Abstract

Renewable energy sources and technologies have potential to provide solutions to the long-standing energy problems being faced by the developing countries. The renewable energy sources like wind energy, solar energy, biomass energy and fuel cell technology can be used to overcome energy shortage in India. To meet the energy requirement for such a fast growing economy, India will require an assured supply of 3–4 times more energy than the total energy consumed today. The renewable energy is one of the options to meet this requirement. India is increasingly adopting responsible renewable energy techniques and taking positive steps towards carbon emissions, cleaning the air and ensuring a more sustainable future. In India, from the last two and half decades there has been a vigorous pursuit of activities relating to research, development, demonstration, production and application of a variety of renewable energy technologies for use in different sectors. In this paper, efforts have been made to summarize the availability, current status, major achievements and future potentials of renewable energy options in India. This paper also assesses specific policy interventions for overcoming the barriers and enhancing deployment of renewable energy devices for the future.
1. Introduction

Less than 300 years of modern industry and consumerism will have exhausted fossil resources that accumulated over 150-200 million years. The depletion of petroleum resources, along with concerns about the warming of the planet by human activities, makes it urgent to shift dependence from fossil resources to renewable energy.

The World Energy Forum has predicted that fossil-based oil, coal and gas reserves will be exhausted in less than another 10 decades. Fossil fuels account for over 79% of the primary energy consumed in the world, and 57.7% of that amount is used in the transport sector and are diminishing rapidly [1]. The exhaustion of natural resources and the accelerated demand of conventional energy have forced planners and policy makers to look for alternate sources. Renewable energy is energy derived from resources that are regenerative, and do not deplete over time. Renewable energy offers our planet a chance to reduce carbon emissions, clean the air, and put our civilization on a more sustainable footing. It also offers countries around the world the chance to improve their energy security and spur economic development. Modern biomass encompasses a range of products derived from photosynthesis and is essentially chemical solar energy storage. Renewable energy supplies 18% of the world's final energy consumption (Fig. 1), counting traditional biomass, large hydropower, and “new” renewables (small hydro, modern biomass, wind, solar, geothermal, and biofuels). Traditional biomass, primarily for cooking and heating, represents about 13% and is growing slowly in some regions as biomass is used more efficiently or replaced by more modern energy forms. Large hydropower represents 3% and is growing modestly, primarily in developing countries [2]. New renewables represents 2.4% and are growing very rapidly in developed countries and in some developing countries. Global renewable energy capacity grew at rates of 15–30% annually for many technologies during the five-year period 2002–2006, including wind power, solar hot water, geothermal heating, and off-grid solar PV (Fig. 2) [3]. Renewable energy markets grew robustly in 2008. Among new renewables (excluding large hydropower), wind power was the largest addition to renewable energy capacity. An estimated $120 billion was invested in renewable energy worldwide in 2008, including new capacity (asset finance and projects) and biofuels refineries Fig. 3 [4].
Renewable energy sources (RES) that use indigenous resources have the potential to provide energy with negligible emissions of air pollutants and greenhouse gases [5]. Renewable energy technologies produce marketable energy by converting natural phenomena/resources into useful energies. The usage of renewable energy resources is a promising prospect for the future as an alternative to conventional energy. India is endowed with vast solar energy potential. About 5,000 trillion kWh per year energy is incident over India’s land area with most parts receiving 4-7 kWh per sq. m per day. Hence both technology routes for conversion of solar radiation into heat and electricity, namely, solar thermal and solar photovoltaic, can effectively be harnessed providing huge scalability for solar in India. Solar also provides the ability to generate power on a distributed basis and enables rapid capacity addition with short lead times. Off-grid decentralized and low-temperature applications will be advantageous from a rural electrification perspective and meeting other energy needs for power and heating and cooling in both rural and urban areas. The constraint on scalability will be the availability of space, since in all current applications, solar power is space intensive. In addition, without effective storage, solar power is characterized by a high degree of variability. In India, this would be particularly true in the monsoon season.

Therefore, an attempt has been made through this paper to review the availability of renewable energy options in India, and provides information about the current status of renewable, future potentials of their uses, and current government policies, delivery and outreach in Indian context. It paints a remarkable overall picture of renewable energy resources and position of India on global map in utilizing these resources.
2. Renewable energy in India

India's population of more than 1028 million is growing at an annual rate of 1.58%. As fossil fuel energy becomes scarcer, India will face energy shortages significantly due to increase in energy prices and energy insecurity with in the next few decades. Increased use of fossil fuels also causes environmental problems both locally and globally. The economy of India, measured in USD exchange-rate terms, is the twelfth largest in the world, with a GDP of around $1 trillion (2008). GDP growth rate of 9.0% of India for the fiscal year 2007–2008, makes it the second fastest big emerging economy, after China, in the world. There is a very high demand for energy, which is currently satisfied mainly by coal, foreign oil and petroleum, which apart from being a non-renewable, and therefore non-permanent solution to the energy crisis, it is also detrimental to the environment. Thus, it is imperative that India obtains energy security without affecting the booming economy, which would mean that the country must switch from the nonrenewable energy (crude oil and coal) to renewable energy.

For these reasons the development and use of RES & Technologies are becoming vital for sustainable economic development of India. Expert consultation at the Asia Energy Vision 2020, organized under the World Energy Council agreed on energy demand projection in India up to 2020 as given in Table 1 [6]. The Expert Committee on Integrated Energy Policy in its Report (IEPR 2006) has estimated that by 2032, i.e., 25 years from now primary commercial energy requirement in the country would need to go up 4–5 times the current level, electricity generation installed capacity 5.6–7 times the current level and oil requirement by 3–6 times the current level.

Table 1: Energy demand projection in India.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electricity</td>
<td>TWh</td>
<td>231</td>
<td>725</td>
<td>1300</td>
</tr>
<tr>
<td>2</td>
<td>Coal</td>
<td>Mt.</td>
<td>229</td>
<td>690</td>
<td>1345</td>
</tr>
<tr>
<td>3</td>
<td>Petroleum products</td>
<td>Mt.</td>
<td>57</td>
<td>165</td>
<td>335</td>
</tr>
<tr>
<td>4</td>
<td>Natural gas</td>
<td>b cum</td>
<td>18.6</td>
<td>65</td>
<td>130</td>
</tr>
</tbody>
</table>

Energy is a basic requirement for economic development and in every sector of Indian economy. It is thus necessary that India quickly looks towards new and emerging renewable energy and energy efficient technologies as well as implement energy conservation laws. Against this background, the country urgently needs to develop a sustainable path of energy development. Promotion of energy conservation and increased use of renewable energy sources are the twin planks of a sustainable energy supply. Fortunately, India is blessed with a variety of renewable energy sources, like biomass,
the solar, wind, geothermal and small hydropower and implementing one of the world's largest programs in renewable energy. India is determined to becoming one of the world's leading clean energy producers. The Government of India has already made several provisions, and established many agencies that will help it to achieve its goal. Renewable energy, excluding large hydro projects already account for 9% of the total installed energy capacity, equivalent to 12,610 MW of energy. In combination with large hydro, the capacity is more than 34%, i.e., 48,643 MW, in a total installed capacity of 144,980 MW. Fig. 4 is showing installed power capacity (MW) in India.

![India Installed Power Capacity (MW)](source: CEA, 2008, MNRE, 2008)

The country has an estimated renewable energy potential of around 85,000 MW from commercially exploitable sources, i.e., wind, 45,000 MW; small hydro, 15,000 MW and biomass/bioenergy, 25,000 MW. In addition, India has the potential to generate 35 MW per square kilometer using solar photovoltaic and solar thermal energy. By December 2009, renewable electricity, excluding hydro above 25 MW installed capacity, has contributed total 16,056 MW installed capacity. There has been phenomenal progress in wind power and, with an installed capacity of over 10925 MW, India occupies the fifth position globally [6] and [7].

The role of new and renewable energy has been assuming increasing significance in recent times with the growing concern for the country's energy security. The renewable energy industry has approximately USD 500 million as turnover, the investment being about USD 3 billion. The Indian Government has been at work, making a comprehensive policy for compulsory use of renewable energy resources through biomass, hydropower, wind, solar and municipal waste in the country, particularly for commercial establishments, as well as Government establishments. The major contribution to renewable energy investment comes from private sector participation. This is due to the support from the government, which leverages the private investment. The financial allocation for renewable energy sources vis-à-vis total allocation, however, remains in the range of 0.1% during Tenth Plan period. This is expected to increase during the Eleventh Plan (Table 2) [8].
Table 2: Allocation to renewable energy vis-a-vis conventional energy sources.

<table>
<thead>
<tr>
<th>Five-year plan (period)</th>
<th>Energy sector outlay (percentage of total plan outlay)</th>
<th>Percentage share in the total plan allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Power</td>
</tr>
<tr>
<td>Sixth (1980–1985)</td>
<td>28.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Seventh (1985–1990)</td>
<td>28.2</td>
<td>17.4</td>
</tr>
<tr>
<td>Eight (1992–1997)</td>
<td>26.5</td>
<td>18.4</td>
</tr>
<tr>
<td>Ninth (1997–2002)</td>
<td>25.58</td>
<td>14.5</td>
</tr>
<tr>
<td>Tenth (2002–2007)</td>
<td>27.26</td>
<td>18.2</td>
</tr>
</tbody>
</table>

According to the 11th new and renewable energy five-year plan proposed by the government of India, from 2008 to 2012 the renewable energy market in India will reach an estimated US $19 billion. Investments of US $15 billion will be required in order to add the approximately 15,000 megawatts (MW) of renewable energy to the present installed capacity. The Indian government has also set specific targets for renewable energy by 2012 it expects renewable energy to contribute 11% of total power generation capacity. This implies that growth in renewable energy will occur at a much faster pace than traditional power generation, with renewables making up 20% of the 70,000 MW of total additional energy planned from 2008 to 2012. From 2002 to 2007, there was 3075 MW of renewable grid-tied power planned, but the actual capacity addition exceeded 6000 MW by 2006. A large share of this was the result of exceptional growth of wind energy in India. Wind energy is expected to add more than 12,000 MW of additional capacity by 2012, followed by small hydro (1400 MW), cogeneration (1200 MW) and biomass (500 MW). The Ministry of New and Renewable Energy (MNRE) is focused on nation-wide resource assessment, setting up of commercial projects, renovation and modernization, development and up-gradation of water mills and industry based research and development.

MNRE has identified renewable energy R&D as an important factor for developing this sector. R&D subsidy is 100% of a project's cost in government R&D institutions, and 50% in the private sector. The R&D subsidy for the private sector may be enhanced for initial stages of technologies that have longer time-horizons. During the last two decades, several renewable energy technologies have been deployed in rural and urban areas. Some of the achievements are given in Table 3 along with the estimated potential [9], [22].
Table 3: Renewable energy in India at a glance.

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Source/system</th>
<th>Estimated potential</th>
<th>Achievements (as on 31 December 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(MW)</td>
<td>(MW)</td>
</tr>
<tr>
<td>I</td>
<td>Power from renewables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Grid interactive renewable power</td>
<td>(MW)</td>
<td>(MW)</td>
</tr>
<tr>
<td>1.</td>
<td>Wind power</td>
<td>16,881</td>
<td>829.50</td>
</tr>
<tr>
<td>2.</td>
<td>Biopower (agroresidues and plantations)</td>
<td>16,881</td>
<td>829.50</td>
</tr>
<tr>
<td>3.</td>
<td>Bagasse cogeneration</td>
<td>5000</td>
<td>1308.0</td>
</tr>
<tr>
<td>4.</td>
<td>Small hydro (up to 25 MW)</td>
<td>15,000</td>
<td>2558.92</td>
</tr>
<tr>
<td>5.</td>
<td>Energy recovery from waste (MW)</td>
<td>2700</td>
<td>65.01</td>
</tr>
<tr>
<td>Sub total (A)</td>
<td>84.776</td>
<td>15,695.56</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Captive/combined heat and power/distributed renewable power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Biomass/cogeneration (non-baggase)</td>
<td>-</td>
<td>210.57</td>
</tr>
<tr>
<td>8.</td>
<td>Biomass gasifiers</td>
<td>-</td>
<td>109.62</td>
</tr>
<tr>
<td>9.</td>
<td>Energy recovery from waste</td>
<td>-</td>
<td>40.25</td>
</tr>
<tr>
<td>Sub total (B)</td>
<td>-</td>
<td>360.44</td>
<td></td>
</tr>
<tr>
<td>Total (A+B)</td>
<td>84.776</td>
<td>16,056.00</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Remote village electrification</td>
<td></td>
<td>6257villages/hamlets</td>
</tr>
<tr>
<td>III</td>
<td>Decentralized energy systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Family-type biogas plants</td>
<td>120 lakh</td>
<td>41.33 lakh</td>
</tr>
<tr>
<td>11.</td>
<td>Solar photovoltaic systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>i.</td>
<td>Solar street lighting systems</td>
<td>-</td>
<td>88,297 nos.</td>
</tr>
<tr>
<td>ii.</td>
<td>Home lighting systems</td>
<td>-</td>
<td>5,84,461 nos.</td>
</tr>
<tr>
<td>iii.</td>
<td>Solar lanterns</td>
<td>-</td>
<td>7,92,285 nos.</td>
</tr>
<tr>
<td>iv.</td>
<td>Solar photovoltaic pumps</td>
<td>-</td>
<td>7334 nos.</td>
</tr>
<tr>
<td>Sl. no.</td>
<td>Source/system</td>
<td>Estimated potential</td>
<td>Achievements (as on 31 December 2009)</td>
</tr>
<tr>
<td>--------</td>
<td>---------------</td>
<td>---------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>12.</td>
<td>Solar thermal systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i. Solar water heating systems</td>
<td>140 million m² of collector area</td>
<td>3.40 million m² of collector area</td>
</tr>
<tr>
<td></td>
<td>ii. Solar cookers</td>
<td>–</td>
<td>6.39 lakhs</td>
</tr>
<tr>
<td>13.</td>
<td>Wind pumps</td>
<td>–</td>
<td>1347 nos.</td>
</tr>
<tr>
<td>14.</td>
<td>Aero generators/hybrid systems</td>
<td></td>
<td>0.95 MW</td>
</tr>
</tbody>
</table>

### IV Awareness programs

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Source/system</th>
<th>Estimated potential</th>
<th>Achievements (as on 31 December 2009)</th>
</tr>
</thead>
</table>

MW = mega-watt; m² = square meter; KW = kilowatt; MWp = mega watt peak

MNRE. [http://mnes.nic.in/](http://mnes.nic.in/).

#### 2.1. Biomass

In recent years, the interest in using biomass as an energy source has increased and it represents approximately 14% of world final energy consumption [10]. Estimates have indicated that 15–50% of the world's primary energy use could come from biomass by the year 2050. Many countries have included the increased use of renewable sources on their political agenda. Biomass is one such resource that could play a substantial role in a more diverse and sustainable energy mix. The energy obtained from biomass is a form of renewable energy and, in principle, utilizing this energy does not add carbon dioxide, a major greenhouse gas, to the atmosphere, in contrast to fossil fuels. As per an estimate, globally photosynthesis produces 220 billion dry tonnes of biomass each year with 1% conversion efficiency [11], [12] and [13]. Biomass resources suitable for energy production covers a wide range of materials, from firewood collected in farmlands and natural woods to agricultural and forestry crops grown specifically for energy production purposes. Energy production from food wastes or food processing wastes, especially from waste edible oils, seems to be attractive based on bio-resource sustainability, environmental protection and economic consideration. India is very rich in biomass and has a potential of 16,881 MW (agro-residues and plantations), 5000 MW (bagasse
cogeneration) and 2700 MW (energy recovery from waste) [7]. Biomass power generation in India is an industry that attracts investments of over Rs. 600 crores every year, generating more than 5000 million units of electricity and yearly employment of more than 10 million man-days in the rural areas.

2.2. Hydropower

Hydropower is another source of renewable energy that converts the potential energy or kinetic energy of water into mechanical energy in the form of watermills, textile machines, etc., or as electrical energy (i.e., hydroelectricity generation). It refers to the energy produced from water (rainfall flowing into rivers, etc.). Hydropower is the largest renewable energy resource being used for the generation of electricity. Only about 17% of the vast hydel potential of 150,000 MW has been tapped so far. Countries like Norway, Canada, and Brazil have all been utilizing more than 30% of their hydro potential, while on the other hand India and China have lagged far behind. India ranks fifth in terms of exploitable hydro potential in the world. According to Central Electricity Authority (CEA), India is endowed with economically exploitable hydropower potential to the tune of 148,700 MW. The basin-wise assessed potential is shown in Table 4 [14].

<table>
<thead>
<tr>
<th>Basin/Rivers</th>
<th>Probable installed capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indus basin</td>
<td>33,832</td>
</tr>
<tr>
<td>Ganga basin</td>
<td>20,711</td>
</tr>
<tr>
<td>Central Indian river system</td>
<td>4152</td>
</tr>
<tr>
<td>Western flowing rivers of southern India</td>
<td>9430</td>
</tr>
<tr>
<td>Eastern flowing rivers of southern India</td>
<td>14,511</td>
</tr>
<tr>
<td>Brahmaputra basin</td>
<td>66,065</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>148,701</strong></td>
</tr>
</tbody>
</table>

The dominant annual rainfall is located on the North-Eastern part of India: Arunachal Pradesh, Assam, Nagaland, Manipur and Mizoram, and also on the west coast between Mumbai (Bombay) and Mahe. Primary hydroelectric power plants are located in Bihar, Punjab, Uttarakhand, Karnataka, Uttar Pradesh, Sikkim, Jammu & Kashmir, Gujarat, and Andhra Pradesh. In India, hydropower projects with a station capacity of up to 25 megawatt (MW) fall under the category of small hydropower (SHP). India has an estimated SHP potential of about 15,000 MW, of which about 17% has been tapped so far. The Ministry of New and Renewable Energy (MNRE) supports SHP project
development throughout the country. So far, 700 SHP projects with an aggregate installed capacity of 2558 MW have been installed. Besides these, 296 SHP projects with an aggregate capacity of 936 MW are under implementation. A series of steps have been taken to promote development of SHP in a planned manner and improve reliability & quality of the projects. The Government continued to provide fiscal and financial incentives to attract private investment in commercial SHP projects apart from supporting State Governments to set up micro/mini/small hydro projects.

2.3. Wind energy

Winds are generated by complex mechanisms involving the rotation of the earth, heat energy from the sun, the cooling effects of the oceans and polar ice caps, temperature gradients between land and sea and the physical effects of mountains and other obstacles. Wind is a widely distributed energy resource. Wind energy is being developed in the industrialized world for environmental reasons and it has attractions in the developing world as it can be installed quickly in areas where electricity is urgently needed. In many instances it may be a cost-effective solution if fossil fuel sources are not readily available. In addition there are many applications for wind energy in remote regions, worldwide, either for supplementing diesel power (which tends to be expensive) or for supplying farms, homes and other installations on an individual basis.

The availability of wind varies for different regions. Wind resources can be exploited mainly in areas where wind power density is at least 400 W/m² at 30 m above the ground. The Wind Resource Assessment Program is being implemented by C-WET (Centre for Wind Energy Technology) in coordination with state nodal agencies. An annual mean wind power density greater than 200 W/m² (watts per square meter) at 50-m height has been recorded at 211 wind monitoring stations, covering 13 states and union territories, namely Andaman and Nicobar Islands, Andhra Pradesh, Gujarat, Karnataka, Kerala, Lakshadweep, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttaranchal, and West Bengal. India’s wind power potential has been assessed at 45,000 MW. A capacity of 10925 MW up to December 2009 has so far been added through wind. Wind power capacity, top ten countries, 2008 has been shown in (Fig. 5) [4]. The Wind Power Program in India was initiated towards the end of the Sixth Plan, in 1983–1984. The program aims at survey and assessment of wind resources, setting up demonstration projects, and provision of incentives to make wind electricity competitive.
India is now the fifth largest wind power producer in the world, after USA, Germany, Spain and China. By the mid 1990s, the subcontinent was installing more wind generating capacity than North America, Denmark, Britain, and the Netherlands. The ten machines near Okha in the province of Gujarat were some of the first wind turbines installed in India. These 15-m Vestas wind turbines overlook the Arabian Sea. Different types of Wind Power Generators used in India for Off grid Power generation, i.e., water-pumping windmills, aero-generators (a small wind electric generator having a capacity of up to 30 kW) and wind–solar hybrid systems [15].

2.4. Solar energy
Solar energy is the most abundant permanent energy resource on earth and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean, etc.) forms. Solar energy, experienced by us as heat and light, can be used through two routes: the thermal route uses the heat for water heating, cooking, drying, water purification, power generation, and other applications; the photovoltaic route converts the light in solar energy into electricity, which can then be used for a number of purposes such as lighting, pumping, communications, and power supply in un electrified areas.

The total annual solar radiation falling on the earth is more than 7500 times the world's total annual primary energy consumption of 450 EJ. The annual solar radiation reaching the earth's surface, approximately 3,400,000 EJ, is an order of magnitude greater than all the estimated (discovered and undiscovered) non-renewable energy resources, including fossil fuels and nuclear. However, 80% of the present worldwide energy use is based on fossil fuels. Most parts of India receive 4–7 kWh of solar radiation per square meter per day with 250–300 sunny days in a year. The highest annual radiation energy is received in Western Rajasthan while the North-Eastern region of the country receives the lowest annual radiation. The MNRE, working in conjunction with the Indian Renewable Energy Development Agency (IREDA) to promote the utilization of all forms of solar power as well as to increase the share of renewable energy in the Indian market. This promotion is being achieved through R&D, demonstration projects, government subsidy programs, and also private sector projects.
The Prime Minister released the National Action Plan on Climate Change (NAPCC) on 30th June, 2008. The Plan proposes to start 8 missions, amongst which one is the National Solar Mission [15]. Solar thermal and solar photovoltaic technologies are both encompassed by the Solar Energy Program that is being implemented by the Ministry (regarded as one of the largest in the world) to utilize India's estimated solar power potential of 20 and 35 MW/km² solar thermal. India's overall potential for solar water heating systems has been estimated to be 140 million m² of collector area. A Government scheme for ‘Accelerated development and deployment of Solar Water Heating systems in domestic, industrial and commercial sectors’ has been introduced, with the object of promoting the installation of another million m² of collector area during FY 2005–2006 and 2006–2007. The scheme offers a number of financial and promotional incentives, along with other measures of support. Solar air heating technology has been applied to various industrial and agricultural processes (e.g. drying/curing, regeneration of dehumidifying agents, timber seasoning, leather tanning) and also for space heating; many types of solar dryers have been developed for use in different situations. Amongst various solar thermal technologies, solar water heating systems and solar cookers have reached a stage of near commercialization. The progress of deployment of solar water heating systems in the country is as shown below in (Fig.6), [22].

![Fig. 6. Solar Water Heating Systems in the country.](image)

The cumulative achievement of solar cookers installed in the country is over 6,39,000 at the end of December 2009; this includes about 6,32,800 box-type solar cookers and about 6,200 dish solar cookers.

The Government provides financial support for solar air heating/drying systems, and also for solar concentrating systems. Solar buildings have been promoted by the MNRE in an effort to increase
energy efficiency; the state government in Himachal Pradesh has actively promoted the incorporation of passive solar design into building design. The Solar Photovoltaic Program (SPV) promoted by the Ministry has been aimed particularly at rural and remote areas. Following the success of the country-wide SPV demonstration and utilization program during the period of the Ninth Plan, it is planned, with certain modifications, to continue it during the Tenth Plan (2002–2007) and 11th Plan. In order to make solar cells and modules cost effective the global R&D efforts are directed to reduce the consumption of silicon and other materials and improve the efficiency of solar cells / modules to achieve significant cost reduction. Further, R&D is also undertaken on non-silicon based solar cell modules and other aspects of PV systems. The Ministry of New and Renewable Energy Sources has been supporting R&D and technology development in solar photovoltaic technology for more than three decades. During the 11th Plan period it is envisaged that the cost of solar photovoltaic modules can be brought down to about Rs. 120 per Wp. In order to achieve this goal the key areas of R&D and technology development have been identified. Research, design and development efforts during the 11th plan are proposed to be focused on development of (i) poly silicon and other materials, (ii) efficient silicon solar cells, (iii) thin films materials and solar cell modules, (iv) concentrating PV systems, and (v) PV system design, with the objective of significantly reducing the ratio of capital cost to conversion efficiency.

3. Other renewable energy technologies
Solar thermal technologies, particularly solar water heating system, solar cookers and solar generation systems are the most commercialized technologies among renewable energy technologies in India. Policies are set to provide further impetus to dissemination of solar technologies.
Biogas represents an alternative source of energy, derived mainly from organic wastes. In India, the use of biogas derived from animal waste, primarily cow dung has been promoted for over three decades now. Biogas is a clean fuel produced through anaerobic digestion of a variety of organic wastes: animal, agricultural, domestic, and industrial. Biogas is the only technology that has put cooking in rural areas on technological ladder and has made cooking a pleasure with associated social and environmental benefits including zero indoor pollution. India’s National Project on Biogas development (NPBD) has been one of the well organized and systematic program to provide logistic and institutional support for that has been under implementation since early 1980s. India Biogas program is one of the most successful program if we compare with other such program implemented in Rural India. Till December 2009, under the Biogas Program, over 4.1 million biogas plants had been installed. The ultimate goal of this program is to set up biogas plants in around 12 million households that have enough cattle to maintain a regular supply of dung.
Biofuel program in the country is at nascent stage. The policy measures currently in place include an excise tax reduction for E-5, the obligation to blend all petrol with 5% ethanol in certain regions since January 2003 and government regulation of the ethanol selling price on the basis of ethanol
production costs. Subsequently the percentage of ethanol mixture in petrol is planned to be increase to 10%. A new biofuel policy for the country is under construction.

Hydrogen energy is also at early stage of development. Ministry of New and Renewable Energy also funded research projects on different aspects of hydrogen energy technology development. India is the member of the International Partnership on Hydrogen economy (IPHE) set up in Washington, DC in November 2003. Future challenges to India includes lowering cost of hydrogen substantially and improve production rates from different methods, development of compact and inexpensive storage capacity, establishment of hydrogen network and development of hydrogen fuelled IC engine and efficiency improvement of different type of fuel cell systems. The road map envisages taking up of research, development and demonstration activities in various sectors of hydrogen energy technologies and visualized goals of one million hydrogen-fuelled vehicles and 1000 MW aggregate hydrogen based power generation capacity to be set up in the country by 2020 [16].

4. Environmental sustainability: renewable energy and climate change

To sustain economic growth and raise living standards, energy shortages could be met by increasing supplies. But there are two other important considerations: environmental sustainability and social development. The current pattern of economic growth has caused serious environmental damage – polluting the air, creating large quantities of waste, degrading biological systems and accelerating climate change – with many of these effects coming from the energy sector. At the same time, it is also vital to consider the impact on social development. The lack of access to energy services aggravates many social concerns, including poverty, ill-health, unemployment and inequity.

In modern economic sectors one of the main sources of energy is oil. Although the world's largest oil consumer is still the United States, four Asian countries are not far behind; China comes second, Japan third, India fourth and the Republic of Korea sixth [17]. Natural gas is also increasingly important: its fuel efficiency makes it an attractive choice for new power generating plants and for the industrial sector.

Other environmental concerns include water pollution and the disposal of waste, particularly nuclear waste. In the rural areas one worry is the overexploitation of environmentally sensitive areas. Many people in rural areas rely on biomass fuels for cooking, heating and lighting. Overuse of these can lead to degradation of watersheds, and loss of biodiversity and habitats. About 70% of total greenhouse gas (GHG) emissions are related to energy, mainly from the combustion of fossil fuels for heat, electricity generation and transport. Countries have many options for reducing GHG emissions-at minimal, zero or even net negative costs. These include energy conservation along with increases in efficiency, better energy management, cleaner production and consumption, and changes in lifestyles. Renewable and other more efficient technologies would also help mitigate climate change. Overall, countries can foster science-based decision-making that creates incentives for cleaner and more energy-efficient economic activities while increasing people's access to modern energy services.
4.1. Climatic changes
Climatic changes, as a result of global warming caused by greenhouse gases, mainly carbon dioxide (CO₂) produced during the burning of fossil fuels, have been causing significant changes in the ecosystems and leading to nearly 150,000 additional deaths every year [2]. This rise is mainly caused by the unsustainable use of fossil fuels and the changes in the use of the land [18].

Global warming describes a gradual increase in the average temperature of the Earth's atmosphere. This is permanently changing the earth’s climate forever. The primary cause of global warming comes from humans, mostly burning of fossil fuels to drive cars, generating electricity and operating our homes and businesses.

Global warming is very real and it is occurring every day. The changes are small, so far, but they are expected to grow and speed up. Within the next fifty to one hundred years, the earth may be hotter than it has been in the past million years. As oceans warm and glaciers melt, land and cities along coasts may be flooded. Heat and drought may cause forests to die and food crops to fail. Global warming will affect weather, plants, animals and people everywhere. One major cause of global warming is the use of fossil fuels. Fossil fuels like coal, oil and natural gas that were formed from the remains of plant material deposited during the earth's carboniferous period. The worldwide consumption of fossil fuels has increased dramatically.

The some facts:
- India is the fifth largest emitter of greenhouse gases, behind China, the United States, the European Union and Russia.
- Its annual carbon dioxide emission is in the range of 1.2 to 1.4 billion tonnes. Its annual greenhouse gas emission (CO₂ plus five other gases, including methane) is in the range of 1.6 to 1.8 billion tonnes.
- India's per capita emission is about 1.2 tonnes per year. That's about one fourth of the global average, about one-tenth of the emissions of developed countries and about one-third of China's. Between 1990 and 2004, India's carbon dioxide emissions grew by about 7 per cent a year on an average.

4.2. Clean development mechanism
The clean development mechanism (CDM) of the Kyoto Protocol has been set up to assist developing countries in achieving sustainable development by promoting greenhouse gas emission reduction projects, that generate emission credits (certified emissions reductions, CERs) for industrialized countries [19]. A number of countries in the region are taking advantage of the CDM. This is a provision of the Kyoto Protocol which was devised originally as a bilateral mechanism through which entities in industrialized countries could gain certified emission reductions (CERs) by investing in clean technologies in developing countries. For the recipient developing countries, this can boost returns on projects by up to 12% for wind, hydro and geothermal projects and by 15–17% for biomass and municipal waste projects (UNEP). Indian enterprises have already committed investment to
generate more than 379 million CERs. Worldwide investments have been made that will generate 1.9 billion CERs by 2012.

5. Future of renewable energy in India

India, faced with twin challenges on energy and environmental front, has no option but to work towards increasing the role of renewable in the future energy systems. The objective of the Jawaharlal Nehru National Solar Mission (JNNSM) [22] is to establish India as a global leader in Solar Energy, by creating the policy conditions for its diffusion across the country as quickly as possible. Solar is currently high on absolute costs compared to other sources of power such as coal. The objective of the Solar Mission is to create conditions, through rapid scale-up of capacity and technological innovation to drive down costs towards grid parity. The Mission will adopt a 3-phase approach, spanning the remaining period of the 11th Plan and first year of the 12th Plan (up to 2012-13) as Phase 1, the remaining 4 years of the 12th Plan (2013-17) as Phase 2 and the 13th Plan (2017-22) as Phase 3. At the end of each plan, and mid-term during the 12th and 13th Plans, there will be an evaluation of progress, review of capacity and targets for subsequent phases, based on emerging cost and technology trends, both domestic and global.

The aim would be to protect Government from subsidy exposure in case expected cost reduction does not materialize or is more rapid than expected. The immediate aim of the Mission is to focus on setting up an enabling environment for solar technology penetration in the country both at a centralized and decentralized level. The first phase (up to 2013) will focus on capturing of the low hanging options in solar thermal; on promoting off-grid systems to serve populations without access to commercial energy and modest capacity addition in grid-based systems. In the second phase, after taking into account the experience of the initial years, capacity will be aggressively ramped up to create conditions for up scaled and competitive solar energy penetration in the country.

To achieve this, the Mission targets are:

- To create an enabling policy framework for the deployment of 20,000 MW of solar power by 2022.
- To ramp up capacity of grid-connected solar power generation to 1000 MW within three years by 2013; an additional 3000 MW by 2017 through the mandatory use of the renewable purchase obligation by utilities backed with a preferential tariff. This capacity can be more than doubled – reaching 10,000 MW installed power by 2017 or more, based on the enhanced and enabled international finance and technology transfer. The ambitious target for 2022 of 20,000 MW or more, will be dependent on the ‘learning’ of the first two phases, which if successful, could lead to conditions of grid-competitive solar power. The transition could be appropriately up scaled, based on availability of international finance and technology.
- To create favorable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership.
· To promote programmes for off grid applications, reaching 1000 MW by 2017 and 2000 MW by 2022.
· To achieve 15 million sq. meters solar thermal collector area by 2017 and 20 million by 2022.
· To deploy 20 million solar lighting systems for rural areas by 2022.

5.1 Research and Development
A major R&D initiative will be to focus: firstly, on improvement of efficiencies in existing materials, devices and applications and on reducing costs of balance of systems, establishing new applications by addressing issues related to integration and optimization; secondly, on developing cost-effective storage technologies which would address both variability and storage constraints, and on targeting space intensity through the use of better concentrators, application of nano-technology and use of better and improved materials. The Mission will be technology neutral, allowing technological innovation and market conditions to determine technology winners. A Solar Research Council will be set up to oversee the strategy, taking into account ongoing projects, availability of research capabilities and resources and possibilities of international collaboration. An ambitious human resource development programme, across the skill-chain, will be established to support an expanding and large-scale solar energy programme, both for applied and R&D sectors. In Phase I, at least 1000 young scientists and engineers would be incentivized to get trained on different solar energy technologies as a part of the Mission’s long-term R&D and HRD plan. Pilot demonstration projects would be closely aligned with the Mission’s R & D priorities and designed to promote technology development and cost reduction. The Mission, therefore, envisages the setting up of the following demonstration projects in Phase I, in addition to those already initiated by MNRE and those, which may be set up by corporate investors:

- 50-100 MW Solar thermal plant with 4-6 hours’ storage (which can meet both morning and evening peak loads and double plant load factor up to 40%).
- A 100-MW capacity parabolic trough technology based solar thermal plant.
- A 100-150 MW Solar hybrid plant with coal, gas or bio-mass to address variability and space-constraints.
- 20-50 MW solar plants with/without storage, based on central receiver technology with molten salt/steam as the working fluid and other emerging technologies.
- Grid-connected rooftops PV systems on selected government buildings and installations, with net metering.
- Solar-based space-cooling and refrigeration systems to meet daytime and summer season peak load. These could be installed on selected government buildings and installations.

The configurations and capacities as mentioned above are indicative and would be firmed up after consultations with various stakeholders. Bidding process will be adopted to set up solar power demonstration plants which would help in better price discovery for determining tariff for solar power. It will be ensured that indigenous content is maximized. The bid documents will also include a

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technology transfer clause. It is expected that these plants will be commissioned in the 12th plan period.

5.2. Solar manufacturing in India
One of the Mission objectives is also to take a global leadership role in solar manufacturing (across the value chain) of leading edge solar technologies and target a 4-5 GW equivalent of installed capacity by 2020, including setting up of dedicated manufacturing capacities for poly silicon material to annually make about 2 GW capacity of solar cells. India already has PV module manufacturing capacity of about 700 MW, which is expected to increase in the next few years. The present indigenous capacity to manufacture silicon material is very low, however, some plants are likely to be set up soon in public and private sector. Currently, there is no indigenous capacity/capability for solar thermal power projects; therefore new facilities will be required to manufacture concentrator collectors, receivers and other components to meet the demand for solar thermal power plants.

To achieve the installed capacity target, the Mission recommends the following:

· **Local demand creation:** The 20 GW plan supported with right level of incentives for solar generation coupled with large government pilot/demonstration programs will make the Indian market attractive for solar manufacturers.

· **Financing & Incentives:** SEZ like incentives to be provided to the manufacturing parks which may include:
  - Zero import duty on capital equipment, raw materials and excise duty exemption
  - Low interest rate loans, priority sector lending
  - Incentives under Special Incentive Package (SIPs) policy to set up integrated manufacturing plants; (i) from poly silicon material to solar modules; and (ii) thin film based module manufacturing plants. Under the SIP scheme of the Department of Information Technology, there are 15 applications in the domain of solar photovoltaic, which includes cell manufacturing, (both crystalline and thin film) and poly-silicon manufacturing among others. The combined capacity projected by these 15 companies could result in the production of 8-10 GW solar power by the year 2022 which would be sufficient for meeting the Mission targets even after accounting for exports.
  - It is also recommended that solar components be covered under the Bureau of Energy Efficiency’s star rating programme to ensure high standards. Similar incentives will be required for manufacture of CSP systems and their components. A Committee may be set up to formulate a policy for promotion of solar thermal manufacture in the country.

· **Ease of doing business:** In consultation with States, create a single window clearance mechanism for all related permissions.

· **Infrastructure & ecosystem enablers:** Create 2-3 large solar manufacturing tech parks consisting of manufacturing units (across the solar value chain), housing, offices, and research institutes. These
will have 24x7 power and water supply and will likely need to be located near large urban centres with good linkages to ports and airports to ensure rapid access to imported raw materials and high quality engineering talent.

5.3. Human resource development

The rapid and large-scale diffusion of Solar Energy will require a concomitant increase in technically qualified manpower of international standard. Some capacity already exists in the country, though precise numbers need to be established. However, it is envisaged that at the end of Mission period, Solar industry will employ at least 100,000 trained and specialized personnel across the skill spectrum. These will include engineering management and R&D functions.

The following steps may be required for Human Resource Development:

- IITs and premier Engineering Colleges will be involved to design and develop specialized courses in Solar Energy, with financial assistance from Government. These courses will be at B. Tech, M. Tech and Ph. D level. Some of the IITs, Engineering Colleges and Universities are teaching solar energy at graduation and post graduation level. Centres for Energy studies have been set up by some of the IITs and engineering colleges. These initiatives will be further strengthened. In addition, a countrywide training programme and specialized courses for technicians will be taken up to meet the requirement of skilled manpower for field installations and after sales service network. The Directorate General of Education and Training under the Ministry of Labour has agreed to introduce training modules for course materials for technicians in order to create a skilled workforce which could service and maintain solar applications. MNRE has already initiated this activity with the Ministry of Labour and a short term training module is to be introduced during the current academic session. In addition, industry is also working with some of the ITIs to create a skilled workforce.

- A Government Fellowship programme to train 100 selected engineers / technologies and scientists in Solar Energy in world class institutions abroad will be taken up. This may need to be sustained at progressively declining levels for 10 years. This could be covered under the ongoing bilateral programmes. Institution to institution arrangements will also be developed. Fellowships will be at two levels (i) research and (ii) higher degree (M. Tech) in solar energy. MNRE is already implementing a fellowship programme in this regard, which will be expanded to include students from a larger number of academic institutions. This may be done in consultation with industry to offer employment opportunities.

- Setting up of a National Centre for Photovoltaic Research and Education at IIT, Mumbai drawing upon its Department of Energy Science and Engineering and its Centre for Excellence in Nano-Electronics.
5.4. Financing the mission activities
The fund requirements for the Mission would be met from the following sources or combinations:

- Budgetary support for the activities under the National Solar Mission established under the MNRE;
- International Funds under the UNFCCC framework, which would enable up scaling of Mission targets.

The Mission strategy has kept in mind the two-fold objectives, to scale-up deployment of solar energy and to do this keeping in mind the financial constraints and affordability challenge in a country where large numbers of people still have no access to basic power and are poor and unable to pay for high cost solutions.

Renewable energy technologies vary widely in their technological maturity and commercial status. In India, renewable energy is at the take-off stage and businesses, industry, government and customers have a large number of issues to address before these technologies could make a real penetration. India with large renewable energy resources (solar PV, wind, solar heating, small hydro and biomass) is to set to have large-scale development and deployment of renewable energy projects [20]. The aim of meeting 10% of the country power supply through renewable by 2012 and also ambitious plans for the distribution of biogas plants, solar PV applications and solar city appears to be within reach. Moreover, introduction of tradable Renewable Energy Certificates (REC) could overcome the existing gap that is hindering the application of quota for renewables and thereby creates a vibrant market.

India would also have to look for international cooperation in renewable energy through well defined R&D projects with proper division of labour and responsibilities for specific tasks with equitable financial burden and credit sharing arrangements. Renewable energy development is considered in India to be of great importance from the point of view of long term energy supply security, environmental benefits and climate change mitigation. The Integrated Energy Policy report has recognized the need to maximally develop domestic supply options as well as the need to diversify energy sources. The Committee has placed emphasis on higher use of renewables in all forms of services. It is expected that the contribution from renewables in power generation alone can be of the extent of 60,000 MW in the year 2031–2032. Renewables will be the key driver in social inclusion of the poor in the development process. A modest assessment of investments in the renewable energy sector will be about Rs. 300,000 crores over the next 25 years. MNRE has included in its mission: energy security; increase in the share of clean power; energy availability and access; energy affordability; and energy equity [21].

A number of government and private organizations such as MNRE, Centre for Wind Energy Technology, Universities, IITs, NITs, Indian Oil Corporation Ltd. (IOCL) and The Energy Resource Institute (TERI) are involved in R&D of renewable energy sources.
6. Current energy policies
The ultimate objective of the renewable energy policy framework is to significantly increase the share of renewable energy source in India's energy mix [20]. These energy policies are set by government.

6.1. National Electricity Policy, 2005
The National Electricity Policy aims at achieving the following objectives; access to electricity, availability of power demand (to be fully met by 2012), energy and peaking shortages to be overcome and spinning reserve to be available, supply of reliable and quality power of specified standards in an efficient manner and at reasonable rates, per capita availability of electricity to be increased to over 1000 units by 2012, financial turn around and commercial viability of electricity sector and protection of consumers’ interests.

6.2. The Electricity Act 2003
The Electricity Act contains the following provisions pertaining to non-conventional energy sources. Under Sections 3(1) and 3(2), it has been stated that the Central Government shall, from time to time, prepare and publish the National Electricity Policy and Tariff Policy, in consultation with the state governments and authority for development of the power system based on optimal utilization of resources such as coal, natural gas, nuclear substances or material, hydro and renewable sources of energy. Section 4 states that the Central Government shall, after consultation with the state governments, prepare and notify a national policy, permitting stand-alone systems for rural areas. Section 61, 61(h) and 61(i) state that the appropriate commission shall, subject to the provision of this Act, specify the terms and conditions for the determination of tariff, and in doing so, shall be guided by the following, namely, the promotion of cogeneration and generation of electricity from renewable sources of energy; and the National Electricity Policy and Tariff Policy. Section 86(1) and 86(1)(e) state that the state commissions shall discharge the following functions, namely, promote cogeneration and generation of electricity from renewable sources of energy by providing, suitable measures for connectivity with the grid and sale of electricity to any person, and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution license.

6.3. Tariff Policy, 2006
The Tariff Policy announced in January 2006 has the following provisions:
1. Pursuant to provisions of section 86 (1) (e) of the Act, the Appropriate Commission shall fix a minimum percentage for purchase of energy from such sources taking into account availability of such resources in the region and its impact on retail tariffs.
2. It will take some time before non-conventional technologies can compete with conventional sources in terms of cost of electricity. Therefore, procurement by distribution companies shall be done at preferential tariffs determined by the Appropriate Commission.
3. Such procurement by Distribution Licensees for future requirements shall be done, as far as possible, through competitive bidding process under Section 63 of the Act within suppliers offering energy from same type of non-conventional sources.
4. The Central Commission should lay down guidelines within three months for pricing non-firm power, especially from non-conventional sources, to be followed in cases where such procurement is not through competitive bidding.

1. Goals include provision of access to electricity to all households by the year 2009, quality and reliable power supply at reasonable rates, and minimum lifeline consumption of 1 unit/household/day as a merit good by year 2012.
2. For villages/habitations where grid connectivity would not be feasible or not cost effective, off-grid solutions based on stand-alone systems may be taken up for supply of electricity.
3. State government should, within 6 months, prepare and notify a rural electrification plan, which should map and detail the electrification delivery mechanism.
4. The Gram Panchayat shall certify and confirm the electrified status of the village as on 31st March each year.

7. Initiatives and steps for delivery and outreach

7.1. District Advisory Committees (DACs)
These Committees have led to the creation of an effective renewable energy promotion network at the grass-root level that will also help in integration of renewable energy schemes with those of other development departments. To date, 550 DACs have been setup in 550 districts of the country.

7.2. Akshay Urja Shops (renewable energy shops)
Akshay Urja Shops were launched to cover all districts of the country to ensure easy availability of such systems/devices. It is expected that the common man will embrace renewable energy technologies in a big way for augmenting energy needs of cooking, lighting and motive power from these shops.

7.3. Energy parks
With a view to integrating the activities of State and District Levels Energy Parks was set up at the national level.
7.4. Rajiv Gandhi Akshay Urja Diwas (Rajiv Gandhi Renewable Energy Day)

The birth anniversary of former Prime Minister, late Sh. Rajiv Gandhi on 20th August 2006 was observed as ‘Rajiv Gandhi Akshay Urja Diwas’ all over the country is organize to increase awareness on a mass-scale at National, State and District levels.

7.5. Akshay Urja Newsletter (Renewable Energy Newsletter)

A bi-monthly newsletter titled ‘Akshay Urja’ was started with a focus on national/international renewable energy developments, technological developments, manufacturer's details, renewable energy education, etc.

7.6. Renewable Energy Clubs

A scheme has been evolved to promote the study of renewable energy through the setting up of RE Clubs in recognized/approved Engineering Colleges/Technology Institutions by All India Council for Technical Education (AICTE) all over the country to educate and sensitize young and future scientists on various aspects of new and renewable energy.

8. Conclusions

Energy security, economic growth and environment protection are the national energy policy drivers of any country of the world. There is considerable work going on in several countries to develop Solar Energy as a clean and alternative source of energy. The need to boost the efforts for further development and promotion of renewable energy sources has been felt world over in light of high prices of crude oil. A critical part of the solution will lie in promoting renewable energy technologies as a way to address concerns about energy security, economic growth in the face of rising energy prices, competitiveness, health costs and environmental degradation. According to NAPCC other sources of renewable energy would be promoted. Specific action points that have been mentioned include promoting deployment, innovation and basic research in renewable energy technologies, resolving the barriers to development and commercial deployment of biomass, hydropower, solar and wind technologies, promoting straight (direct) biomass combustion and biomass gasification technologies, promoting the development and manufacture of small wind electric generators, and enhancing the regulatory/tariff regime in order to mainstream renewable energy sources in the national power system. Accordingly, increased focus is being laid on the deployment of renewable power that is likely to account for significant share in the electricity-mix by 2032. Alternate fuels, essentially bio-fuels, are proposed to be progressively used for blending with diesel and petrol, mainly for transport applications.

The National Solar Energy Mission is a major initiative of the Government of India and State Governments to promote ecologically sustainable growth while addressing India’s energy security challenges. It will also constitute a major contribution by India to the global effort to meet the challenges of climate change. Solar Energy, therefore, has great potential as future of energy. It also
has the advantage of permitting the decentralized distribution of energy, thereby empowering people at the grassroots level.

Finally, renewable energy provides enormous benefits and can contribute significantly in the national energy mix at least economic, environmental and social costs and it is expected that the share of renewable energy in the total generation capacity will increase in future.

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