable sources of energy such as solar and wind are emerging as viable alternatives to meet the growing energy demand of the burgeoning population. Strengthening of transmission and distribution network with the integration of local generating units (RE-based standalone units) would help in meeting the demand. Distributed generation (DG) with micro grids are required to minimize transmission and distribution (T and D) losses, and optimal harvesting of abundant local resources (such as solar, biofuel, etc.). The focus of the current communication are (i) understanding the energy scenario in India; (ii) sector- and source-wise energy demand with the

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scope for energy conservation; and (iii) prospects of renewable energy with smart grids to meet the distributed energy demand while optimizing harvest of local energy sources. Source wise energy analyses reveal that total primary energy consumption has increased manifolds during the past three decades from 18 MTOE (in 1980) to 104 MTOE (2011) in India. Coal consumption has increased from 213 MT (1990–91) to 615 MT (2013–14) and therefore, has grown more than 3 times over the years. Transportation tops in oil consumption (54.28 MTOE) followed by industrial (28.8 MTOE) and domestic (24.89 MTOE) sectors. Total natural gas production in the country was about 18 BCM (billion cubic meters) during 1990–91 and increased to 34.64 BCM now. Electricity generation shows a growth of over 26 times in 40 years that has increased from 43,724 GWh (1970–71) to 11,79,256 GWh. Renewable energy is being used in various forms as is evident from the dependence on bio-energy to an extent of 85% among the rural population (constitutes 70% of the total) since time immemorial. Grid interactive power generating plants from RE sources constitute 37,414 MW with the major share of wind energy plants (24376.26 MW, 65%) followed by biomass/bagasse cogeneration plants (4418.55 MW, 12%), solar photovoltaic (4346.82 MW, 12%), and small hydro (4146.82 MW; 11%). Power generation from municipal solid waste accounts for a very small fraction. Sector-wise and source-wise energy analyses reveal that the energy consumption per GDP (Energy intensity) of India is 0.42 kgoe/million USD. Comparison of the energy intensity (the ratio of energy consumption per GDP) versus GDP per capita of various countries reveal that the energy intensity of India is more than 12 times that of Switzerland, 4 times that of Germany, 3 times that of USA and about 1.3 times that of China, indicating the inefficient use of energy and the need for energy conservation through end use energy efficiency improvements to enhance the GDP with the present level of energy consumption.

Keywords Indian energy scenario · Sustainable energy · Distributed generation Renewable energy · Energy trajectory

1 Introduction

Energy, the basic need of human kind, plays a significant role in the development of a region or country. Energy utilization by human beings has increased from 2,500 kJ/day to more than 2 lakh kJ/day with the evolution of technologies. Every human activity, from crop growing (agriculture) to space research, is dependent on the energy availability and supply. Exploitation of more energy resources helped in innovation of new technologies which made life easier, but caused substantial impacts on the ecology and environment. All economic activities utilize energy. Energy supply has an impact on intermittent production and end use. Economy of the country is influenced by energy, technology improvement from extraction to end use, and supply-demand balance. However, energy is also a limiting factor with inefficient use and fossil fuel dependency (Asafu-Adjaye 2000).

Energy plays an important role in everyday human life and there is disparity in energy consumption across various regions, which depends on the availability, technical, economic, and social aspects. Most parts of India depend on traditional sources of energy such as fuel wood for cooking, water heating, etc. Globally, about 3 billion people depend on bioenergy for domestic purposes and 1.5 billion do not have access to electricity (Rehman et al. 2012; Energy Realities 2013; EIA 2013). Per capita energy consumption varies across countries. It is higher in developed nations (USA—7.3 TOE, Canada—7.6 TOE, Japan—3.7 TOE) compared to the developing (India—0.6 TOE, China—1.8 TOE, Brazil—1.4 TOE) and less developed nations (<0.4 TOE). Figure 1 compares the energy consumption per capita versus GDP (Gross Domestic Product) per capita among the countries (Top 25 GDP countries). Norway (99,933 million USD) tops in GDP per capita followed by Switzerland (79,024 million USD), Australia (65,430 million USD) and Sweden (55,341 million USD) which shows the effective utilization of energy. The per capita GDP value of India is 1555.50 million USD, which is lowest among these countries. Energy consumption per GDP (Energy intensity) of India is higher, hinting the inefficient use of energy. Figure 2 compares the energy intensity (the ratio of energy consumption per GDP) versus GDP per capita of various countries. Energy intensity of India is about 0.42 kgoe/million USD which is more than 12 times that of Switzerland (0.033 kgoe/million USD), more than 4 times that of Germany (0.092 kgoe/million USD), more than 3 times that of USA (0.137 kgoe/million USD) and about 1.3 times that of China (0.325 kgoe/million USD). The prosperity of a nation depends on the efficient use of energy or the energy intensity than the per capita energy consumption.

Most of the Asian countries have high energy intensity (energy/GDP) and lower per capita consumption, which illustrates the inefficient use of energy. This highlights the need of improved end use efficiency to enhance the GDP with the present level of energy consumption (Ramachandra 2011; Ramachandra et al. 2006).

Global studies emphasizing the efficient use of the energy have also demonstrated the relationship between efficient energy consumption and economic

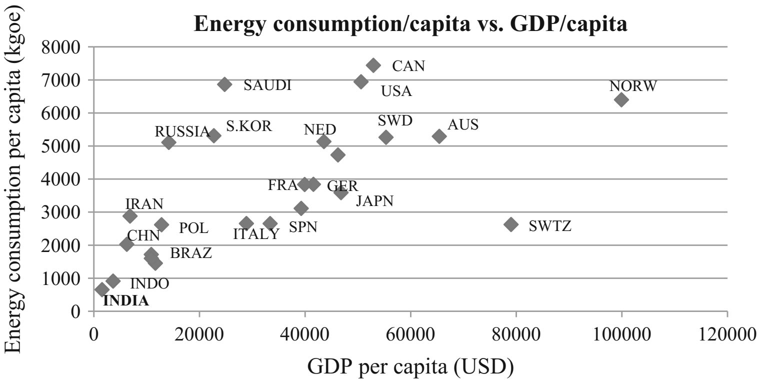

Fig. 1 Country-wise energy consumption per capita versus GDP per capita

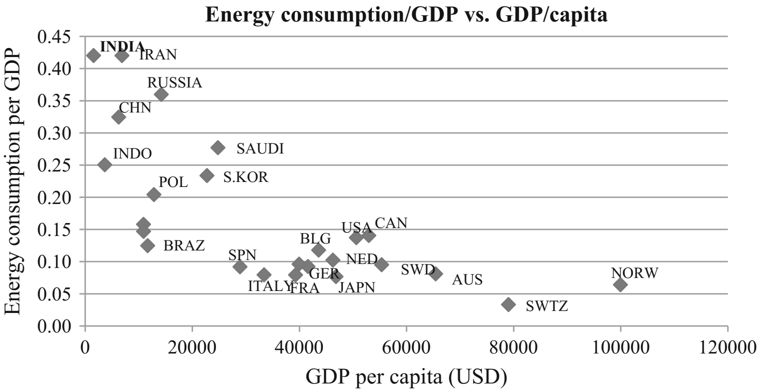

Fig. 2 Country-wise energy consumption per GDP versus GDP per capita

growth. Emission of greenhouse gases (GHG) is proportional to energy utilization and is found higher in developing countries due to the inefficient use of energy (Al-mulali and Che 2012).

Environmental pollution, health related issues, and other global problems have increased with increased fossil fuel extraction and consumption. Unplanned urbanization and industrialization have increased the energy demand. Burning of fossil fuels has led to the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2), oxides of sulfur (SO_x), carbon monoxide (CO), water vapours, etc., apart from the release of particulate matter, solid and liquid waste to the environment. This emphasizes the need for exploiting renewable energy (RE) sources to mitigate pollution and address the problem due to dwindling stock of fossil fuels.

1.1 Indian Energy Scenario

India is the seventh largest geography and ranks fourth among high energy consuming countries in the world with over 1.27 billion population. Total primary energy consumption has increased manifolds during the past three decades from 18 MTOE (in 1980) to 104 MTOE (2011) in India (EIA 2013; TEDDY 2013). Coal, natural gas, and crude oil are the leading commercial sources of energy of the country in which most of the crude oil are being imported. Even though the industrial and commercial sectors make use of fossil fuel resources, the Indian domestic sector largely depends on non-commercial energy sources such as fuel wood, agricultural and horticultural residues, animal residues, biogas, and combustible waste. However, the commercial consumption of bioenergy has decreased with switch over to fossil energy sources (coal, crude oil, natural gas, etc.) over the years (Pachauri and Jiang 2008). Rural population constitutes 70% in India and largely depends on bio resources for domestic energy. About 75% of the rural households depend on firewood, 10% on dung cake, and 5% on LPG for cooking whereas, 22% of the urban households depend on firewood, 22% on kerosene, and 44% on LPG for cooking in the country. Some fraction of the urban households is also dependent on fuel wood for cooking, water heating, and space heating (NSSO 2007). Consumption of non-commercial energy sources in the country remained the same with minimal variations. However, the exploitation of fossil fuels has increased substantially to meet the growing demand of industrial, commercial, and transportation sectors with the favourable policies (Simron et al. 2012). Realizing the growing concerns due to large-scale utilization of fossil fuels on the environment and also to reduce the high imports, India is promoting RE (Renewable Energy)-based energy harvesting programmes through JNNSM (Jawaharlal Nehru National Solar Mission), RGGVY (Rajiv Gandhi Gram Vidyut Yojana), etc., with a goal to have 20,000 MW of grid connected and 2000 MW standalone solar power by 2022. Energy conservation and rural electrification are made mandatory under the Energy Conservation Act, 2011, and Electricity Act, 2003, by the Government of India towards the goal of energy independence and to lower the energy demand (MNRE 2013a). Economic development with financial security of a region is dependent on energy independence and achieving the same is a daunting challenge. Exploitation of renewable sources with efficient use of energy and demand-side management would ensure sustainable growth in the energy sector while reducing environmental pollution (Bhattacharyya 2010). This will bridge the supply-demand gap through reduction in the energy loss from generation to end use.

Electricity has a wide range of applications as it is a clean and an efficient media of energy transport. Per capita electric energy consumption in India is about 879 kWh (2012) and the source of electricity generation plays a significant role in energy management and conservation. Electricity generation has been largely dependent on fossil fuels (coal) which are mostly centralized. Centralized generation and sparsely located loads are the prime reasons for un-electrified rural households with higher transmission and distribution (T & D) losses. Indian electrical power transmission and distribution network encounters higher losses ($\sim$24%) compared to other countries (China—6%, Australia—5%, Bangladesh—10%, Germany—4%) and world average ($\sim$10%) due to un-metered electricity supply, un-authorized expansion, theft and pilferage at the distribution side (CEA 2013). Transmission networks are being strengthened with the advanced (electronic) metering facility in many urban regions. In this context, innovations in power sector through distributed/decentralized generation (DG), micro-grid and smart grid would pave the way for efficient and effective power systems in India (ISGTF 2013; MoP 2013).

Implementation of DG results in direct economic benefits including reduction in operation and maintenance (O&M) costs, capital investment to upgrade the generation, fuel cost, and dependency on fossil fuels. Other indirect benefits include reduced investment for pollution prevention and health-related expenses, apart from achieving the national and local energy independence (El-Khattam et al. 2005; Pathomthat and Ramakumar 2004). DG and micro-grid have the versatility of incorporation of next generation power technologies such as smart grid architecture, advanced metering infrastructure (AMI), biofuel generation using algae, electricity from solid waste, and energy plantation. Certainly the future energy resources have to renewable in nature, to meet the growing demand; distributed generation and micro-grid facilitates energy generation near load centers. Exploitation of RE sources and reduction of T & D losses certainly make the energy sector sustainable while achieving energy independence.

1.2 Need for the Study

India with fastest growing economy, the dependence of energy has increased manifold due to industrialization and the impetus given to infrastructure development. The trajectory of energy generation, transportation and consumption has to be understood in order to adopt the sustainable energy management strategies to avert any energy crisis (Ramachandra 2008; Ravindranath and Balachandra 2009). Effective DSM (Demand Side Management) techniques include budgeting non-commercial energy resources in the present energy scenario and end use efficiency improvements. The present study analyses developments in the energy sector in India from generation to end use. Energy conservation needs to be achieved through the improvements in the end-use devices to have a sustainable and pollution free growth. Technological interventions will give scope to utilize locally available non-conventional, renewable energy resources (Kumar et al. 2013). Substitution of fossil fuels through RE sources will also help in attaining energy independence in the region. However, this requires assessment of the resources and patterns of energy consumption from various resources (commercial and non-commercial), apart from techno-economic feasibility of alternate energy trajectory.

Centralized options of generating electricity and supply to remote and sparsely located loads have often faced technical challenges apart from lack of economic viability. Electrification of rural India is yet to gain momentum as is evident from the absence of electricity supply to more than 74,00,000 households of 18,000 villages. The electrification of remote villages to meet the basic electricity demand is possible through standalone RE source based generation (Ramachandra and Shruthi 2005; Ramachandra et al. 2014a; Nouni et al. 2009). Potential assessment of RE sources through geographical information system (GIS) has helped in optimizing the availability (Ramachandra et al. 2014b) and integration of resources towards a reliable supply. Energy conservation and demand side management is the other aspect to flatten the load curve and to reduce the peak demand. DSM techniques and efficient methods in end use of energy will have a direct impact on generation. The present study analyses the prospects of RE sources, non-commercial energy sources, scope for the improvement of end use efficiencies, and options to ensure sustainable energy path, while reducing the supply-demand gap. The main objectives of the current research are as follows:

(i) Understanding the energy situation in India—sector- and source-wise energy demand with the scope for energy conservation through DSM and end use efficiency,
(ii) Prospects of renewable energy with DG and smart grids to meet the distributed energy demand while optimizing harvest of local energy sources.

This chapter consists of three major section—second section brings out the source-wise energy scenario over the last five decades. Third section elucidates the scope for renewable energy and the fourth section argues for the energy conservation through improvements in end use efficiencies, smart grid framework, etc.

2 Temporal Changes in Energy Utilization: An Overview

Energy resources can be categorized as commercial (coal, crude oil, natural gas, etc.) and non-commercial (fuel wood, animal residues, agricultural and horticultural residues) depending on the market mechanism. Commercial energy resources are mainly used in industries, transportation, electricity generation, and commercial sectors. Domestic sectors' energy demand is mainly met by locally and freely available non-commercial resources in rural areas (Ramachandra et al. 2000). India is blessed with very few energy resources such as coal, natural gas, biomass, water, etc. Traces of crude oil sources are found in few places which are not able supply the huge demand. Analysing the temporal change of energy resources will help to understand the resource status and take appropriate action to meet the forthcoming demand.

2.1 Coal

Coal mining in India started during the eighteenth century for meeting the fuel demand of railways and industries. India is the third highest coal producer in the world with annual production of 739.92 million tonnes (MT) in 2013–14. India has a proven coal reserve of 293.5 billion tonnes available at Jharkhand, Chhattisgarh, Odisha, Madhya Pradesh, and West Bengal (MoC 2013). Resource assessment predicts that the approximate life of coal is 169 years with present reserve and consumption. Figure 3 gives the temporal patterns in coal production and imports over the last two decades. Coal consumption has increased from 213 MT (1990–91) to 615 MT (2013–14) and therefore, has grown more than 3 times over the years. About 168.44 MT of coal is imported in 2013–14 to meet the growing demand in the power sector.

Calorific value of Indian coal varies from 4000 to 7000 kcal/kg, which is relatively lower. Coal utilization for electric power generation tops the consumption with 463.71 MT (2013–14) followed by the industrial sector (Fig. 3). Steel industries consume 23.16 MT, followed by cement (13.36 MT) and textile industries.

There are numerous environmental and economic problems associated with coal mining, combustion, and power generation. Coal mining results in geographical

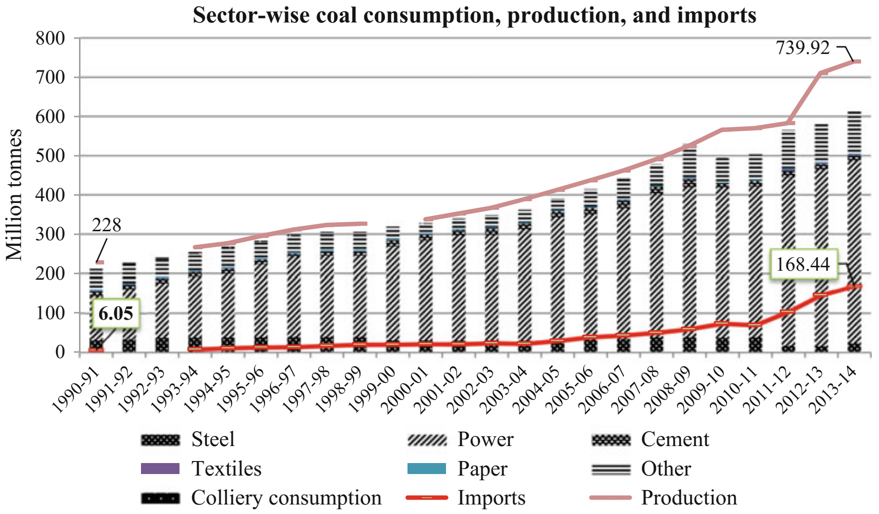

Fig. 3 Temporal change in coal production, imports, and sector-wise consumption

change of land, with the minimal scope for restoration to its original state. Coal-based thermal power plants have been polluting the neighbouring environment, thus, causing respiratory and other health problems (Ramachandra et al. 2012). Air pollution from coal mines is mainly due to the emissions of particulate matter and greenhouse gases (GHG) including methane (CH_4), sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), etc. These pollutants contaminate water resources, air, soil, and consequent changes in the climate.

2.2 *Crude Oil, Natural Gas and Petroleum Products*

Transportation tops in oil consumption (54.28 MTOE) followed by industrial (28.8 MTOE) and domestic (24.89 MTOE) sectors. Figure 4 gives the sector-wise consumption of crude oil in the country (2012–13). India is blessed with very few oil resources which are located in Mumbai High, Bay of Bengal, and Rajasthan which are being monitored by the Oil and Natural Gas Corporation (ONGC).

The total oil production in India has marginally increased from 33 million tonnes (1990–91) to about 37.7 million tonnes (2013–14). Consumption of oil has increased multiple times with industrialization and revolution in transportation system, leading to a radical escalation in oil imports. Imports of crude oil increased from 20.7 million tonnes (1990–91) to 189 million tonnes (2013–14). Figure 5 illustrates the temporal changes in crude oil production and imports (MoPNG 2013). Drastic change in imports occurred during the end of last century, emphasizing the need for energy conservation, demand side management, and renewable energy-based capacity addition, in order to minimize the dependency on other countries.

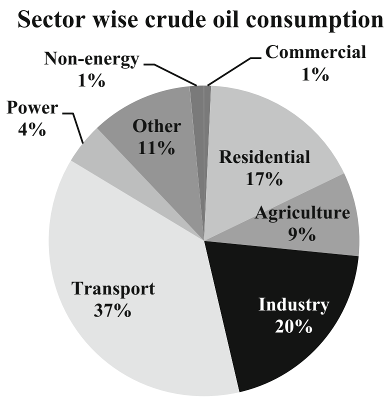

Fig. 4 Sector-wise crude oil consumption (MTOE) in India

Natural gas is one of the prominent energy sources in power and industrial sectors. Total natural gas production in the country was about 18 BCM (billion cubic meters) during 1990–91 and increased to 34.64 BCM in 2013–14. Natural gas is available in India at Mumbai High basin and in Gujarat. Offshore gas reserves are also located in Andhra Pradesh coast (Krishna Godavari Basin) and Tamil Nadu coast (Cauvery Basin). Onshore reserves are located in Gujarat and the North Eastern states (Assam and Tripura). The country has 1437 BCM of natural gas reserves which may last for 30 years at the present level of consumption. Figure 5 depicts the natural gas production and annual imports from 1990–91 to 2013–14.

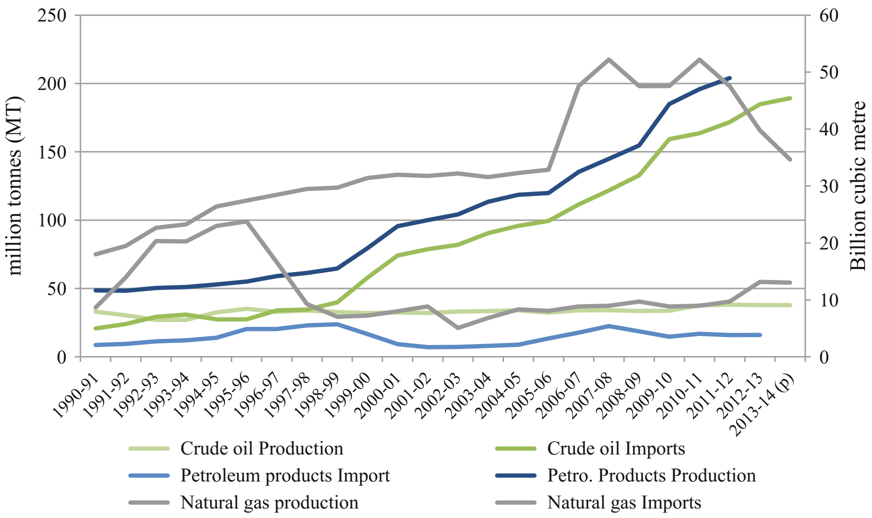

Fig. 5 Temporal change in crude oil, natural gas, petroleum products, and their imports

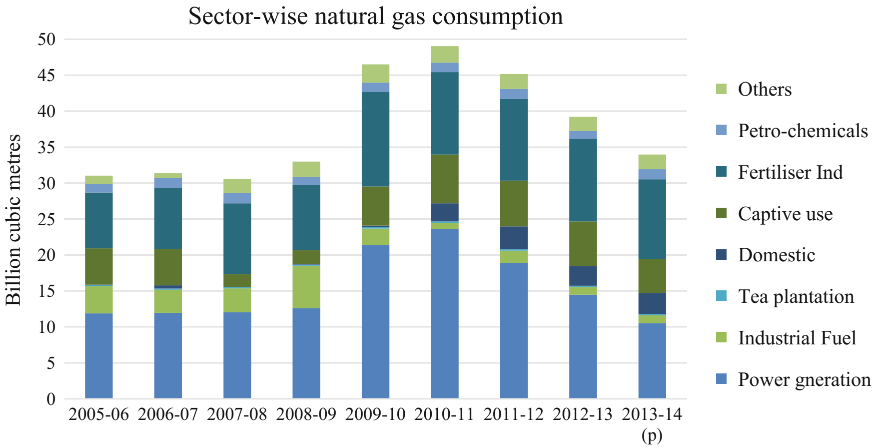

Fig. 6 Sector-wise consumption of natural gas in India

Figure 6 shows the sector-wise consumption of natural gas in the country. Fertilizer industries are the major consumer of natural gas (11.06 BCM) followed by power generation (10.53 BCM) (MoPNG 2013). Petroleum products and their utilization have been increasing at a higher rate since globalization era (after 1990s). The total consumption of petroleum products was about 55 MT (1990–91) which has increased to 148 MT (2011–12). Figure 5 also gives the temporal change in petroleum product production and consumption. Import of petroleum products is about 15.85 MT (during 2011–12) and the increase in crude oil imports is directly dependent on the rise in petroleum product consumption. However, the import of final products is expensive compared to crude oil, which affects the country's economy. Production of petroleum products also increased significantly from 48.5 MT (1990–91) to 204 MT (2011–12), indicating the four-fold growth (MoPNG 2013). Rapid increase in consumption has resulted in numerous environmental and economic problems due to inefficient combustion. This necessitates a paradigm shift from fossil fuel-based energy to renewable energy to achieve the energy independent sustainable development.

2.3 Electric Power

India is one of the major electric energy consuming countries in the world with the annual generation of 11,79,256 GWh (2013–14) and largely depends upon fossil energy resources. Figure 7 illustrates the share of energy sources in total installed power capacity in the country. Coal is the prominent energy source (170,737.88 MW) followed by hydro (42,623.42 MW), nuclear power plants (37,415.53 MW) and renewable energy sources (27,541 MW). The government

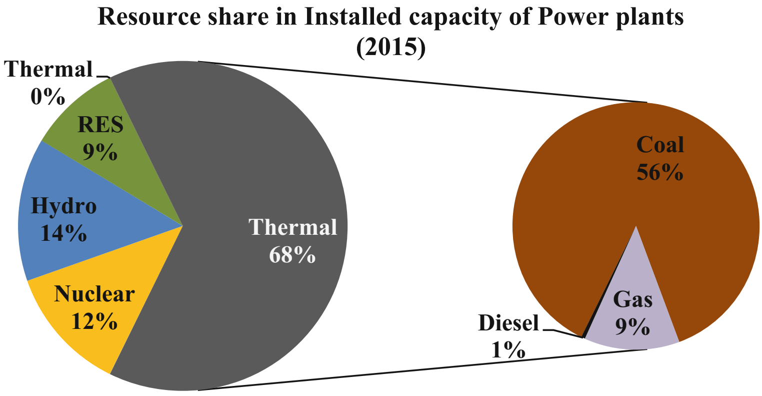

Fig. 7 Share of energy sources in total installed capacity

has proposed augmentation of nuclear power generations to 20,000 MW by 2020 (CEA-LGBR 2013). Electricity generation has increased from 43,724 GWh (1970–71) to 11,79,256 GWh (2013–14) showing a growth of over 26 times in 40 years. Industrialization, revolution in agriculture and elevated consumption in commercial sector have necessitated an additional increment in electricity demand. Figure 8 gives the sector wise temporal electric energy consumption. Industries top the consumption with 346,469 MW (44.8%), followed by agriculture (133,650 MW, 17.3%), domestic (170,034, 22%) and commercial sector (69,266, 9%) (MoP 2013).

2.4 *Renewable Energy (RE) Sources*

India is bestowed with ample renewable energy resources throughout the region with the scope for harvesting wind, bio-energy, solar (PV and Thermal), micro hydro, biogas, geothermal, tidal energy, etc. (Ramachandra 2011). Figure 9 depicts the

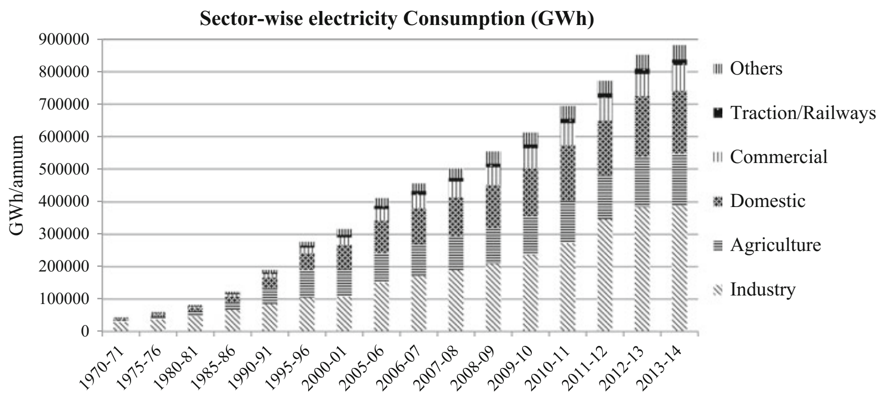

Fig. 8 Sector-wise electricity consumption in India

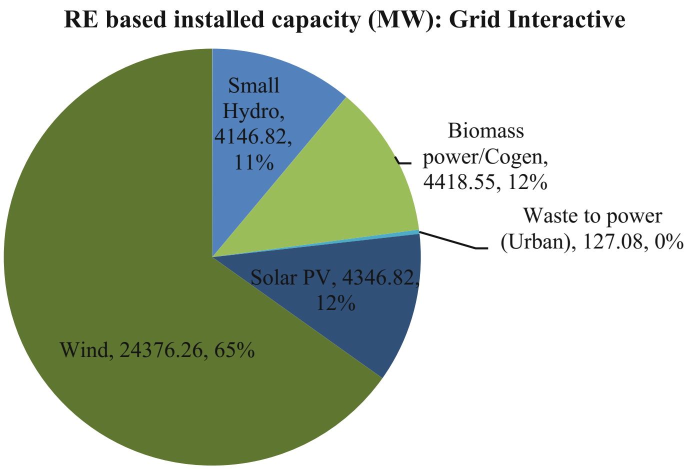

Fig. 9 Share of RE sources (Grid interactive) in total installed capacity

share of RE sources, based on the total installed capacity. Renewable energy is being used in various forms as is evident from the dependence on bio-energy to an extent of 85% among the rural population (constitutes 70% of the total) since time immemorial. Grid interactive power generating plants from RE sources constitute 37,414 MW with the major share of wind energy plants (24376.26 MW, 65%) followed by biomass/bagasse cogeneration plants (4418.55 MW, 12%), solar photovoltaic (4346.82 MW, 12%), and small hydro (4146.82 MW; 11%). Power generation from municipal solid waste accounts for a very small fraction (MNRE 2013a, b).

Figure 10 shows the share of RE energy sources in off-grid installation (1228.48 MW_e) for remote area electrification and as captive generation in industries.

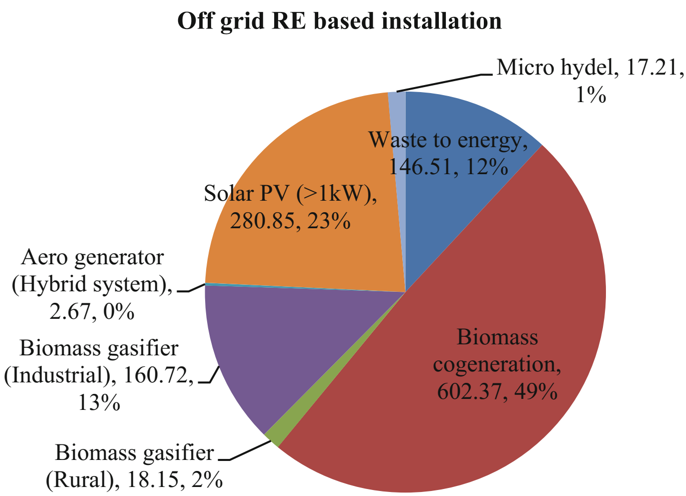

Fig. 10 Share of RE energy sources (MW_e) in off-grid installation

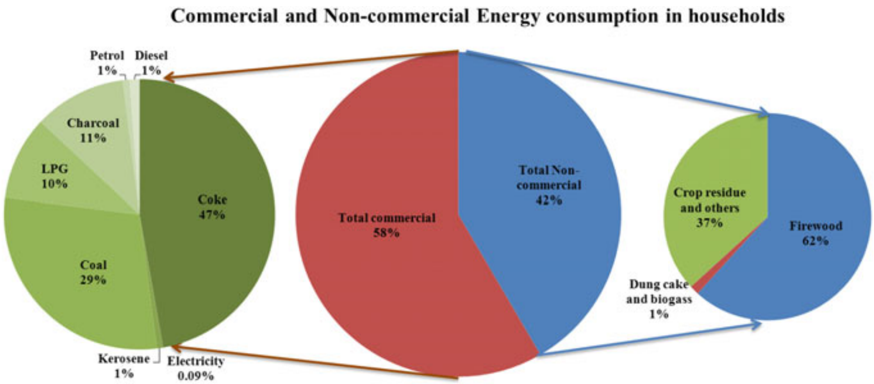

Fig. 11 Commercial and non-commercial sources in domestic energy consumption

The Government of India is encouraging RE-based capacity installation through National Solar Mission, Jawaharlal Nehru National Solar Mission (JNNSM), projects under Clean Development Mechanism (CDM), incentives for biogas installation, etc. Policy initiatives such as Feed-in-Tariff (FIT) and Generation Based Incentives (GBI), tax holidays, and subsidy on capital investments will help to boost the RE-based capacity addition. Sustainable energy development can take place with renewable energy-based generation while reducing the GHG emission.

Solar cookers, dryers, and improved cook stoves can be used in the domestic sector whereas, solar and wind driven pumps are reliable in irrigation (Ramachandra 2011). Captive electric energy generation using solid waste, bagasse, agricultural and horticultural residues, wind and solar energy are viable in the industrial sector. Hence, the RE sources can replace the present energy mix with a higher share with distributed generation and micro-grid (rooftop) generation.

The Indian energy scenario shows that the present energy mix is dominated by conventional energy sources. Dependency on fossil fuels has increased the imports which is affecting the country's economy. Development in the energy sector is likely to deviate from sustainable path hinting the energy crisis in future. Figure 11 gives the share of commercial and non-commercial sources in the energy mix of the domestic sector of the country. About 58% of the demand is met by commercial energy sources wherein coke dominates the consumption (47%), followed by coal (29%), charcoal (11%), and LPG (10%). Non-commercial sources supply 42% of the demand in which firewood tops with a share of 62%, followed by crop residues and others (37%). Figure 13 highlights an increase in carbon dioxide (CO_2) emission from 143 million tonnes (1962) to 2,073 million tonnes (2014). Mitigation of changes in the climate entails lowering GHG emissions, through energy conservation and improvements in end use devices efficiency.

The current level of energy extraction, transportation, and inefficient consumption pattern and its impact on the environment and nation's economy has necessitated a paradigm shift in the energy planning to achieve sustainable development.

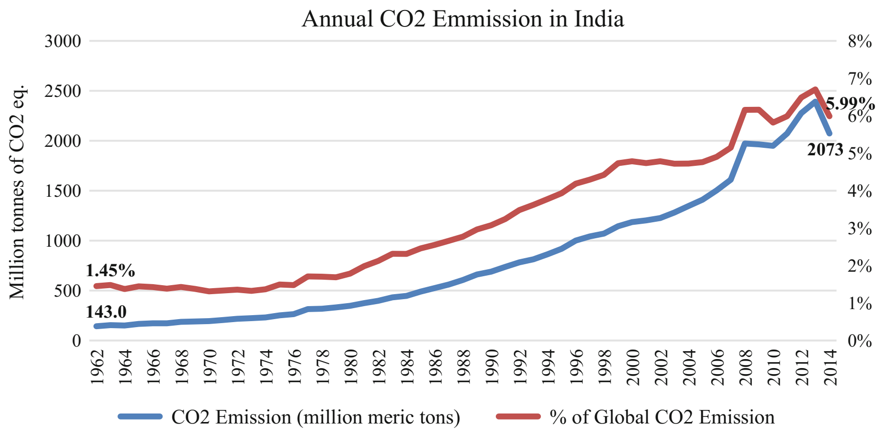

Fig. 12 CO_2 emission (million tons) from 1962 to 2014

Figure 12 shows the increasing trend of GHG emissions. Power generation and transportation sectors are the major contributors to emissions which entails the transition to renewable energy and innovations in vehicle design, etc. Apart from that, end use energy efficiency improvement with DSM would help to conserve energy. Adoption of smart grid architecture would further improve the energy sector through intelligent, reliable, efficient, and less pollutant systems (Ramachandra 2009a; Dabrase and Ramachandra 1999; Prakash and Bhat 2009).

3 Scope for Renewable Energy

3.1 Solar Energy

India is one of the best recipients of solar energy due to its favourable location in the solar belt (40 °S to 40 °N) and receives annual sunshine of 2600 to 3200 h.

Figure 13 illustrates that the Gangetic plains (Trans, Middle, and Upper) Plateau region (Central, Western, and Southern), Western dry region, Gujarat Plains, and hill region as well as the West Coast plains and Ghat region receives annual global insolation above 5kWh/m^2/day. These zones include major federal states of Karnataka, Gujarat, Andhra Pradesh, Maharashtra, Madhya Pradesh, Rajasthan, Tamil Nadu, Haryana, Punjab, Kerala, Bihar, Uttar Pradesh, and Chattisgarh. The eastern part of Ladakh region (Jammu & Kashmir) and minor parts of Himachal Pradesh, Uttarakhand, and Sikkim, which are located in the Himalayan belt also receive similar average global insolation annually. These regions with a viable potential constitute solar hotspots covering nearly 1.89 million km^2 ($\sim$58%) of India (Fig. 14) with the favourable prospects for solar-based renewable energy technologies, which could help meet her escalating power requirements in a

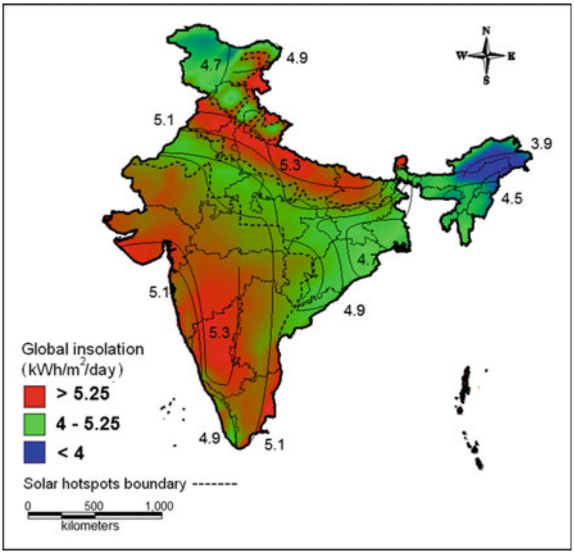

Fig. 13 Annual average global insolation map of India showing the isohels and solar hotspots

decentralized, efficient, and sustainable manner. A techno-economic analysis of the solar power technologies and a prospective minimal utilization of the land available within these solar hotspots demonstrate their immense power generation as well as emission reduction potential. A major thrust for R&D in solar technologies is essential to lower the generation cost and enable competition with the conventional fossil fuel-based options.

Regions receiving global insolation of 5kWh/m^2/day and above can generate at least 77 W/m^2 (actual onsite output) at 16% efficiency. Hence, even 0.1% of the land area of the identified solar hotspots (1897.55 km^2) could deliver nearly 146 GW of SPV-based electricity (379 billion units (kWh) considering 2600 sunshine hours annually). Figure 14 gives the district wise solar power density of the country. This power generation capacity would enhance considerably with the improvement in efficiency of SPV technology. Solar technologies have the potential to offset a huge volume of GHG emissions as demonstrated and help realize a low carbon economy at a faster rate. It will create numerous employment opportunities, especially at the village level. Learning from other developing countries as well as its own past experiences, India can be a world leader in solar power generation. With an ambitious solar mission, and positively evolving policy instruments, the nation will rightly adorn the epithet of 'Solar India' in the near future.

The National Solar Mission (NSM) launched in 2009 by the Government of India has given a great boost to the solar scenario in the country. The mission targets achieve 175 GW by the year 2022 which includes 100 GW from solar, 60 GW from wind, 10 GW from bio-power, and 5 GW from small hydro-power. The solar energy installation comprises of 40 GW rooftop and 60 GW through large- and medium-scale grid connected solar power projects. About INR 6,00,000 crores

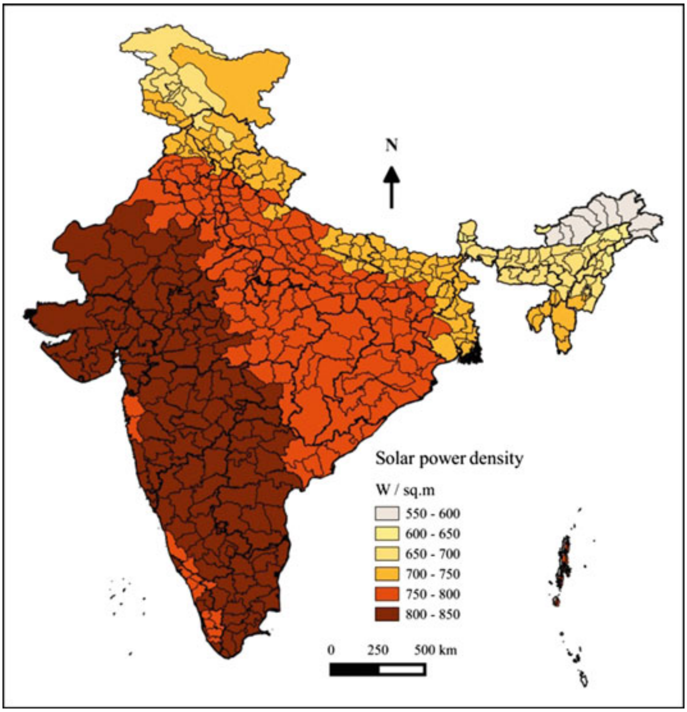

Fig. 14 District-wise solar power density of the country

investment is expected for the commission of 100 GW solar projects (CEA—LGBR 2013). However, considering the current level of T & D losses in a centralized system, inefficient, and unreliable electricity supply, it is necessary to promote decentralized energy generation. Small capacity systems are efficient, economical, and more importantly would meet the local electricity demand. The incentives could be

(i) Solar Rooftop PV systems can be installed on residential/commercial/industrial buildings in the state. Excess generated energy can be fed to the grid with net metering with incentives (of INR 9.56/unit—without subsidy and INR 7.20/—with subsidy).
(ii) Buyback programmes for the electricity generated at household level and in micro grid—GBI of INR 9.56 for electricity generation (<5 kW) feeding to the grid by SPV.
(iii) Install solar rooftops in all new government/local body buildings—implementation of solar rooftops could be in a phased manner in the existing government/local body buildings, etc.
(iv) Commercial lighting in advertisement boards should only be from RE sources. Complete ban on usage of grid electricity for these purposes.

(v) Impetus to energy research through generous funding for the R & D activities to ensure further improvements in the grid, technologies, two-way communication energy meters (to connect rooftop generation with existing grid), efficient luminaries' production, low cost wiring, switchgears, appliances, etc.
(vi) Energy education (focusing mainly on renewable energy technologies, end-use energy efficiency improvements, energy conservation) at all levels. School curriculum shall include renewable energy (RE) concepts.
(vii) Awareness about energy independence and the necessity of RE sources in the present gloomy energy scenario to the consumers.
(viii) Education and awareness about applications and importance of renewable energy sources.
(ix) Capacity building of youth through technical education for installation and servicing of SPV panels.
(x) Setting up service centers in block development offices to meet the requirement of service support for RE technologies (solar, biogas, energy efficient chulas, etc.).

3.2 Wind Energy

India ranks fifth (after China, US, Germany, and Spain) with over 19 GW wind installed capacity. Wind energy accounts for 8.5% of the total installed capacity. Figure 15 gives the district-wise wind power density potential in India. The total wind energy potential in country is estimated as 49.13 GW in which about 38% has been utilized for energy generation (Sharma et al. 2012). The state of Tamil Nadu leads in wind energy extraction with the installed capacity of 6,286 MW followed by Maharashtra (2,400 MW), Gujarat (2,337 MW), and Karnataka (1,773 MW) (C-WET 2012). Energy extraction from wind resources primarily depends on the wind speed available in the region. The available wind energy potential is directly proportional to the wind speed and area swept by the wind turbine. Hence, the primary need is to assess the annual wind speed of the region which indicates the potential regions for energy extraction. The coastal region of the country experiences high wind speed which ranges from 3 to 5 m/s annually. The southern and central part (west coast) of the country experiences higher wind speed during monsoon (June to September) which will be more than 5 m/s. During winter, the high elevated region of the country experiences high flow of wind that ranges from 4 to 5.25 m/s (Ramachandra and Shruthi 2007). Estimation shows that the western coast (Karnataka, Tamil Nadu, Kerala, Maharashtra, Gujarat) and plains (Rajasthan, Gujarat, Karnataka) are the ideal places for wind energy harvesting where the annual average wind speed is higher. However, there is vital scope for decentralized wind energy generation in hilly regions (such as Jammu and Kashmir, Himachal Pradesh) and islands (such as Anadaman and Nicobar, etc.). Distributed wind

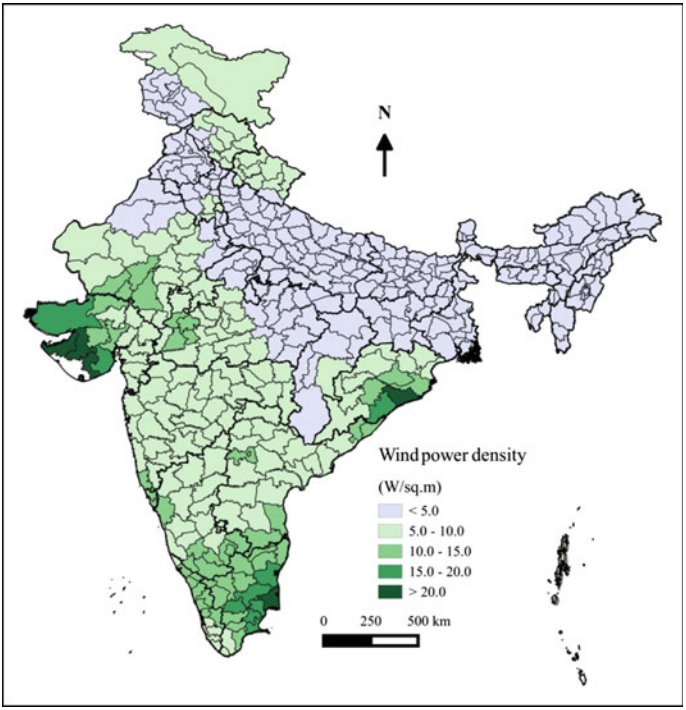

Fig. 15 District-wise wind power density potential in India

applications in water pumping and milling could meet the energy demand for irrigation and domestic sector of the region (Ramachandra and Krishnadas 2012).

3.3 Bio-Energy

Bio-energy is a prominent component of total primary energy consumption in India. About 70% of the population lives in the rural region of the country where agriculture and horticulture are the primary occupations. Residues obtained during the processing of the yield are one of the major sources of bio-energy in the country (Ramachandra et al. 2014). Forest residues and fuel wood are the primary energy sources for heating and cooking in rural India. The sector-wise available bio-energy is estimated and compared with the energy demand. Figure 16 gives the state-wise supply to demand ratio of biogas and biomass energy, which shows the ratio of 0.25–0.5 for most of the states. Cattle dung and biogas generation meets the significant domestic energy demand for cooking in rural and suburban areas. The north-eastern part of the country with good forest cover shows a better resource status.

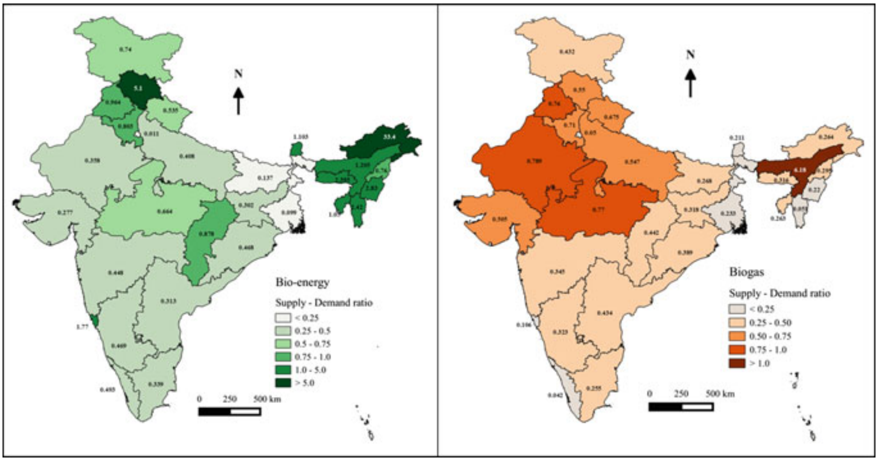

Fig. 16 State-wise bioenergy and biogas status (supply/demand ratio)

The Ministry of New and Renewable Energy (MNRE), Government of India, has come up with policies and plans to encourage bio-energy utilization in the country. The country has a total installed capacity of 1,284 MW biomass power plants and 2,392 MW of bagasse generation plants which are synchronized with grid (MNRE 2013b). Waste to power generation grid interactive plants of about 100 MW installed capacity demonstrate the productive way of municipal solid waste (MSW) management (MNRE 2013a; Ramachandra 2009b). The country has more than 750 MW installed capacity off grid/captive power plants which gives the new avenues for decentralized power generation (MNRE 2013b). Improvement in bio-energy technologies (BETs) and effective management of wasteland, friendly policies, and incentives would certainly increase the energy potential and capacity addition using more bio-energy resources (Singh and Setiawan 2013).

3.4 Biofuel

In the face of increasing CO_2 emissions from conventional energy sources and the projected scarcity of crude oil, there is an immediate need for cost effective renewable alternative energy sources. Bio-diesel generation from gasoline secreting diatom solar panels is a revolutionary change to meet the future crude oil demand. Diatoms, the major group of planktonic algae, can be used sustainably for production of bio-fuel, by the usage of diatom-based solar panels. Studies have shown that diatoms could make 10 to 200 times as much oil per hectare as oil seeds. Some diatoms secrete more lipid content when subjected to unfavourable environment or culture conditions, such as nutrient starvation or extreme temperatures (Mahapatra et al. 2014). Since diatoms multiply rapidly, they can double their biomass within an hour to a day's time. Since each diatom creates and uses its own gas tank, it is estimated that diatoms are responsible for up to 25% of global carbon dioxide (CO_2) fixation. This shows that while diatoms can be cultivated for oil extraction, they can automatically reabsorb carbon dioxide in the process. Diatoms have the potential to meet the future oil demand which also plays a major role in CO_2 absorption. This enables the scope for mimicking the natural process to extract oil which leads to sustainable growth (Ramachandra et al. 2013).

3.5 Biofuel from Wastewater Algae

Third generation biofuel, based on microalgae, is emerging as one of the most promising sources due to algae's high photosynthetic efficiency and faster replication as compared to other energy crops. However, optimization of the conditions for the growth and technologies for biomass harvest and energy extraction are necessary for sustainability, together with a cost effective way of algal cultivation. Abundant wastewaters, generated in urban localities every day, provides the nourishment to nurture algae for biofuel generation. Domestic wastewaters potentially provide economic and sustainable means of dense algal growth. Algae have the ability to uptake nutrients which aid in the treatment of wastewater. The total lipid content of *Euglena* species was higher (24.6%) compared to *Spirogyra* sp. (18.4%) followed by *Phormidium* sp. (8.8%) and their annual lipid yield potential was 6.52, 1.94, and 2.856 t/ha/yr., respectively. These species showed higher content of fatty acids (palmitate, stearate followed by oleic and linoleic acids) with the desirable biofuel properties. This suggests that algae based treatment option for removal of nutrients from wastewater as well as biofuel production for fostering the sustainable production of renewable energy. Thus, extraction of lipid from micro-algae, grown in wastewater, would serve the dual purpose of cost effective waste treatment and help in meeting the regional energy demand (Ramachandra et al. 2009).

3.6 Capacity Addition Through Renewable Energy Sources

The Indian power sector is facing installed capacity deficiency problem due to the ever-increasing load. A large number of new loads are being added to the grid, but increasing installed capacity is not an overnight process. Accumulated load has severe impact on the power system supply which is a challenging task. The present generating stations are working to their maximum capacity and most of them are centralized. Power sector equipment (transformers, transmission lines, insulators, compensators, etc.) are aged, working with lower efficiency; replacing or up-gradation is a costly affair and takes more time. Overloading of such equipment is presently not possible which may lead to blackout. Adoption of new trending technologies such as smart grid, energy management system (EMS), SCADA is a tough task and expensive with the present power system network. Connecting un-electrified load to the present grid increases the load which might collapse the grid. In this perspective, to meet the ever growing load, there is a need to exploit the renewable energy potential in the country. Capacity addition through RE sources and decentralized installation of generation plants will reduce the load on transmission network and also narrow the energy demand gap (Nouni et al. 2008; Hiremath et al. 2007).

Renewable energy technologies (RET) such as individual/community level rooftop installation of solar PV, biomass gasifiers, wind energy conversion systems, biogas plants, etc., have the potential to substitute grid electricity. Since the country receives solar insolation over 5 kWh/m^2/day for more than 300 days annually, solar PV installation on rooftop and in wasteland could be viable option to build up the capacity. India has over 7,000 km of coastline which are high potential wind regions. Installation of wind turbine near sea shores (fraction of area) could generate enormous amount of energy which also adds to the natural splendour. Most of the Indian population residing in rural areas practices agriculture. Agricultural and horticultural residues have the potential to meet village level domestic energy demand through gasification. The prime advantage of this system is that it produces electricity, gas, and manure which can be returned to the farmer. These systems can be installed by individuals or as a community (pay for service) in larger scale which can also be connected to the grid. Hybridization of locally available RE sources makes the system more reliable, efficient, economically viable, and sustainable (Ghosh et al. 2002; Balamurugan et al. 2009).

4 Energy Conservation and New Energy Technologies

4.1 End-Use Efficiency Improvement

More than 70% of the population resides in rural regions and 85% of the energy requirement is met by traditional fuel through energy inefficient devices. Industrial energy consumption is also inefficient in most of the cases due to the aged equipment, lack of lubrication, torn out parts, and non-scientific combustion. The overuse of energy resources in the commercial domain and unmetered energy supply for irrigation pumps have aggravated the energy crisis.

The primary need of energy resources in rural India is for cooking, water/space heating, and lighting. Most of the energy for cooking and heating is supplied by bioenergy (fuel wood, dung cake, etc.) which is locally available. However, the conventional cook stoves used for combustion of biomass have lower thermal efficiency (<10%). Compared to these, improved cook stoves (ICS) have higher efficiency (20–30%) and there is a scope to reduce 27 to 42% of the fuel wood requirement (Ramachandra et al. 1999). A typical rural household consumes about

5 l of kerosene every month. Average electricity consumption in rural household ranges between 50 and 60 kWh/month which is mainly used for lighting, entertainment, water pumping, and air cooling. About 30–40% of energy conservation is possible in the domestic sector using CFL/LED lamps for lighting, energy efficient heaters, and coolers (Reddy 1999).

The domestic energy requirement of an urban household is supplied by electricity, LPG (Liquefied Petroleum Gas), fuelwood, etc. Even though an urban household consumes about 11 kg of LPG per month, 22% of the urban households depend on firewood and kerosene as primary energy need. Electricity is the main source of lighting, cooling, and water heating in urban area where the consumption ranges from 100 to 125 kWh per month (TEDDY 2013). Use of ICs, CFL/LED lamps, and energy efficient heaters and coolers can conserve a significant amount of energy. Solar water heater and rooftop solar PV installation can substitute electricity and biomass consumption for lighting and water heating, respectively (Vishwanathan and Ravikumar 2005).

Energy conservation in irrigation pump sets is possible by avoiding over capacity installation, maintenance and lubrication, selecting proper foot valves and pipelines, drip irrigation, and sprinkler installation, etc. Energy supply for agricultural purposes is to be metered and tariff has to be applied on the basis of installed capacity. This would help in the optimal irrigation of agriculture fields. Wind pumps and solar PV pumps can be installed for small area irrigation (5–10 hp) which would replace the diesel or kerosene fueled pumps (Kumar et al. 2010).

Industries are the highest energy consumers in India which use all forms of energy resources. Many of the Indian industries use coal, oil, and electricity. About 30–40% of energy conservation is possible with upgradation of equipment and technology. However, there is a need to reform policies and tariffs for industrial energy consumption to promote captive generation through renewable energy sources (Gupta and Sengupta 2012; Ramachandra and Subramanian 1995).

Energy consumption in the commercial sector has increased considerably during the last decade. Energy conservation in the commercial sector through interventions in lighting technologies (LED/CFL), green buildings, and energy efficient equipment would reduce the energy consumption and decrease the energy intensity.

4.2 Demand Side Management (DSM)

The techniques and measures taken in load side to improve the reliability and quality of power are termed as demand side management (DSM). DSM techniques include use of energy efficient equipment (CFL/LED lamps), reactive power compensators (STATCOM, series/parallel capacitors/inductors), load shifting, and load shaving, etc. (Palensky and Dietrich 2011). Capacity addition through renewable energy sources is also a DSM technique which reduces the consumer's dependency on the grid. DSM techniques immediately affect the power system (generation and load) which narrows the supply-demand gap. Demand response, the widely used DSM technique, basically includes two ways—Intensive based programme (IBP) and Price-based programme (PBP). In IBP, consumer will not derive direct benefit for cutting down the load, however, the same shall be earned through incentives such as tax reduction and tax holidays. In PBP, different types of power tariffs are applied to the consumer, from which direct benefit is possible in electricity bills. Various tariffs such as time of use (TOU), maximum demand (MD) pricing, critical peak pricing (CPP), real time pricing (RTP), power factor tariff, etc., will control the electricity bill (Albadi and El-Saadany 2007).

4.3 Smart Grid and Energy Management System

Smart grid is an intelligent system (manual/automated) which integrates all components of the power system (generator, transmission and distribution network, end users) for reliable, efficient, and environment-friendly energy supply. It also plays a key role in demand response, peak load management, unit commitment, and to have effective renewable mix in the installed capacity. Well-established information and communication technology (ICT) and control networks are the backbone of smart grid for which the supportive grid network is required (Vijayapriya and Kothari 2011). Power sector in India is evolving and adopting modern grid technologies such as supervisory control and data acquisition (SCADA), energy management system (EMS), distribution automation (DA), advanced metering infrastructure (AMI) such as prepaid meters, etc. However, the communication network is limited to high voltage transmission equipment and feeble parts of the present power network need to be strengthened to have the smart grid architecture. India is planning to have a full phase smart grid by 2025, for which required devices such as FACT (flexible AC transmission) controllers and phasor measurements units (PMUs) are being installed. Around 14 pilot projects are being implemented by Indian Government under Restructured Accelerated Power Development and Reforms Programme (R-APDRP) and the US–India Partnership to Advance Clean Energy-Development (PACE-D) programmes. Data management technologies and automatic screening of data, collected through remote terminal units (RTUs) is the worldwide challenge to make the network smart and to take quick decisions (ISGTF 2013). However, smart grid is a visionary and revolutionary change in the power sector which requires contributions from industry, academic, and research institutions. Smart grid architecture varies from place to place and essentially depends on the present grid structure, load dynamics, and resource availability. The Indian power sector still suffers from huge unmet demand due to lack of peak load management and high T & D losses. Smart grid would primarily reduce the network losses and narrow the energy demand gap. Power sector should be analysed, considering the future demand and then the grid architecture should be decided, whereas replicating the smart grid architecture may not be the solution.

4.4 Innovations in Energy Sector

Development of economically viable and technically feasible new energy harvesting technologies is expected to change the present energy mix. Technology innovation in non-fossil energy resources - solar thermal and PV, bioenergy, off-shore wind, hydrogen, artificial photosynthesis, etc. would meet the future energy demand (Abas et al. 2015). The current focus is on bioenergy, bio-oil, and biological hydrogen production. Technologies like bio-oil and ethanol production from algae would significantly replace the fossil oil for transportation and electricity generation (Gupta and Verma 2015). Many of these technologies are in the lab scale at the moment and thus, have shown great potential in cutting down the cost and also tapping a wide range of renewable energy sources.

Significant improvements are also found in energy storage technologies in order to resolve the intermittency issues in renewable energy sources. Table 1 summarizes a few energy storage technologies which are being developed and also used across the globe. However, industry collaboration would be necessary in order scale up/widen the new energy technologies and also for wide-scale dissemination.

In the face of increasing CO_2 emissions from conventional energy (gasoline) and the anticipated scarcity of crude oil, a worldwide effort is underway for cost effective renewable alternative energy sources. Efforts are in progress at Energy & Wetlands Research Group, CES (http://ces.iisc.ernet.in/energy), at the Indian Institute of Science, Banaglore, towards developing the gasoline secreting diatom solar panels to produce gasoline from diatoms sustainably. Diatoms being the major group of planktonic algae (Fig. 17) can be used sustainably for production of bio-fuel, by the usage of diatom-based solar panels. Studies have shown that diatoms could make 10 to 200 times as much oil per hectare as oil seeds (Ramachandra et al. 2009) and the techniques involved towards developing oil secreting diatoms to minimize the cost of oil extraction. It was found that some diatoms secrete more lipid content when subjected to unfavourable environment or culture conditions, such as nutrient starvation or extreme temperatures. Unlike crops, diatoms multiply rapidly. Some diatoms can double their biomass within an hour to a day's time. Since each diatom creates and uses its own gas tank, it is estimated that diatoms are responsible for up to 25% of global carbon dioxide fixation. This means that while diatoms can be cultivated for oil extraction, they can automatically reabsorb carbon dioxide in the process. Diatoms may have a major role to play in the coming years with regard to the mass production of oil. This entails appropriate cultivation, harvesting and extraction of oil, using advanced technologies that mimic the natural process while cutting down the time period involved in oil formation.

Energy from Wastes: Urban areas are generating a large quantum of waste. For example, Greater Bangalore generates about 1,200 MLD of liquid waste and about 2,800 tonnes of solid waste every day. Untreated wastes are contributing to greenhouse gases (GHG) in the system and also to global warming (Ramachandra 2009b). Viable technologies are available to convert waste to energy. For example, an algae photo-bioreactor that grows algae in municipal wastewater to produce

Table 1 Energy storage technologies (Decourt and Debarre 2013; Paksoy 2013)

Technology	Location	Output	Efficiency (%)	Initial investment cost (USD/kW)	Primary application
Pumped Storage	Supply	Electricity	50–85	500–4600	Long-term
Underground Thermal Energy Storage (UTES)	Supply	Thermal	50–90	3400–4500	Long-term storage
Compressed air storage	Supply	Electricity	27–70	500–1500	Long-term storage, arbitrage
Pit storage	Supply	Thermal	50–90	100–300	Medium temperature applications
Molten salts	Supply	Thermal	40–93	400–700	High-temperature applications
Batteries	Supply, demand	Electricity	75–95	300–3500	Distributed/off-grid storage, short-term storage
Thermochemical	Supply, demand	Thermal	80–99	1000–3000	Low, medium, and high-temperature applications
Chemical-hydrogen storage	Supply, demand	Electrical	22–50	500–750	Long-term storage
Flywheels	T&D	Electricity	90–95	130–500	Short-term storage
Supercapacitors	T&D	Electricity	90–95	130–515	Short-term storage
Superconducting magnetic energy storage (SMES)	T&D	Electricity	90–95	130–515	Short-term storage
Solid media storage	Demand	Thermal	50–90	500–3000	Medium temperature applications
Ice storage	Demand	Thermal	75–90	6000–15,000	Low-temperature applications
Hot water storage (residential)	Demand	Thermal	50–90	Negligible	Medium temperature applications
Cold-water storage	Demand	Thermal	50–90	300–600	Low-temperature applications

Source Abas et al. 2015

biofuel and a variety of other products is in place (Mahapatra et al. 2014). This bioreactor will not compete with agriculture for land, fertilizer, or freshwater. Similarly, to handle the organic fraction of municipal waste (which constitute 60–70% of Bangalore's municipal waste), Centre for Sustainable Technologies at the Indian Institute of Science (IISc), Bangalore, has developed a viable technology.

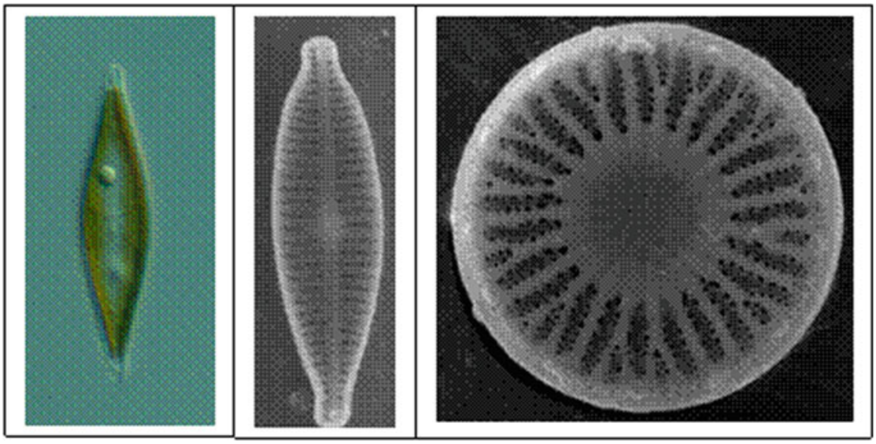

Fig. 17 Pennate and centric diatoms (*Navicula* sp., with an oil droplet)

The policy shift, political-will, and active participation of decision makers and all stakeholders (local community) are required to see these technologies are in place and Bangalore is free of wastes (Ramachandra 2009b; Chanakya et al. 2007a, b, 2009).

4.5 Future Energy Scenario

Natural resource exploitation in the country has increased manifold over the years to cater the energy requirements in all sectors. Resource extraction is forecasted till 2021 using the historical rate of consumption and is given in Fig. 18. It shows an increasing trend which necessitates the immediate energy conservation and

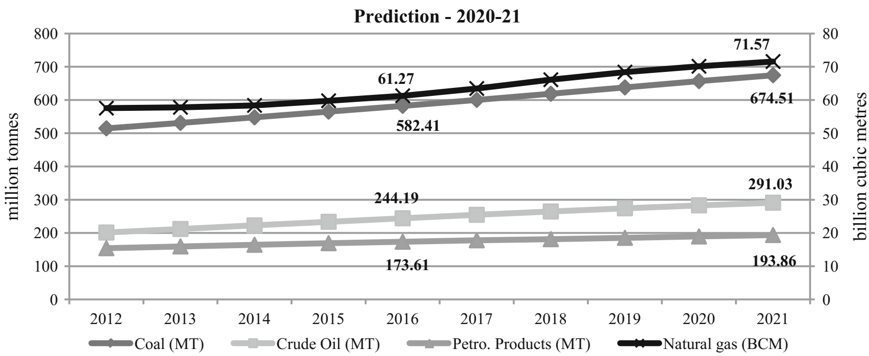

Fig. 18 Resource consumption prediction for 2021

exploitation of non-conventional sources of energy. Extraction of coal resources is projected as 674 million tonnes, which is about 34% more than the present consumption (2011). Estimation also reveals an increment of 38 and 31% in crude oil and petroleum production consumption. Increase in the natural gas consumption is expected to be marginal ($\sim$25%) with respect to the present consumption. This demands radical government policies focusing on renewable energy, revolutionary improvements in end-use technologies, and changes in the resource utilization practices. Nevertheless, the current trend of consumption of fossil fuel resources has caused many environmental problems, thus, necessitating restructuring of energy portfolio.

5 Conclusions and Recommendations

The Indian energy sector is at the tipping point as alternate renewable energy technologies have gained significance during the last two decades. There is a need to navigate the energy transition for sustainable growth in socio-economic aspects of the country. Though the energy consumption per GDP is higher, production of valuable goods is quite low in the country which shows that there is a need to improve the end-use efficiency. Energy utilization from non-conventional energy sources holds the major share after fossil fuels, which has to be considered for technology improvement. Indian electric power generation mainly depends on coal and hydro resources which are centralized. Sparsely located load centers, theft, pilferage, and unmetered supply causes high T & D losses which needs to be reduced through distributed generation and micro-grids. Capacity addition through renewable energy sources will ensure the effective renewable mix in total installed capacity, while meeting the future demand. Demand-side management and end use efficiency improvements are the short term requirements to fill the supply–demand gap and for reliable energy supply. It also reduces the derivatives (ash, fumes, GHG gases, etc.) by increasing the net productivity. Smart grid technology will make the power system more reliable, secure, efficient, and environment-friendly. New energy sources and effective use of available resources would keep the country on a sustainable path leading to achievement of energy independence.

The sustainable energy option requires the government support for the identification, exploitation and use of renewable sources of energy, which should be at least as high as for conventional sources. A generation based incentive (GBI) would encourage decentralized electricity generation at individual rooftops. In addition to this, there is a need to promote solar rooftops in Government infrastructure and buildings such as (i) solar powered street lights, (ii) install solar rooftops in all new government/local body buildings, (iii) implementation solar rooftops in a phased manner in the existing government/local body buildings, and solar power systems for all street lights and water supply installations in local bodies in a phased manner. The current study shows that the renewable energy experiences all the useful kinds of problems that affect most economic development projects. Lack of capital, skilled labour and service backups are serious impediments to the progress of alternate devices such as fuel efficient stoves, biogas, wood gasifiers, etc. Even more serious concern is the lack of coordinated effort among various bureaucratic setup and ministries. These are the main hurdles to the successful implementation of biomass cultivation projects and development of bioenergy. Policies are to be formulated to remove the constraints at local/regional level. Policies must engender the communication between the different institutions and government sectors involved with the establishment of a significant and sustainable bioenergy programme that is the agricultural, forestry, land planning and energy sectors. Hence, the prudent management practices involving energy generation from renewable sources, while meeting the energy requirements at decentralized levels efficiently would offer the opportunity to address multiple environmental concerns such as land degradation, bio diversity, acid rain pollutants, local and regional health problems.

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