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Feature article

Solar rooftop in India: Policies, challenges and outlook

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Abstract

Solar photovoltaic rooftop has emerged as a potential green technology to address climate change issues by reducing reliance on conventional fossil fuel based energy. With a strong commitment to increase the renewable sources based energy capacity to 175 GW by 2022, India has a target to install 100 GW of solar energy capacity. Of this 40 GW would be the share of grid connected solar PV rooftop. This paper examines global growth in solar energy, world's major rooftop installed capacity countries' policies and solar rooftop policy instruments in India. The current Indian goals, issues & challenges in achieving them and trends in further development are discussed.

Keywords: Solar energy; India; Rooftop PV; Policies; Outlook

1. Introduction

> *Solar or coal? the energy India picks may decide Earth's fate*
>
> *– Charles C. Mann in December 2015*

The above statement is indicative of India's strengths in renewable energy. The climate change threats are driving our dependence on pollution free sources of energy to minimize greenhouse gas emissions. No doubt solar PV energy is one of the cleanest sources of electricity and is being considered as next to fossil fuel based conventional electricity systems.

World cumulative installed solar energy capacity of 3.7 GW in 2004 has reached 177 GW in 2014 i.e., increasing almost 50 times in ten years [1]. Global investment in Renewable Energy (RE) has been growing steadily and increased five times since 2004, from $62 bn to $316 bn in 2014 in ten years [2]. The share of investment in the solar rooftop and other solar PV projects is increasing more rapidly and was 12% higher than in the previous year and became 67.4 bn in 2015, thus making it one of the fastest growing industries worldwide. International Energy Agency (IEA) Technology Roadmap: Solar PV Energy envisions total production of SPV electricity to increase to 16% in 2050 (in place of 11% projected earlier) with China and India having major shares [3].

Looking inwards, India is having fourth largest electricity generation capacity in the world after US, China and Russia. Its Renewable Energy (RE) share increased to 13.16% in 2015 with solar energy having a share of 11.62% in it. Between 2005 and 2015 the renewable grid connectivity has increased from 6.2 GW to around 36 GW for both solar and wind. As on June 2016 renewable based capacity became 43,727 MW in the total installed capacity of 303,100 MW [4].

1.1. Historical developments in solar PV in India

Solar Photovoltaic (SPV) Program of India was conceived in 1970s in response to the world oil crisis, as one of the largest national programs in the world. The SPV research & development in the country began in late 1970s and a programme for energy development was launched in early 1980s

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with three main objectives; (i) research on solar cell materials, (ii) development of production and manufacturing capabilities of SPV module, and (iii) promotional measures and incentives for installation of SPV electricity. The manufacturing base was strengthened and over 300,000 smaller systems aggregated to 22 MW have been installed until 1995 making India third largest Solar PV user. Export had a share of almost 46% in 2002 [5]. Remaining catered to telecommunication towers, street lighting, agricultural water pumping and others [6]. Solar Home Systems (SHS) were encouraged. First major PV plant connected to the grid was set up in Jamuria, Asansol district; West Bengal of 1 MW capacity. Though distributed SPV in rural & remote areas and for strategic applications remained one of the key programmes.

In 2010 Jawaharlal Nehru National Solar Mission (JNNSM) was introduced as part of National Action Plan on Climate Change 2008 giving a target to install 20 GW solar capacity by 2022. The mission is to be implemented in three phases namely; Phase I (2010–12), II (2013–17) and III (2017–22). Under phase I of JNNSM one of the component related to solar rooftop is 'Rooftop PV and Small Scale Generation Programme' (RPSSGP) aimed to encourage development of rooftop or ground-mounted solar systems with maximum capacity size of 2 MW [7]. A total of 100 MW is targeted under this scheme. Projects under the RPSSGP scheme -remain mostly ground-mounted with negligible share of solar rooftop. Grid connected solar power plants capacity was assessed at 45.5 MW in July 2011.

Being a tropical country, India is solar rich country having on average 300 sunny days in a year. India has higher solar irradiance compared to many other countries and solar electricity potential is between 4 and 7 kWh per sq. m per day in its most parts. Government of India has revised Solar Mission in 2014 with a target of 100 GW installed capacity of solar electricity by 2022. Out of which 40 GW is now projected to come through grid connected rooftop solar systems. Centralized grid connected and standalone solar energy strategy development is aiming towards energy security of nation for achieving '24 × 7 power to all'. States and Union Territories in the country have identified their solar energy potential (Fig. 1).

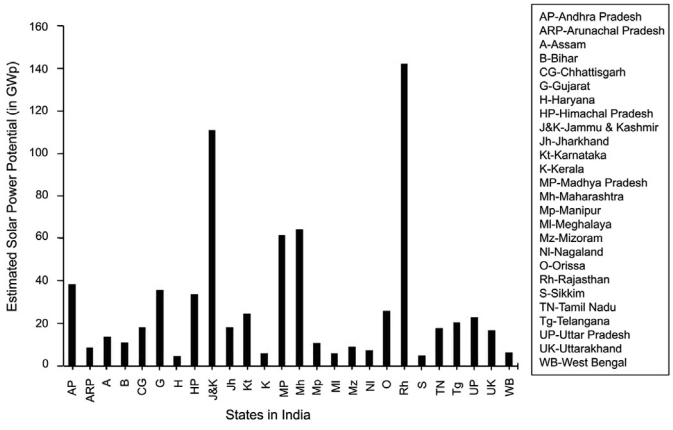

Fig. 1. Solar energy potential of different States in India (Source – Ministry of New and Renewable Energy vide notification dated 24.11.14).

1.2. Solar rooftop PV

A solar photovoltaic (SPV) power plant consists of different components i.e., photovoltaic modules, mounting system, dc–ac converter and electrical connections. The Roof Top PV (RTPV) systems are smaller PV systems in comparison to land mounted ones, installed on rooftops of residential, commercial or industrial building complexes. It comprises of solar inverter, meters for regulating electricity generated and various components for modification of electrical output and input rate in kWp (peak kilowatts, the expected electrical power from a system when sun is overhead) [8]. The electricity generated from such systems could either be entirely fed into the grid at regulated feed-in-tariffs (FiT), or used for self consumption with the net metering approach. A net metering mechanism allows for a two-way flow of electricity wherein the consumer is billed only for the 'net' electricity (total consumption – own PV production) supplied by the DISCOM. Such RTPV systems could be installed with one integrated net meter or two separate meters, one for export to grid and one for self consumption. Full potential of non-grid RTPV is yet to be utilized as the cost continues to be high. With part financial support provided by the state to promote their use, such systems are considered most appropriate for rural and remote areas. In the regions of power shortages, performance reliability of non-grid RTPV can also be improved with at least 1 h of back-up battery and this helps in bringing down the cost.

2. Global status of SPV development

The United States of America (USA), Canada, European Union (EU), Japan, China as well as India have been early starters and leading countries in solar energy research & development (R&D). Germany, China, Japan, Italy, USA are currently leading in solar PV capacity as on March 15, 2016 [9]. A 2008 study from the National Renewable Energy Laboratory (NREL), USA estimated that solar rooftop could technically generate 819 TWh/yr (through 661 GW), which is 22% of the demand for electricity in USA in 2006 [10]. In 2006 European Union (EU) has set a target of 20% share of renewable energy in total energy consumption by 2020. The growth trend of total global installed SPV capacity from 2004 to 2014 is shown in Fig. 2.

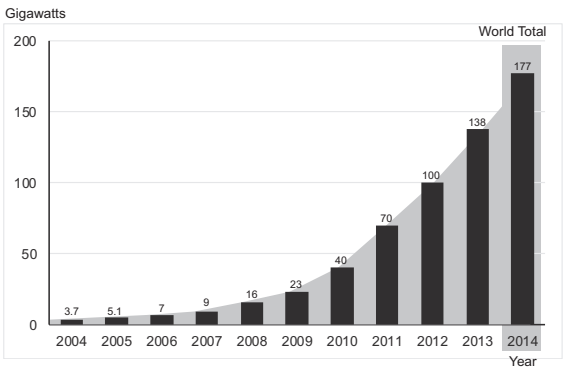

Fig. 2. Growing trends in solar PV capacity addition 2004–2014 (Source – REN21, Renewables 2015, Global Status report).

2.1. Overview of policy instruments of different countries

Germany with more than 38.25 GW of accumulated installations has almost a share of one fourth of world's PV capacity. The RTPV share was 9% residential, 26% commercial and 24% industrial capacity with 1% from building envelop, remaining 40% capacity is from ground based installations. Beginning 1999, 1,00,000 rooftops were adopted to encourage solar installation in residential sector with 0% interest loan. The government has incentivized rooftop by a significant fall in the costs, by introducing user friendly policies for installations and Feed-in-Tariff (FiT) periodically updated. In 2009 gross metering was introduced to encourage solar project development independent of captive load of the consumers. Household owners get income from preferential tariff [11]. Small consumers who produced electricity for their use were give premium FiT EURO 0.25/kWh and those who also supplied to grid at EUR 0.47/kWh. The government in 2013 has decided to support battery back-up in each household to facilitate storage to further incentivize RTPV use. In addition to financial incentives, regulatory measures included Renewable Resources Act guidelines for interconnection on priority basis and with low voltage grid.

China is second highest next to Germany. In 2005 the country was heavily dependent on coal and it was contributing to 68.75% of electricity. Solar energy was being utilized mostly for electricity in remote villages and telecommunication towers because of its high cost. The government enacted 'Renewable Energy Law' in 2005 to facilitate renewable energy generation and number of new supporting regulations and guidelines were introduced. Research & development, training for manpower skills and public participation were given due emphasis [12]. The SPV industry in China has grown faster than any other country. The market share of Chinese PV increased from 1% to 35% in 8 years. The government has established PV industry chain for assured supply of material and products. In 2014 giving a renewed thrust Rooftop Subsidy programme of $2.4/W and Golden Sun Demonstration (GSD) programmes have been launched. Under GSD 50% support for large grid connected rooftop of >300 kW, and 70% for off-grid systems is provided. China has achieved 28.33 GW SPV capacity as on March 2016.

Japan is third among the leading countries with 23.4 GW capacity, having invested majorly in R&D for grid connected solar rooftop under its Sunshine and New Sunshine Projects since 1970s. A "Basic Guidelines for New Energy Introduction" was decided upon in December 1994 with introductory targets for PV power generation set at 400 MW in 2000 and 4.6 GW in 2010. In 2004, target of 100 GW in 2030 was set up with a roadmap 'PV2030' [13]. Japan has given incentives to small producers from buying power at double the price and capital subsidy & soft loans to larger systems. 10–1000 kW RTPV systems have grown significantly. In 2013 FiT was introduced to encourage private sector participation. On regulatory side Electrical Utility Industries Act provide provisions for utilities. Renewable Purchase Obligations and saving in electricity bills are other incentives.

Italy having 18.6 GW capacity is at fourth position. In 2000 net metering scheme was introduced with direct incentives for RTPV. More generous incentives were provided in 2007 and in 2008 FiT 'canto energia' act for RE development was enacted. Tax credits are given for plants up to size of 20 kW and in 2014 new rules for electricity storage connected to grid have been published. The target set for 2020 of 15 GW has already been exceeded.

United States of America (USA) with a SPV capacity of 18.3 GW had adopted 'Public Utility Regulatory Policies Act' to support energy alternatives way back in 1978. During 1980s Investment Tax credits' (ITCs) and Production Tax Credits (PTCs) were established for incentivizing RE technology. Initially ITC was reduced to 10% for promoting commercial scale development. In 2005 residential and business ITCs were raised to 30% and exempted for 3 years resulting in doubling of solar PV capacity. ITCs have undergone many changes and again being reduced to 10%. In 2010 Department of Energy (DOE) has established goal of generating 10–15% of the nation's energy from solar sources by 2030. 'Clean Energy Standard Act' was introduced in 2012. A PACE (Property-Assessed Clean Energy) financing mechanism has been introduced with Municipalities providing 100% loan to owners and charging through property tax bills. Out of 3.5 GW RTPV capacity in U.S. 1.0 GW is from residential sector and 1.5 GW is from RTPV installed in commercial buildings. Remaining 1.0 GW is large scale share owned by utilities.

The RTPV success stories in these countries have relied not only on financial incentives and metering arrangements, but also on regulations of grid connectivity and successful business models. The changing dynamics of policies has been a dominant factor. In most countries there has been dominance of feed-in-tariff and direct capital subsidy mode until 2011. But in the year 2012 trends changed. Soft loans, tax credits, role of municipalities and market based mechanisms have played dominant roles in encouraging peoples' participation. As a result self consumption mode of implementation increased from 3.4 per cent to 12 per cent. On the other hand in Spain which has most abundant solar irradiation among EU countries (varying from 1.48 to 3.56 kWh per sq. m per day) had renewable energy plan 2005–2010 approved in 2005. Spain attained second position in top five countries in 2010 having 3.4 GW installed solar capacity. However, subsequent retroactive support to FiT cuts did not permit self consumption of solar electricity [14], made it costlier than the electricity price and the growth in solar rooftop had a slowdown. It is now picking up again.

2.2. Solar energy policies in India

Policy infrastructure in renewable energy sector in India took shape when Commission of Alternate Sources of Energy (CASE) was created in 1981 in the Department of Science & Technology. It became independent Department of New Energy Sources (DNES) in 1982 and full fledged Ministry in 1992. Ministry's guidelines to various States to purchase RE power at Rs. 2.25 per unit with 5% annual escalation with

1993 as base year triggered early development of RE sector especially the wind energy. The government has announced several policies to promote solar energy. Direct and indirect tax benefits such as sales tax, excise duty exemptions and custom duty exceptions have been given. Project developers were exempted from income tax on all earnings from a project in its first 10 years of operation and accelerated depreciation (AD) for solar energy producers to claim 80 per cent of the costs in the first year itself. Policies and acts impacting direct solar energy development 2000 onwards are discussed below.

Electricity Act 2003 – The Act provides a framework for overall growth of electricity sector in India. Provisions for preferential tariff and quotas for integration with renewable energy have been made. Mandatory Procurement of RE power for Distribution Licensees and facilitation of grid connectivity were incorporated. Based on optimal utilization of resources including renewable sources of energy, it suggested that a policy for permitting standalone systems would be prepared.

National Electricity Policy 2005 – The policy allowed preferential tariff for electricity produced from renewable energy sources. In order to reach the areas where no grid connectivity was there it aimed to provide access to electricity to all, 'Power to all by 2012' and increase minimum per capita availability to 1000 kWh per year by 2012.

Tariff Policy 2006 – The mechanism of Renewable Energy Portfolio (RPO) to fix a minimum percentage of purchase of energy consumption by the States from renewable energy sources and giving special tariff for solar energy among others were its main contribution.

Integrated Energy Policy 2006 – This integrated policy document while giving overall policy guidelines for action recommended special focus on RE development and set specific targets for capacity addition.

National Action Plan on Climate Change (NAPCC) 2008 – Government of India enunciated mission mode action plans for sustainable growth under NAPCC to address climate change. Its first mission was intensification of solar energy development. It also advised that RPO's be set at 5% of total grids purchase, and be increased by 1% each year for 10 years.

Generation based Incentives (GBI) for Solar – Introduced in 2009 for small grid solar projects below 33 kV, GBIs are provided for bridging the gap between a base tariff of INR 5.5 (by 2010–2011, with an annual escalation of 3 per cent) and the tariff determined by the Central Electricity Regulatory Commission (CERC) as a fiscal incentive.

Jawaharlal Nehru National Solar Mission (JNNSM) 2010 – The mission gave specific targets of 20,000 MW of grid-connected and off-grid solar power capacity by 2022 with 2000 MW as share of off-grid capacity.

Renewable Energy Certificates (RECs) – A market based mechanism, RECs was introduced in 2011 to enhance renewable energy capacity by leveling the inter-state divergences of renewable energy generation and the requirement of the obligated entities to meet their RPOs with differentiated price for solar and non-solar.

Clean Energy Cess – Introduced in 2010 to levy the amount of INR 50 to every tonne of national or imported coal used in the country. A National Clean Energy Fund (NCEF) created from the cess aims to fund clean energy projects and provide up to 40 per cent of the total costs of RE projects through the Indian Renewable Energy Development Agency (IREDA). The cess has now been increased to INR 400 per tonne of coal used.

Joint Liability Group (JLG) for Off-grid installations – By synthesizing business and social potential a small group of 4–10 local entrepreneurs as JLG to avail loans for non-farming activities which could be applied for micro-grid installations.

Corporate Social Responsibility (CSR) – To encourage the private sector participation in the national growth and for meeting social goals such as pollution free generation the CSR funds are channelized by top 500 companies as 2 per cent of their profits towards off-grid solutions.

2.3. Major achievements

India currently has one of the largest renewable energy capacity expansion programmes in the world having a target of 175 GW installed capacity as contribution of RE by 2022, with solar contributing to 100 GW. The year wise growth of solar energy capacity in India is shown in Fig. 3.

A metering policy has been introduced to encourage self consumption of electricity generated from the solar rooftop. Almost all states have notified their regulations to provide net metering/gross metering facilities. The policy initiatives of selected states in India are given in Table 1. Gujarat is the pioneer state, already allocated 25 MW and has announced to expand it to 50 MW in the current year. The project owners will get upfront subsidy. Tamil Nadu targets 350 MW of RTPV of which 50 MW is for residential sector. Karnataka has set a target of 400 MW and providing state capital subsidy for small size projects of 0.5–1 kW. Other states are also in the process of evolving guidelines.

In 2015 Government of India has considered increased provisions of funding for implementation of grid connected rooftops over next five years. The subsidy is of 30% to all states and up to 70% to special category states. The

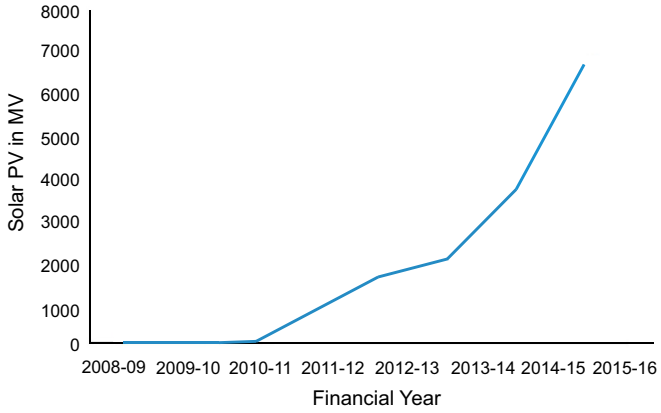

Fig. 3. Solar PV Installed capacity in MW in India from 2008 onwards (source - MNRE).

Table 1
Overview of RTPV policies of selected states in India.

S. no.	State	Policy guidelines	Target segment
1.	Andhra Pradesh	Scheme of Net metering with excess energy sold to utility at average pooled purchase cost (APPC) 20% subsidy of capital cost up to 3 kW in domestic sector	All 3 phase service consumers Single phase consumers are not eligible
2.	Chhattisgarh	Gross & Net metering. FiT INR 4.35/kWh. Energy banking allowed	Residential, Commercial & Industrial
3.	Gujarat	Gross metering at INR 9.63/kWh with accelerated depreciation INR 10.75/kWh with no depreciation Roof owners get lease rental and project developer get FiT for 25 years 5 MW rooftop PPP model is now being extended to 5 more cities.	Government, Residential, Commercial, Industrial, Institutional Buildings
4.	Karnataka	Gross & Net metering at INR 9.56 without subsidy INR 7.20 with subsidy	All Consumers 1–5 kW in single phase 230 V 5–50 kW in 3 phase 415 V 50 kW–1 MW in 11 kW line
5.	Kerala	Net metering State subsidy of Rs. 39000/per system for the approximate cost of the plant of Rs. 2.5 lakh Rs. 10,000/kW capital subsidy for smaller units	All consumers
6.	Rajasthan	Net metering, Tariff based competitive bidding INR 7.50/kWh without accelerated depreciation INR 6.63/kWh with depreciation.	All consumers
7.	Tamil Nadu	Net metering Self consumption and energy banking for one year Generation based incentive of INR 2/kWh for first 2 years, INR 1/kWh for next 2 years and 0.5/kWh for Subsequent 2 years	50 MW for domestic Customers 300 MW for government buildings and rural & urban lighting <10 kW in 240 V 10–15 kW in 415 V 100 kW in 11 kV
9.	West Bengal	Net metering Tariff applicable to net energy supply Energy banking allowed for one year	All consumers
10.	Haryana	Gross & Net metering (off-grid & grid connected) Energy banking allowed for one year	All consumers

Source: Credit Analysis & Research Limited (CARE Ratings).

commercial and industrial sectors are made eligible for accelerated depreciation, custom duty concession, excise duty exemption and tax holidays. It is proposed to make solar rooftop mandatory for properties with connected loads greater than 20 kW. Growth trend is continuing and in Feb 2016 total achievement in solar PV has crossed 5547 MW [15] with RTPV share of approximately 10% in it.

2.4. International Solar Alliance

India took a lead in creating 'International Solar Alliance'(ISA) of solar rich resource nations in the 21st Meeting of Conference of Parties (COP 21) held in Paris under United Nations Framework Convention on Climate Change (UNFCCC). The premises are that solar energy technologies have made significant progress and are considered an option for meeting energy needs in a sustainable manner. The 121 countries lying fully or partially between Tropic of Cancer and Tropic of Capricorn are endowed with excellent solar insolation, but their solar potential remains largely untapped, are members of it. ISA is conceived as a coalition to address their special energy needs with the objective to provide a platform to collaborate on addressing the identified gaps through a common, agreed approach. Government of India is supporting ISA with US$ 62 millions initially [16] mainly to build headquarter infrastructure. The recurring expenditure on ISA will be met from membership fee; contributions from bilateral and multi-lateral agencies and other sources. ISA is expected to make a positive contribution to the common goal of increasing utilization of solar energy in the region. At present ISA Secretariat is housed in the National Institute of Solar Energy (NISE), Gurgaon.

3. Current challenges and outlook for India

International Energy Agency [3] analyses suggest that the Amendments in the Acts, Tariff Policy 2006, State-level policies and a greater participation of the private sector have played a key role in the overall growth of RE installed capacity in India. However as India is moving ahead to achieve the target of 175 GW of RE by 2022 and 100 GW solar based installed power capacity, new challenges are being faced in RTPVs target of 40 GW at different stages of installation and use. Several policy analyses have been made [17–19]. The Climate Group [17] while suggesting that performance of commercial and industrial sector would play a greater role towards meeting the target, strongly recommends greater partnership of private sector so as to double the current capacity. The various pillars of growth are schematically depicted in Fig. 4. Net metering and a package of incentives to

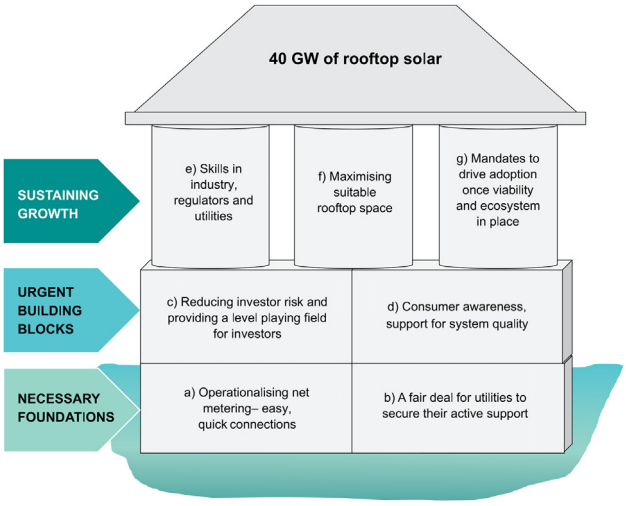

Fig. 4. Seven pillars of growth for attaining solar RTPV targets in India (Source – [17]).

utilities are no doubt necessary foundations. Means of covering Investors risk and greater consumer awareness can be the basic building blocks. Skill development, maximizing rooftop spaces and mandates to support the adoption of rooftop solar can lead to a sustained growth. The study recommends that mandates would have highest contribution in driving the movement.

Nonetheless the main barriers faced during large scale deployment of RTPV include lack of awareness among consumers about the system, lack of manufacturing facilities, lack of skilled workforce, high upfront cost and lack of business models and regulatory challenges. We discuss below the challenges as well as the outlook.

3.1. Consumer awareness and acceptance

Consumer awareness about the RTPV and its market acceptance is the most significant challenge in promoting solar energy, which is having a social bias. In a developing country affordability in residential sector is much lower than in an advanced country, where 60–70% use of RTPV is growing in residential sector. The consumer not only has greater affordability and awareness about the consumer rights, but is also facilitated with dynamic policy instruments which are consumer friendly. In developing countries people are less aware of the government policies and the available incentives. Being cleanest source of energy its climate change imperatives are not fully understood. Studies have shown that Solar Home Systems (SHS) as small as 50 W in rural areas of East Timor in early 2000s led to GHG emissions reduction of 9 tonnes of CO_2 equivalent by 20 years of use as compared to baseline [20]. Consumer guidance centers to educate about placement and function of meters, process for metering and interconnection with grid as well as maintenance are needed so as to achieve the potential of rooftop.

3.2. Manufacturing of solar cells and R&D

Manufacturing capabilities of solar cells, inverters and storage systems for improving performance of RTPV require investment in basic research on materials and industrial R&D. Global R&D spending on RE was $ 9.66 b in 2012 with solar research having a share of 51% [2]. In solar PV the emphasis has been on improving energy output of PV cells and efficiency of cell production. USA, Japan and Europe have been the largest centers for R&D in solar and were early starter too. The corporate R&D investment in solar energy exceeded the government R&D, Today China not only is world's biggest investor in solar R&D but has government component higher than the corporate sector (Fig. 5). Basic R&D on solar cell materials for achieving higher efficiency continues. Feltrin et al. [21] analyzed several solar photovoltaic technologies from thin film to silicon-single crystal and polymer crystalline, multi-junction new materials for large scale deployment of solar cells. Use of solar concentrator system is also studied for different materials. While organic dye solar cells are looking promising, their inherent decay in efficiency with time is seen as a drawback. CIGC (Copper Indium Gallium Diselenide) are potential candidate materials. Paper or wood based solar cells are seen to outperform all other cell materials in optical transparency, low cost and high efficiency, but need to enlarge their application base. Perovskite based solar cells are currently emerging as most promising materials. Their efficiency is seen to jump from 3.9% in 2009 to 19.3% in 2014. These are also being called ‘Wonder Solar Cells’.

India has been a manufacturing hub for solar technology and had been contributing to exports until early 2000s. With the phenomenal growth taking place worldwide currently dependence on imports is growing and corrective measures are needed. India's current ‘Make in India’ mission is likely to boost manufacturing sector including solar cell modules and other components. Although R&D investment for renewable energy development in India started early, at present

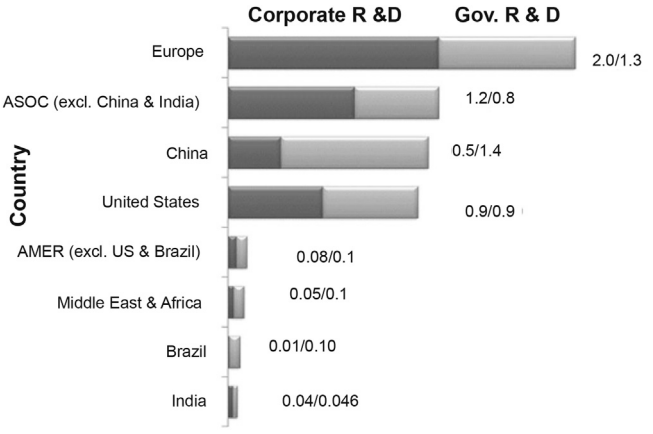

Fig. 5. Global R&D investment in renewable energy by corporate sector and government (Source – Bloomberg New Energy Finance, IEA, IMF, various government agencies).

investment is getting mobilized in solar R&D to develop solar PV and RTPV system manufacturing capacities. India needs a phenomenal increase in the investment for goal oriented and internationally collaborative solar R&D [22], both from government and industry to achieve the extraordinary goal of the National Solar Mission by 2022.

3.3. Installation technology & skilled workforce

RTPV installation technology in urban or rural areas requires intervention for (i) Grid connected solar installation; (ii) Solar system synchronized with diesel genset (iii) Off-grid solar installations with battery back-up. Designing of RTPV according to local conditions, is the basic engineering skills required. Methods must be devised to capture low radiation energy and converted into actual power for optimization [23]. Effective shading and resistive losses can be about one third of the coverage fraction of the cell grid [24]. A good design would integrate these location specific parameters with RTPV system, therefore has a great potential to become a job creation industry. From successful rooftop installation of 80 kW for Hero Motorcycle factory it was estimated the requirement is of 2.71 fulltime equivalent jobs over 25 years (PV lifetime) period [25]. Skill workforce requirement for installation, maintenance and repairs is expected to grow. Government of India has a 'Sector Skill Council for Green Jobs' under its 'Skill India' mission, to oversee the RE industry led skill development activity and also to re-skill them. It is estimated that over one million skilled workers will be needed by 2022 to fulfill the target of 100 GW. To meet these challenges the educational institutions in the country are being mobilized for developing curricula and standards for the training for engineers. The equipment testing laboratories and certification centers are in the pipeline.

3.4. Need for new business models

High capital cost of PVRT system which is estimated as INR 75,000/kW (on the lower side) has been a key challenge for its adoption by the industry or small consumers. The payback period is 6 to 7 years and 9 to 10 years in commercial and residential sectors, respectively. The success of RTPV therefore remains dependent on new business models evolved from time to time to overcome the cost barrier. At present three types of business models are envisaged, (i) Self owned, the roof owners owns the PV system and electricity generated. It is called CAPEX model and the risk is of the owner who invests in the system. (ii) Third party ownership, in which third party or a developer bears the cost of solar rooftop and sells to customer at a rate lower than grid tariff. This is called OPEX (operational expenditure) model because developer which is also Renewable Energy Service Company (RESCO) pays for the system for specified number of years and also owes the risk. Third party investment model has only 10% share at present. It is yet to pick up because of high contract default risks arising from rapid declining cost of solar energy [17]. (iii) The third is Lease model in which customer leases the system and pays for it overtime. This type of arrangement may suit multi-storey flat owners but not yet come into existence. To make solar RTPV an attractive proposition Indian Renewable Energy Development Agency (IREDA) is joining hands with Banks and multi-lateral financial institutions to provide soft loans.

Energizing villages – New business model for rural areas & villages are proposed to increase coverage of RTPV in the country. Generally losses due to longer transmission lines required to reach remote villages increase the cost of electricity in rural areas. The government or utility has to bear the loss as the tariff is normally lower there than in urban areas. Karnataka state in South India has set an example by introducing ambitious *Surya Ratha Programme* which allows no metering by farmers. Under the scheme a farmer can install SPV pump set on his farm with 90% subsidy and government can purchase excess power. The states of Punjab and Haryana are also proposing similar farmer friendly schemes. In remote and rural areas where there is no access to grid, development of off-grid systems that are '*Grid ready*' is another business model opportunity.

3.5. Micro and mini grid development for distributed generation

Solar PV systems offer unique benefits in distributed power applications. With this in view Ministry of New and Renewable Energy (MNRE) in June 2016 has issued a draft 'National Policy for Renewable Energy based Micro and Mini Grids', which aims to encourage the use of micro and mini grids for reaching 237 million un-served people across the country in the remote areas [26]. Such mini grids can provide electricity for a group of households, for small commercial activities and community requirements in daily life. Although the concept has been pioneered in the 1990s for the Sunderban delta region of West Bengal and forest regions of Madhya Pradesh (now Chhattisgarh), a 25 kWp capacity plant was installed in 1996 by West Bengal Renewable Energy Development Agency (WBREDA) in Sagar Island, and in Chhattisgarh at Lamni in Bilaspur district. Looking at the slow growth the new draft policy also provides for Rural Energy Service Providers (RESPs) for venturing into such micro and mini grid installations, by giving them support and certain other privileges. Micro-grid technologies are maturing rapidly worldwide and the economic modeling studies suggest that ~2 MW mini grids in several scenarios – campuses, cluster of homes, and more with storage are essential policy tools for the energy security (http://www.renewableenergyworld.com).

3.6. Integration of solar energy into national grid

Although today India operates world's largest synchronous grid connecting the entire country, grid interconnectivity with renewable in an efficient manner is a great challenge. As the share of solar rooftop increases integration of millions of RTPVs that may become available in coming years need to be achieved. The quality of power from conventional sources has

to be free from harmonics so as to avoid frequent imbalances. Power evacuation at the time of generation due to small sizes of RTPV in residential sector, avoidance of grid congestion in industrial sectors and management of power during shortages are the main issues before distribution companies. Forecasting of solar generation, related technologies and strategies that encourage penetration of small scale distributive generators into grid will be required to be implemented. Power Grid Corporation of India has proposed Green Energy Corridors connecting eight RE rich states namely; Tamil Nadu, Karnataka, Andhra Pradesh, Gujarat, Maharashtra, Rajasthan, Himachal Pradesh and Jammu & Kashmir. Systems that are intelligent and can manage residential RTPV or smart grid systems will facilitate automatic load control [27] are required to be developed. While forecasting of renewable power and smart grid connectivity are the challenges to be met, linking of solar energy with the current 'Digital India' mission has a promise for transformation of entire power system in the country by increasing interconnectivity through use of ICT.

3.7. Challenges in regulatory framework

From the analysis of different countries it is evidenced that regulations need to change from time to time to make RTPV a success. With this in view the regulatory framework in India from solar has been continuously evolving. The solar energy cost declined from INR 17/kWh in 2011 for meeting solar RPO obligations of various states to INR 4.63/kWh in 2015 as lowest though solar bidding route for a plant in the state of Andhra Pradesh. Model net metering guideline to allow deemed RPO for utilities against the electricity consumption from net-metering based solar rooftop-only against self consumption by consumers is defined as obligated entities [28]. For better forecasting of solar/wind generation for the purpose of grid integration, Renewable Regulatory Fund (RRF) regulations in 2010 as per the provisions of the Indian Electricity Grid Code Regulations, 2010 were introduced [19]. However, present regulations on connectivity do not recognize rooftop connectivity at low voltage (say 230/415V). Regulations to remove prevailing cross subsidy (subsidizing a particular group of consumers and recovering the cost by charging higher price from another group) so that tariff can become more attractive and execution guidelines for energy accounting process and Time of Day (TOD) settlement to connect at HT lines level and LT level consumers need to be evolved.

India's 'Smart *Cities*' project launched in 2014, envisages solar energy to make 10% contribution in the total electricity of selected cities. Amendment in building by-laws for making provision of rooftop solar can give it a boost. New constructions would take place and to make new buildings '*Rooftop ready*', with proper zoning and utilization of car park areas are to be addressed by the urban planners, along with regulation of favorable mandates for retrofitting in old buildings. From a study of solar energy potential of Nashik city in Maharashtra state it emerged that grid connectivity is going to be major issue in solar energy contribution for smart cities [29].

3.8. Outlook for RTPV in residential, commercial and industry sectors

Solar PV Rooftop market potential for India has been assessed as 124 GW by taking the total area under urban settlements as 77,370 km^2 [30]. The residential sector has a share of 38%, commercial/institutional 4% and industry 3% of the total usable area for RTPV, remaining 55% is other area. Emergence of domestic sector as the second largest energy consuming sector after industries is seen in India in the last few years. The electricity consumption in residential sector grew from 32 GkWh in 1990 to 198 GkWh in 2013. It is expected to increase to 1270 GkWh in 2040 [31]. In growing cities as the number of households is increasing, the residential sector electricity needs are growing rapidly. It is anticipated that about 30% of the solar rooftop target capacity of 40 GW can be met from the residential sector provided integration with grid is made. There are 331 million households according to 2011 census. On average a 3 kW system per household will require approximately 4 million RTPV households, which is less than 0.01% of the total. The scenario analysis suggests aggressive market supports with tax incentives and consumer centric regulations such as; amendment in building by-laws for considering solar rooftop structure as temporary structure so that it does not need fresh approval for raising height of the building by local municipalities will be important drivers for achieving the goal.

Most cities in India have flat structure low height buildings with lesser number of high rise buildings at present. Distribution Companies (DISCOMS) can facilitate by providing grid interconnection and reduction in electricity bills by selling at lower rate in proportion to higher wattage achieved from solar installation. As for the multi-storey housing complexes new models may emerge. A study in Tamil Nadu suggests third party lease model that has responsibility of building up structure, selling and buying electricity and transferring it to households is most suited [32]. Business models for both grid connected and off-grid RTPV are being developed. Power Trading Corporation in India has signed a MoU with Solar Energy Corporation of India to purchase and sale of power generated from 3000 MW solar projects on a long-term basis. Power Financing Corporation of India and Infrastructure Leasing & Financial Services (IL&FS) Infrastructure Development Corporation Limited are actively involved in developing Green Energy Corridors for grid transmission of RE.

4. Conclusions

Solar energy production does not emit greenhouse gases and is a climate friendly option. During operation a solar plant contributes to significant reduction of CO_2 emissions without consuming any fuel. In India, a country having practiced decentralized system for so long, a new thrust to grid connected solar electricity has been given and solar rooftop has emerged as an achievable goal for residential, commercial and industrial sectors. The National Solar Mission targets 100 GW

of solar electricity capacity by 2022 with 40 GW as RTPV. To fulfill these impressive targets technology and investment have to be in the top gear.

A review of global experience in RTPV installation in top solar countries has been made. It indicated dominance of feed-in-tariff and direct capital subsidy mode until 2011. But in the year 2012 it was observed that self consumption mode of implementation increased from 3.4 per cent to 12 per cent. Soft loans, tax credits, role of municipalities and market based mechanisms have played dominant roles in encouraging peoples' participation. Residential and commercial sectors top in numbers in RTPV installation in most countries.

Policies for growth of rooftop solar, challenges and outlook in India have been discussed. Government of India is leading by example through installation of solar rooftops widely on government buildings, airports, railways network, educational institutions, residential sector and commercial complexes. Though high growth is expected and cost wise it can reach parity with coal based power generation very soon, it is to be noted that unlike thermal power plants, RTPV generation is consumers dominated and therefore peoples' participation and acceptance are critical issues for its success. At the national level, manufacturing capacity, investment in R&D, investor friendly environment, skill development, low voltage grid connectivity of variable solar resource and regulatory decisions are major challenges to be resolved. As the penetration of RTPV has to increase boost to manufacturing capabilities not only in solar modules but also in inverters and batteries is must. In skill development providing skills for jobs of engineers, manufacturers, suppliers, repairs, maintenance, testing facilitators are some of the important challenges before the state agencies.

While strong foundations are being built in India through net metering policies and revising package of incentives; at city level greater role of municipalities in amendment of building by-laws for considering solar rooftop structure as temporary structure so that it does not need fresh approval for raising height of the building and role of DISCOMS in providing reduction in electricity bills by selling at lower rate in proportion to higher wattage achieved from solar installation so as increase home owners' contribution in energy security for 24 × 7 power for all are being considered. Provisions are also needed for soft loans, tax credits in property and investment. An outlook for linking of solar energy targets with the current missions on 'Make in India', 'Smart city mission' and 'Digital India' as a promise for developing capabilities and transformation of entire power system in the country is recommended. Development of off-grid systems that are '*Grid ready*' for rural and remote areas, and making by-laws for new buildings for grid connected as '*Rooftop ready*' should be the suggested goals for the future.

Conflict of interests

The author declares no conflict of interests.

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