Grid Parity of Residential Building Rooftop Solar PV in India

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Abstract

Rooftop solar photovoltaic(PV) installation in India have increased in last decade because of the flat 40 percent subsidy extended for rooftop solar PV systems (3 kWp and below) by the Indian government under the solar rooftop scheme. From the residential building owner's perspective, solar PV is competitive when it can produce electricity at a cost less than or equal grid electricity price, a condition referred as "grid parity". For assessing grid parity of 3 kWp and 2 kWp residential solar PV system, 15 states capital and 19 major cities were considered for the RET screen simulation by using solar isolation, utility grid tariff, system cost and other economic parameters. 3 kWp and 2 kWp rooftop solar PV with and without subsidy scenarios were considered for simulation using RETscreen software. We estimate that without subsidy no state could achieve grid parity for 2kWp rooftop solar PV plant. However with 3 kWp rooftop solar PV plant only 5 states could achieve grid parity without subsidy and with government subsidy number of states increased to 7, yet wide spread parity for residential rooftop solar PV is still not achieved. We find that high installation costs, subsidized utility grid

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supply to low energy consumer and financing rates are major barriers to grid parity.

Keywords: Grid parity, rooftop solar PV, RETscreen and NPV.

1 Introduction

India with a population of 1.3 billion is the second most populous country in the world and the third-largest economy measured by purchasing power parity (PPP). India has set a target growth rate of 9%, and likely to become USD 5 trillion economy by 2024–25, one of the fastest-growing economy in the world. India's sustained economic growth is placing an enormous demand on its energy resources. Key indicators of economy, population and energy between 2001 and 2017 are shown in Figure 1. India intend to reduce emissions intensity of its gross domestic product (GDP) by 33 to 35 percent by 2030 from 2005 level [1]. Any effort to achieve this target is depend upon increasing energy efficiency in all sectors, especially in the building sector. The building sector in India consumes over 30% of the total electricity [2].

Residential buildings consumed 75% of the total electricity in the building sector. The gross electricity consumption in residential buildings has been rising sharply over the years. For instance, the consumption figure rose to about 260 TWh in 2016–17 from about 55 TWh in 1996–97 [3]. It is estimated that this will increase to anywhere between 630 and 940 TWh by 2032 [4].

Present study focuses on rooftop solar PV energy usage for Indian household sector. This kind of approach helps to understand the scope of rooftop solar PV and its economic characteristics for different cities in India.

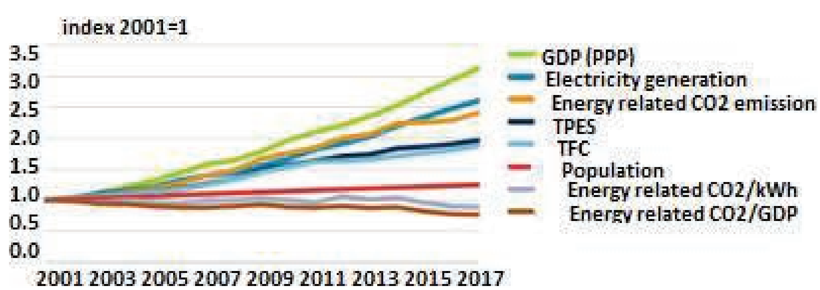

Figure 1 Trend in economy, population and energy (source India 2020 energy policy review, IEA report).

RETscreen simulation carried to ascertain the grid parity for rooftop solar PV in Indian states. For grid parity the factors considered were solar radiation, electricity tariff, government subsidy and initial cost of solar rooftop and other economic factors. The final section of article presents the conclusions that can be derived from this study.

2 Literature Survey

In India, domestic sector consumed 24% of electricity by in 2018–19. Details of electricity consumption by different sector is given in Figure 2. To address energy efficiency in the commercial building sector, Energy Conservation Building Code (ECBC) was launched in 2007 [5], code was applicable to building having connected load of 500 kW or greater/contact demand of 600 kVA or more. In 2017, ECBC 2007 modified to ECBC 2017 and is applicable to buildings or building complexes that have a connected load of 100 kW or greater or a contract demand of 120 kVA. ECBC provides minimum requirements for the energy-efficient design and construction of buildings. The code was extended to residential building though ECBC 2018-R (Eco-Home guidelines) and it is applicable to all residential use building built on plot area greater than or equal to 500 m^2.

In 2005, India's residential and commercial floor area was estimated to be 1.6 and 0.5 billion m^2 which has doubled to 3.5 and 1 billion m^2 in 2012.

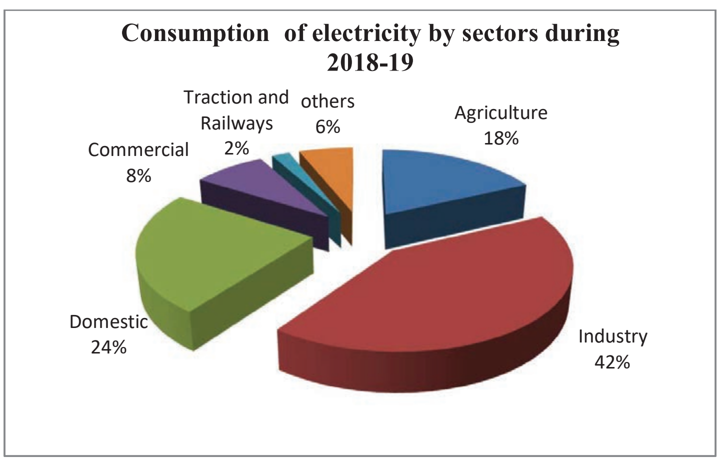

Figure 2 Consumption of electricity by sectors during 2018–19 (http://www.mospi.gov.in/sites/default/files/publication_reports/).

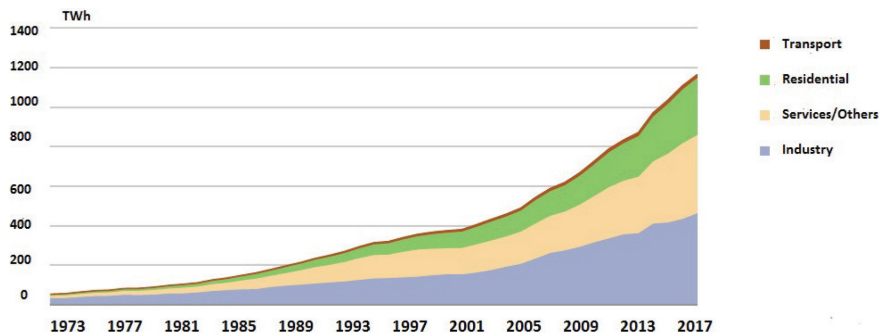

Figure 3 Electricity consumption different sectors (IEA India Report, 2020) [7].

Figure 4 Rooftop solar PV target Map for Indian states [9].

It is also estimated that by 2030, residential and commercial floor space will increase to 7.0 from 1.5 billion m^2 [6]. Residential sector is the third largest consumer of electricity and has increased by 26% between 2014 and 2017 [7].

India has a renewable energy target of 175 GW by 2022. The solar energy will contribute 100 GW of this 40 GW would be from solar PV rooftop. India has already installed 28 GW of solar capacity as of March 2019 [8]. National Institute of Solar Energy (NISE) estimated rooftop SPV potential of 42.8 GW and considered certain system sizes on roofs of various public and private building. Rooftop SPV potential of different states of India is

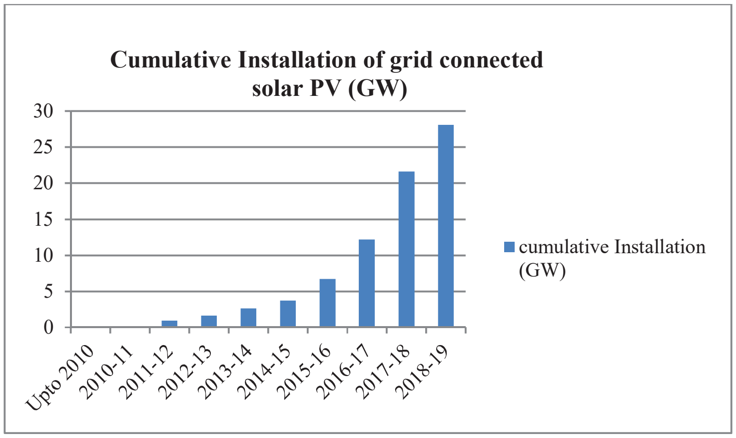

Figure 5 Grid integrated Solar PV rooftop installation 2010–19 [8].

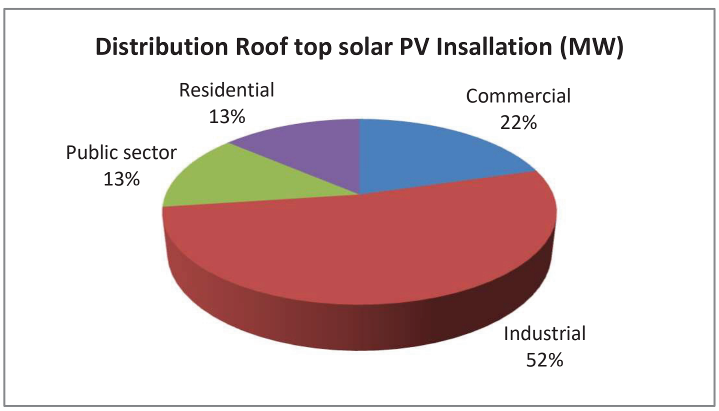

Figure 6 Distribution of installed rooftop Solar PV till Jun 2020 [9].

given Figure 4. Progress of installation from 2010 to March 2019 is shown in Figure 5. Rooftop solar PV installation has reached 5.95 GW in June 2020 and installation is predominately in industrial and commercial building whereas only 13% is installed in residential sector. Distribution of rooftop solar PV till June 2020 in different sector is shown in Figure 6 [9].

Ministry of New and Renewable Energy (MNRE) allocated state targets of 1 GW and more rooftop solar for is tabulated in the Table 1. These states target will help in achieving more than 88.2% of India's rooftop solar PV target. Therefore economics of rooftop solar PV in these states was undertaken in this study.

Table 1 States rooftop solar PV target for year 2022

State	Rooftop Solar PV Target (MW) Year 2022	Installation (MW) as on 30 June 2020
Andhra Pradesh	2000	240
Bihar	1000	27
Delhi	1110	178
Gujarat	3200	383
Haryana	1600	275
Karnataka	2300	402
Maharashtra	4700	851
Madhya Pradesh	2200	313
Odisha	1000	59
Punjab	2000	169
Rajasthan	2300	526
Tamil Nadu	3500	481
Telangana	2000	174
Uttar Pradesh	4300	324
West Bengal	2100	143

Study of rooftop solar photovoltaic potential for Mumbai (India) suggest that it can meet 12.8–20% of the daily energy demand [10]. Simulation of 6.4 kW roof top solar PV plant for Ujjain (India) demonstrated that it not only meets building energy demand but also feed surplus energy of 8450 kWh annually into the grid [11] Computer simulation of installation of rooftop PV system at five locations in India shows that energy required for roof-induced cooling load decreased between 73% and 90% [12]. Energy simulation of 110 kWp standalone rooftop solar PV system for Bhopal (India) demonstrated payback period of 8.2 years [13].

Study of Andalusia (Spain) suggest that rooftop solar PV would satisfy 78.89% of residential energy demand [14]. In US (2015), with residential solar incentives, 18 of the 51 target cities could reach the break-even point [15]. Study of city of Al-Khobar in Saudi Arabia suggest villas and apartment buildings can offset 19% of the electricity demand by utilizing 25% of the building roof for Solar PV. In addition cooling load also reduces by 2% due to the shading effect of panels [16]. Hawaii (US) has achieved socket parity for residential rooftop solar PV without the use of subsidies [17].

3 Material and Method

The present work is the study of ascertaining the viability of rooftop solar PV for residential sector. This study also aims to estimate the grid parity of rooftop solar PV for different states of India. The key objectives of the study are to:

- Is grid parity attainable for solar power in the residential sectors in different states in India?
- Economic returns of rooftop solar PV for the residential building

3.1 Electricity Tariff Across Indian States

Electricity tariff for the residential building in Indian states is based on the energy consumption. Baesd on the the resedential energy tariff consumers can be categoriesed into low, moderate and high, tabulated at Table 2. The electicity charges are telescopic where conumer with higher energy cosumption falls in higher elecrticity tariff bracket and pay more. Grid electricity tariff for medium and high consumer for selected Indian states is tabulated at Table 3. Future tariff rate rises have been estimated by calculating the compound annual growth rate (CAGR) from 2009–10 to 2018–19 for the slab 400 kwh/month and 1000 kWh/month from Centre of Electicity Authority (CEA) annual report [18]. Based on tariff rates over the last 9 years for the states (Table 1), an average calculated CAGRs for 400 kWh/month and 1000 kWh/month residential urban consumer across selected states is 5% and 5.4% respectively. Therefore for residential urban consumer electricity CAGRs is taken as 5% over the 25 year lifetime of a PV system.

3.2 Estimation of Electricity Generation from Rooftop Solar

Residential rooftop PV system of 2 kWp is considered for consumers whose electricity demand is less than 400 kWh/month and 3 kWp rooftop PV system for consumer whose electricity demand is in the range of 400–1000 kWh/month. MNRE gives flat 40% subsidy on solar PV plant rating up to 3

Table 2 Consumer categorization based on energy consumption per annum

Group	Categorization of Resedential Consumer	Energy Consumption (E)/Month
A	Low	$E \leq 200$ kWh
B	Moderate	$200 < E \leq 400$ kWh
C	High	400 KWh $< E$

Table 3 Electricity Tariff for medium and high energy consumers [19]

State	Electricity Tariff Rs/kWh (200–400 kWh/month)	Electricity Tariff Rs/kWh (400–800 kwh/month)
Andhra Pradesh	7.50	8.50
Bihar	6.67	6.67
Delhi	4.50	6.50
Gujarat	5.20	5.20
Haryana	6.30	7.10
Karnataka	7.80	7.80
Maharashtra	10.36	11.82
Madhya Pradesh	6.50	6.50
Orisa	5.30	5.70
Punjab	7.30	7.30
Rajasthan	7.65	7.95
Tamil Nadu	4.60	6.60
Telangana	8.50	9.0
Uttar Pradesh	6.50	7.0
West Bengal	6.64	7.0

Table 4 Tata Rooftop solar PV system cost [21]

Rooftop Solar PV System	Cost Without Subsidy (Rs)	Cost with Subsidy (Rs)
3 kWp	1,90,000	1,40,000
2 kWp	1,40,000	1,05,600

kWp. This subsidy reduces to 20% for rooftop solar PV plants rating between 3 kWp and 10 kWp [20]. Tata solar is the leader in Indian rooftop solar PV market from last six years (2014–20). Cost of 3 kWp and 2 kWp of Tata solar rooftop system considered for the study is tabulated in Table 4.

Electricity generation cost from the rooftop solar PV system calculated for the 34 cities in these states mentioned at Table 1 by using RETScreen version 8, a software program developed by Natural Resource Canada (2005). The energy cost output RETscreen simulation with subsidy (40%) and without state subsidy for 3 kWp and 2 kWp rooftop solar PV plant. The results obtained and its comparison with grid electricity tariff is shown in Figures 7–10.

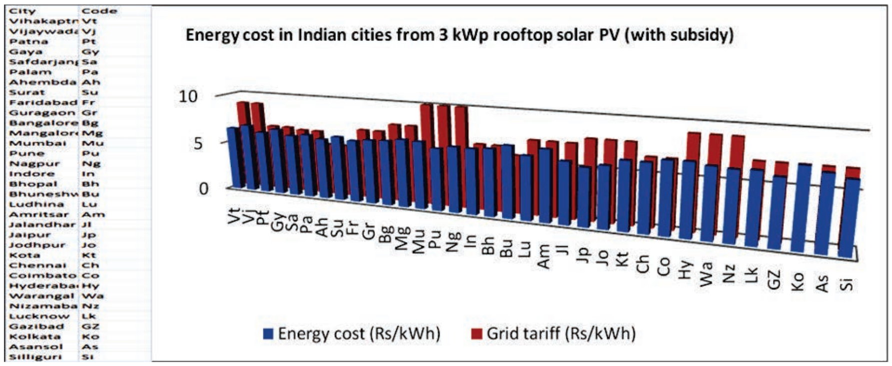

Figure 7 Energy cost of 3 kWp rooftop solar PV in Indian cities (with subsidy).

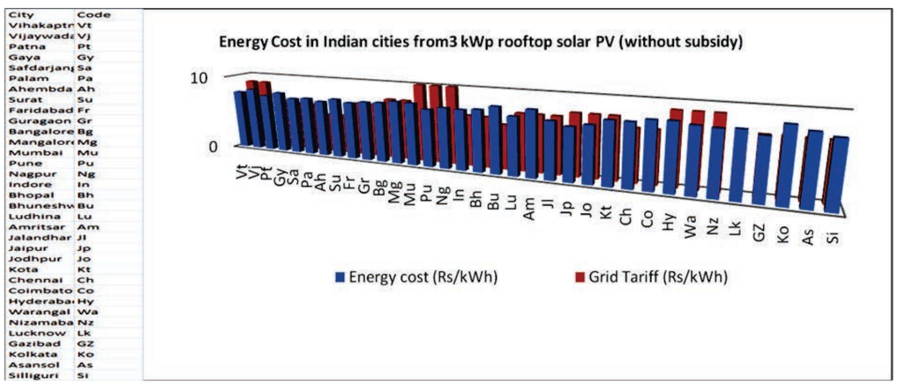

Figure 8 Energy cost of 3 kWp rooftop solar PV in Indian cities (without subsidy).

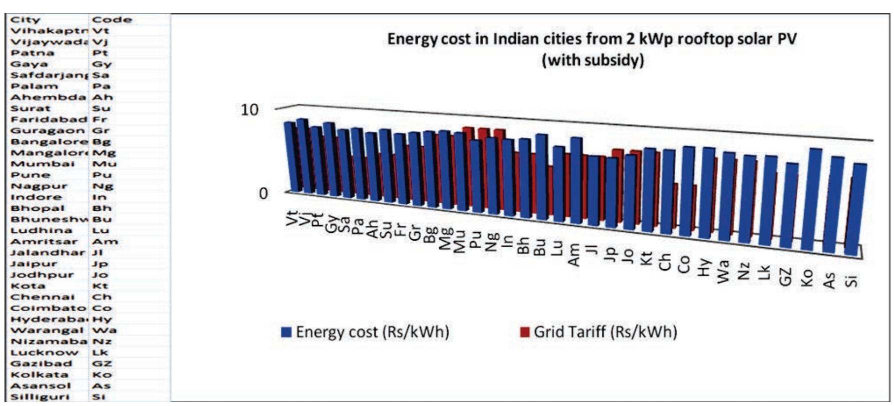

Figure 9 Energy cost of 2 kWp rooftop solar PV in Indian cities (with subsidy).

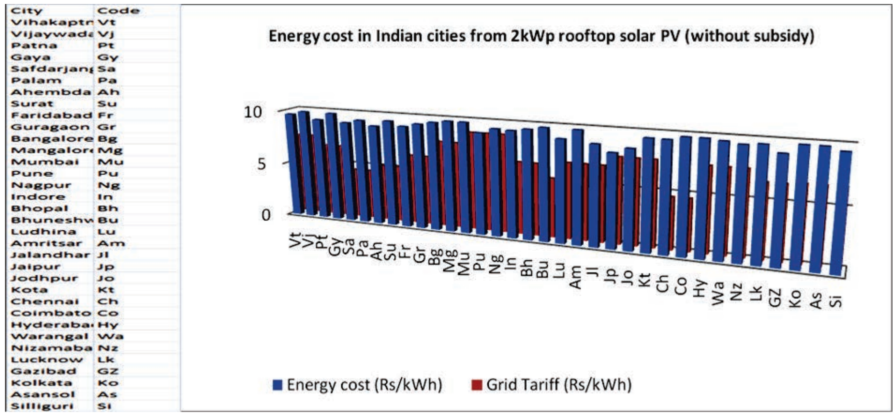

Figure 10 Energy cost of 2 kWp rooftop solar PV in Indian cities (without subsidy).

On analysis of RET simulation result of 3 kWp rooftop solar PV (with subsidy) energy cost, 24 cities out of 34 cities could achieve grid parity (energy cost obtained from rooftop solar PV is lower than grid cost). However in absence of subsidy only 12 cities could achieve competitive energy cost from rooftop 3 kWp solar PV as compare to grid cost. Jaipur city in Rajasthan state achieve the lowest energy cost of Rs 5.60/kWh, whereas in most of other cities energy cost varies in the range of Rs 6.50/kWh-Rs 7.00/kWh. Maharashtra state leads other states in the grid parity. In addition to Maharashtra, Rajasthan, Telangana, Karnataka and Andhra Pradesh are the only states which could achieve grid parity in absence of subsidy for 3 kWp rooftop solar PV.

On analysis of RET simulation result of 2 kWp rooftop solar PV (with subsidy) energy cost, 5 cities out of 34 cities could achieve grid parity. Due to lower electricity tariff for moderate consumer, 2 kWp rooftop solar PV couldn't achieve grid parity in any of the states in absence of subsidy. Maharashtra and Rajasthan could only achieve grid parity for 2 kWp rooftop with the 40% subsidy. Jaipur city achieve the lowest energy cost of Rs 6.68/kWh, whereas in most of other cities energy cost varies in the range of Rs 7.50/kWh-Rs 8.50/kWh.

3.3 Step 2. Simulation for Economic Analysis of Solar Roof top PV Plant

For evaluating the economics of residential rooftop solar PV break-even of electricity price is used because residential customer is concerned about the cost of electricity coming from the rooftop solar PV plant as compared with the cost of the electricity they buy from utility. In addition to capital cost, Operation and Maintenance (O&M) cost, recurring cost of inverter (Rs 30,000 and Rs 24,000 for 3 kWp and 2 kWp solar PV plant respectively) at 13th year were also considered. Net Present Value (NPV) and Internal Rate of Return (IRR) were also obtained from RETscreen software's finance module for Tata solar 3 kWp, 2 kWp cost with and without subsidy. Utility electricity prices escalation and other economic parameters used for obtaining payback period, NPV and IRR tabulated in Table 5.

Table 5 Financial parameters considered for viability of solar PV rooftop

Parameter	Description	Source
Electricity escalation rate	5%	[18]
Inflation rate	5%	[22]
Discount rate	9.36%	[23]
Project life	25 years	[24]
Debt ratio	70:30	[24]
O& M cost	5% of system cost	[24]
Debt interest ratio	10.5%–11.5% (average-11%)	[25]
Debt terms	10 yrs	[24]

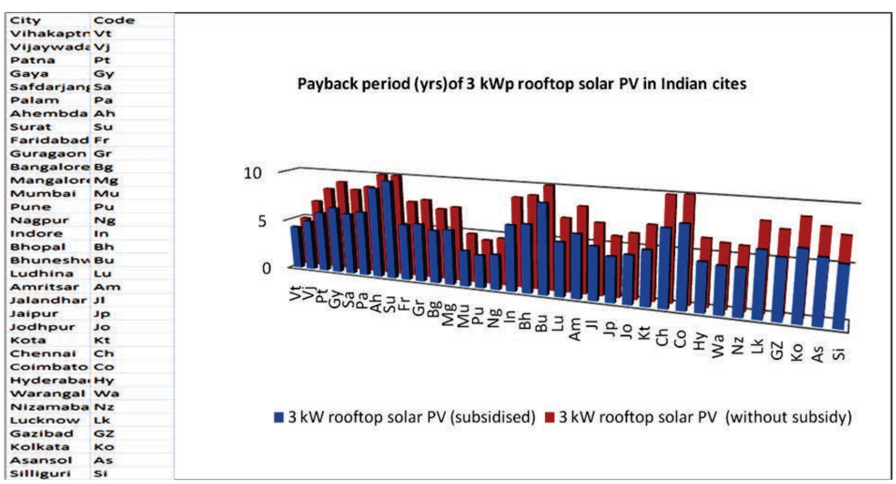

Figure 11 Payback Period (yrs) of 3 kWp rooftop solar PV for Indian cities.

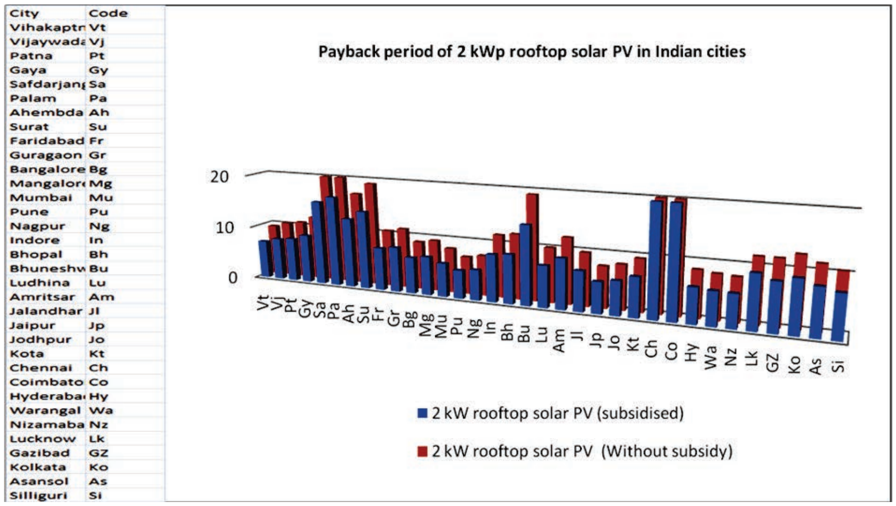

Figure 12 Payback Period of 2 kWp rooftop solar PV for Indian cities.

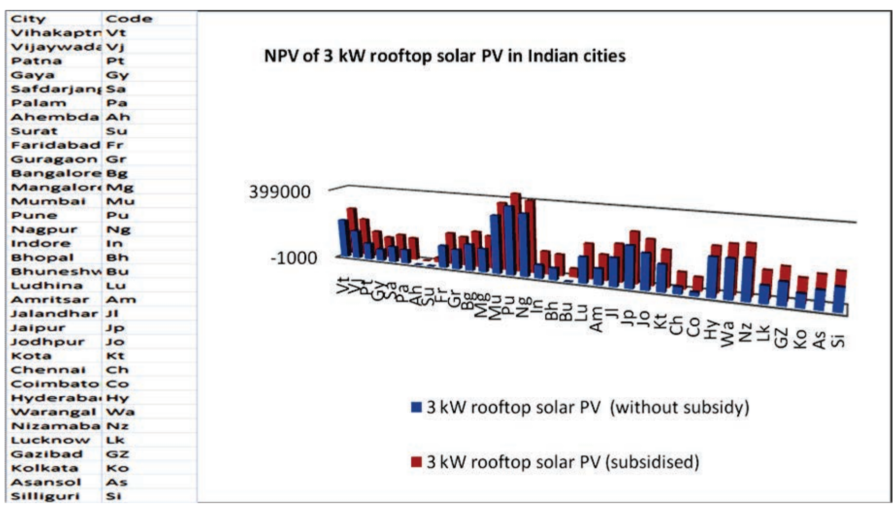

Figure 13 NPV of 3 kWp rooftop solar PV for Indian cities.

On analysis of RET financial simulation result of 3 kWp rooftop solar PV (with subsidy), 25 cities out of 34 cities could achieve IRR more than 11% (economic parity – IRR more than debt interest rate). However, in absence of subsidy only 8 cities could achieve this competitive IRR. Pune city in Maharashtra state achieve the highest IRR and NPV (with subsidy) of

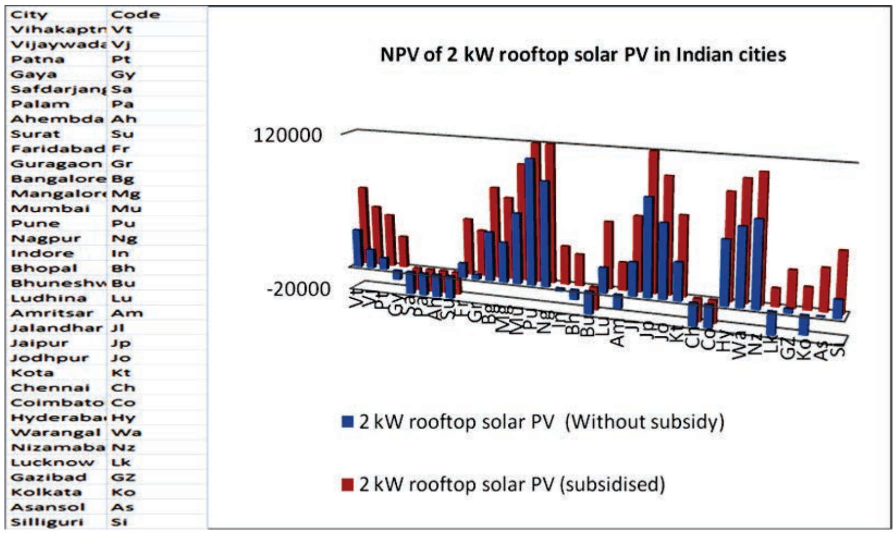

Figure 14 NPV of 2 kWp rooftop solar PV for Indian cities.

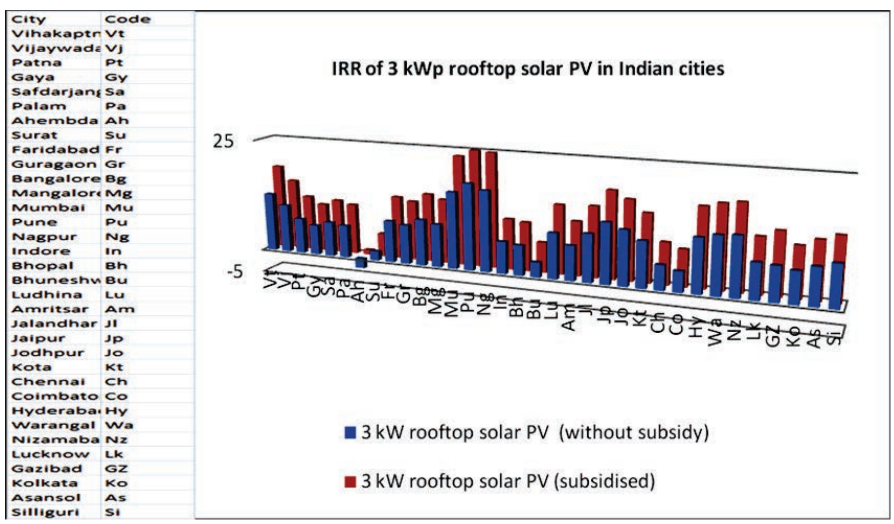

Figure 15 IRR of 3 kWp rooftop solar PV for Indian cities.

26.4% and Rs 4,32,121 respectively. Ahmadabad city in Gujarat achieve the lowest IRR and NPV (with subsidy) of 0.99% and Rs −12,174 respectively. In absence of subsidy IRR and NPV for Pune and Ahmadabad reduced to 18.7%, Rs 3, 79,589 and −2.1%, Rs −64,178 respectively.

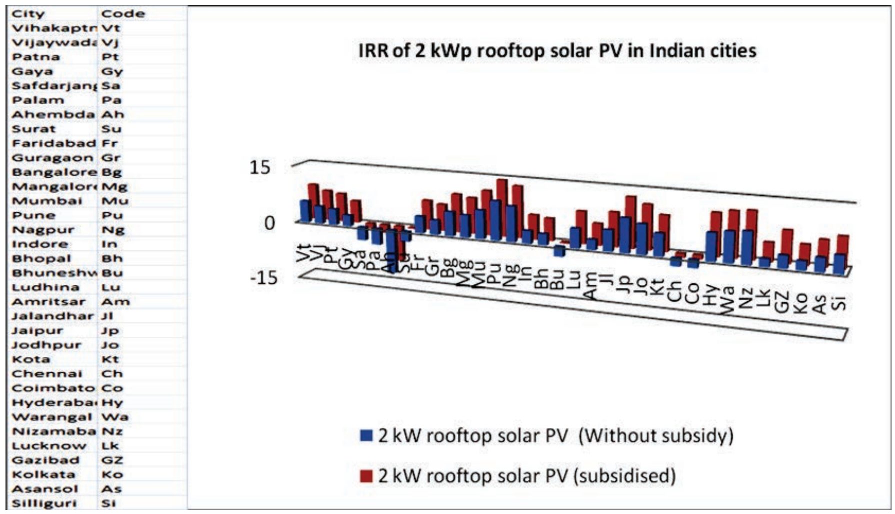

Figure 16 IRR of 2 kWp rooftop solar PV for Indian cities.

On analysis of RET financial simulation result of 2 kWp rooftop solar PV (with subsidy), 8 cities out of 34 cities could achieve IRR more than 11%. However, in absence of subsidy no city could achieve competitive IRR. Pune city in Maharashtra state achieve the highest IRR and NPV (with subsidy) of 14.4% and Rs 1,45,162 respectively. Ahmadabad city in Gujarat achieve the lowest IRR and NPV (with subsidy) of −9.19% and Rs −59,235 respectively. In absence of subsidy IRR and NPV for Pune and Ahmadabad reduced to 10%, Rs 1,09,345 and −11.3%, Rs −95,385 respectively.

4 Discussion and Results

Based on the simulation results discussed in above section the cities (state) can be graded as most favorable, preferred and not favorable for rooftop solar PV (3 kWp and 2 kWp). Criteria employed for this classification are tabulated in Table 6. If simulation results of cities (state) satisfying any two or more criteria of the classification (energy generation/payback period/NPV) is considered for the same category. Based on this country map for 3 kWp (with subsidy), 3kWp (without subsidy) and 2 kWp(with subsidy) are shown in Figures 17–19 respectively.

Table 6 Classification of criteria for rooftop solar PV for Indian states

Classification of states	Energy Generation Cost (Rs /kWh)	Payback Period (years)	NPV (Rs)
Most Favorable	Less than grid tariff	Less Than 6	More than 50% of capital cost
Favorable	Within 10% of grid tariff	6–7.5	Between 50%–25% of capital cost
Not favorable	More than 10% of grid tariff	More than 7.5	Less than 25% of capital cost

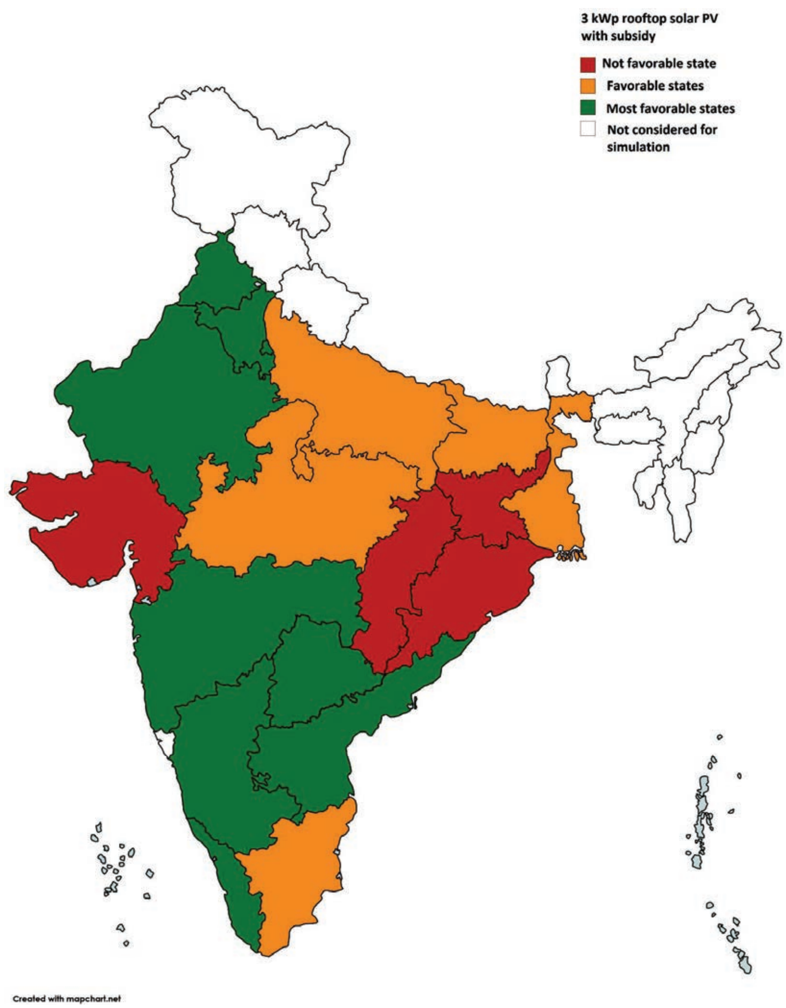

Figure 17 County Map for 3 kWp rooftop solar PV with subsidy.

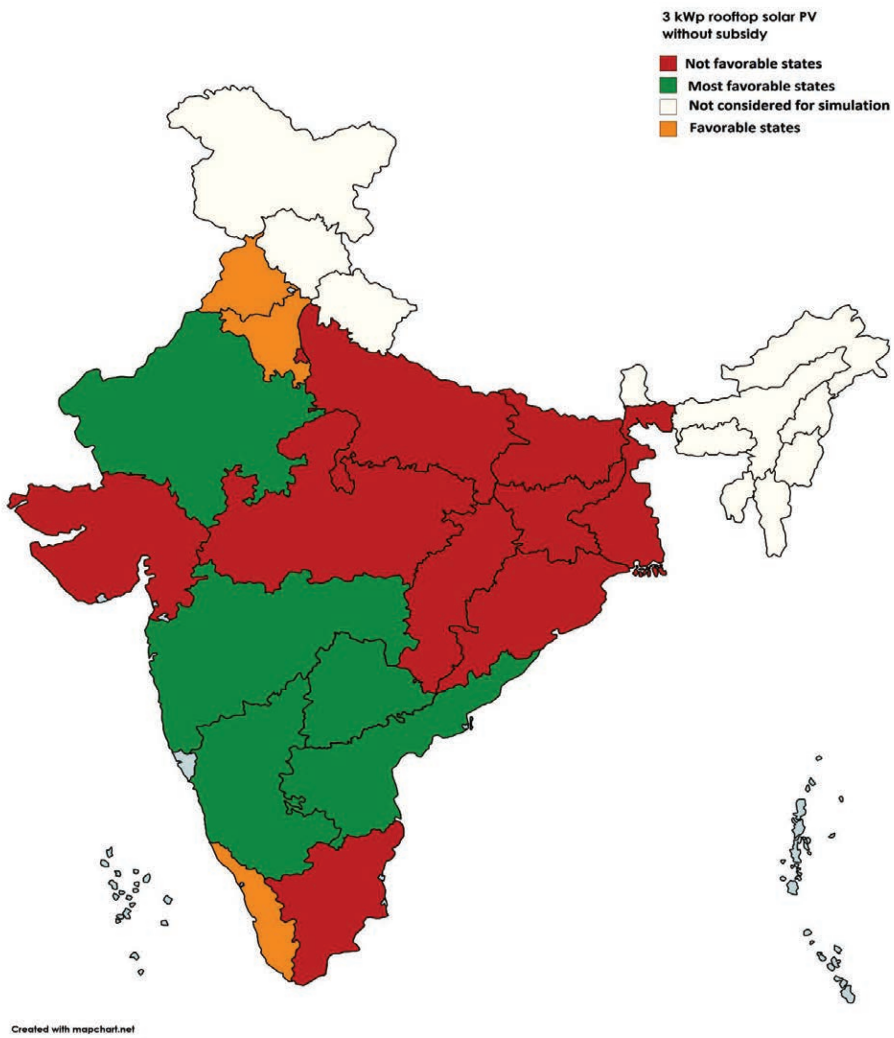

Figure 18 Country Map for 3 kWp rooftop solar PV without subsidy.

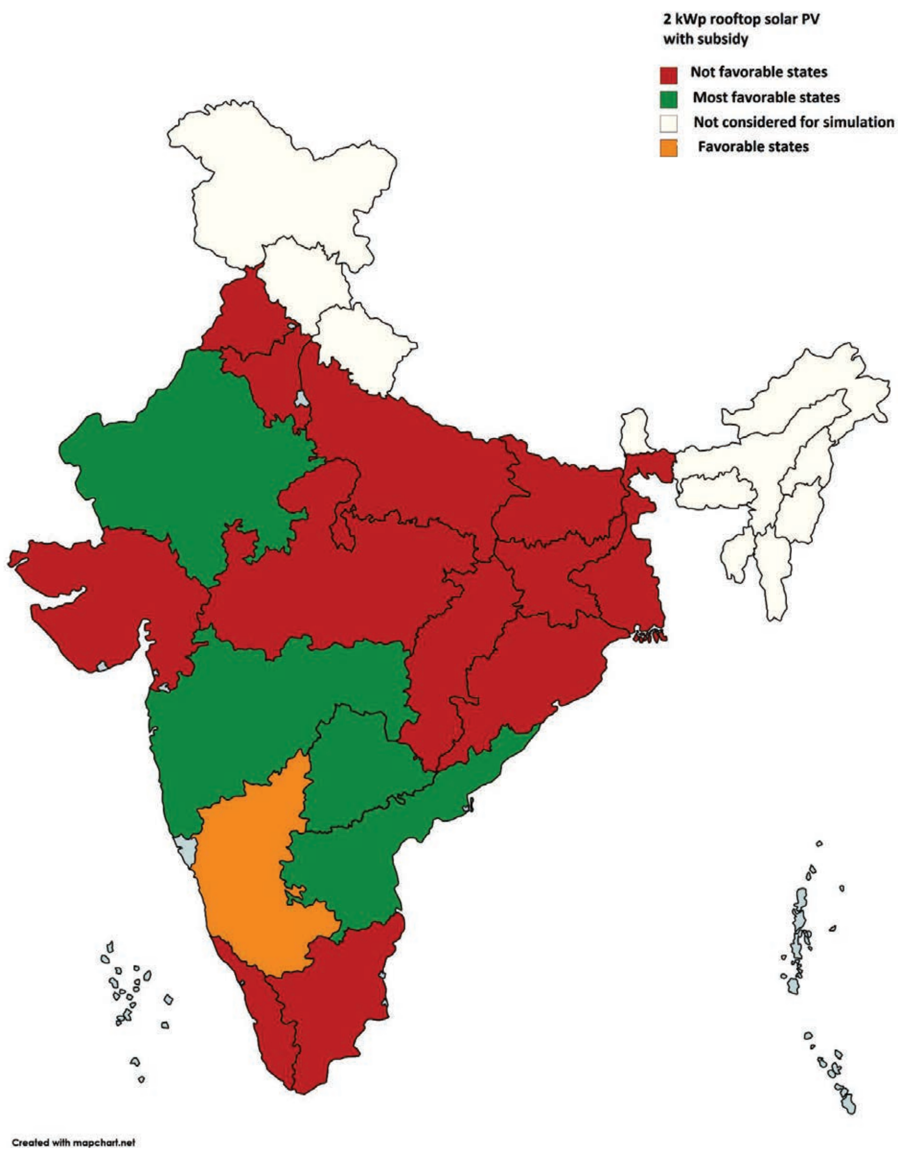

Figure 19 Country Map for 2kWp rooftop solar PV with subsidy.

5 Conclusion

In summary, results suggest that grid parity without subsidies has not yet become a reality for Indian states. For residential solar systems to reach grid parity, continued installation-cost reduction is critical, along with the availability of low-interest loans and reducing grid residential electricity subsidy for low and moderate energy consumer as grid parity is highly dependent on grid electricity tariff. Because of the study restricted to engineering and economic analysis of the residential sector, it does not consider potential societal benefits of increased solar PV penetration. These benefits may provide sufficient incentive for government for maintaining subsidies until the solar rooftop target of 40 GW is achieved. Subsidies have enabled some states to achieve grid parity that would not otherwise occur with current installation costs. Given different goals, it may be necessary to reallocate subsidies instead of providing the same level of support throughout every location.

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