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Climate Action: Mitigation and Adaptation in a Post Paris World

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CONTENTS

Comparative Techno-Economic Analysis of Rooftop PV (RTPV) Systems in Various States in India

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Abstract: The growth of RTPV has been sluggish compared to ground-mounted installations. This study analyses the techno-economics of RTPV in different states with their respective net-metering (NM)/gross-metering (GM) regulations and state policies to assess the financial performance of RTPV systems. States having abundant amount of solar potential such as Karnataka, Gujarat, Rajasthan, Maharashtra and Tamil Nadu are considered. The results of this analysis show that there is a lack of favourable consumer-end economics indicated by equity Internal Rate of Return (IRR) and payback period findings. According to our calculations, residential consumers with higher capital costs per kW and lower retail tariffs have the least favourable business cases for RTPV in India whereas commercial consumers with lower capital costs per kW and higher retail tariffs have the best business cases. Karnataka and Rajasthan have the most attractive business cases for all categories of prospective RTPV consumers. States such as Gujarat and Maharashtra procure excess RTPV-based generation at Average Pooled Purchase Cost (APPC) and states such as Tamil Nadu have no provisions to procure excess RTPV based generation. These states need to revise the NM/GM rate to ~Rs. 5.5/kWh to ensure the viability of business cases for RTPV across all consumer categories in India.

Keywords: Net-metering, rooftop PV (RTPV), gross-metering, feed in tariff (FiT), equity IRR, payback period

Introduction

The Government of India launched the Jawaharlal Nehru National Solar Mission in January, 2010 with the aim of adding 22 GW of solar energy by the year 2022 [1]. To further this, the Ministry of New and Renewable Energy (MNRE) is implementing a 'Grid Connected Rooftop and Small Solar Power Plants Programme' in the country [2]. In the 12th Plan period, the financial outlay for this scheme was Rs. 600 crores. Later, in 2015 the solar target was ambitiously revised to 100 GW out of which 40 GW needs to come from rooftop PV (RTPV) installations [3]. Following this, the Cabinet Committee on Economic Affairs revised this budgetary outlay to Rs.5,000 crore for implementation of 4.2 GWp of RTPV over a period of five years up to 2019-20 [4].

Till 2017, almost all states in the country have rolled out net-metering (NM)/gross-metering (GM) schemes to encourage domestic, institutional, industrial and commercial consumers to install RTPV systems ranging from 1 kWp to 500 kWp and even up to 1 MWp in some states [5]. These regulations along with annual orders on suo-motu determination of levelized tariff by different State Electricity Regulatory Commissions (SERCs) have created a plethora of business models which warrant detailed analysis and a documentation of best practices.

At present, the total commissioned rooftop capacity in the country stands at 1,660 MW [6]. Tamil Nadu is the leading state followed by Maharashtra, Rajasthan, Gujarat and Karnataka [7]. Industrial and commercial sectors have adopted more RTPV installations than domestic sector due to higher retail tariff rates. States are playing a critical role in the deployment of grid connected solar power [8] [9] [10]. This article explores the best business cases in the RTPV sector in India by making use of representative cases in five leading states viz. Gujarat, Rajasthan, Maharashtra, Tamil Nadu and Karnataka. The next section outlines the financial incentives and policy frameworks applicable for consumers willing to adopt RTPV systems as a means of energy security and worthwhile investments.

Background

For setting up an RTPV system in India, various financial and policy incentives are available through multiple channels. Some relevant ones are described in the following sub-section.

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RTPV Policy Regime in Indian States

To perform techno-economic assessments of various consumer categories of RTPV systems in Indian states, a policy overview in the five states of Karnataka, Gujarat, Rajasthan, Tamil Nadu and Maharashtra is presented to highlight the challenges and opportunities along with the key factors that need to be taken into consideration for financial analyses (Table 14). The benchmark cost of RTPV systems in the aforementioned states along with other pertinent financial parameters that are considered while performing techno-economic calculations in this study are shown in Table 15

Retail Tariff Structure of DISCOMs

DISCOMs have tariff schedules each year for consumers with the rationale for tariff design varying across states. The broad categories of consumers are domestic, industrial, commercial and institutional. However, retail tariff also depends on the connected load/contract demand of the consumer which divides them into HT (High Tension) or LT (Low Tension) categories. HT category is applicable for bulk consumers and use 11 kV or above while an LT supply is of 400 V for a three-phase connection and 230 V for a single-phase connection. A simplistic division of consumers is used for the purpose of this paper to enable a comparative study across the five states.

i. Residential consumers: LT category: domestic households

ii. Commercial consumers:

   a) LT category: small shops, offices, guest houses, hotels, etc.

   b) HT category: shopping malls, film studios, etc.

iii. Industrial consumers:

   a) LT category: small scale manufacturing units, medium, small and micro enterprises

   b) HT category: large industrial complexes

iv. Institutional consumers:

   a) LT category: govt. schools, administrative buildings

   b) HT category: govt. colleges and universities

The DISCOMs that are chosen are the primary public distribution utilities in the state which are regulated by the SERCs (Table 14). Private distribution utilities are not considered for this analysis since their operational parameters for RTPV are different. The retail tariff structure slabs for respective DISCOMs in the five states considered for analyses are presented in Table 15.

Specific case studies (for each category of consumer) which fall under the scope of each of the policies mentioned above are considered and the economic viability of RTPV systems is arrived at in the five states. Gaps in policies are identified and suitable policy recommendations are made.

Methodology

The objective of this research article is to compare the techno-economic performance of RTPV systems in five leading states in India, viz. Karnataka, Gujarat, Rajasthan, Maharashtra and Tamil Nadu. The focus on Karnataka is because most of the primary data obtained for this research has been obtained from DISCOMs in this state. Since RTPV is a decentralized distributed power generation system and can be adopted by various consumer categories, viz. residential, commercial, industrial and institutional, the economics vary significantly based on each specific application. Typical capacities and types of RTPV systems are taken into consideration and financial analyses are performed across the five states. The chosen sizes and types of RTPV systems in each consumer category are elaborated upon in the following sub-sections.

Residential RTPV Systems

In this study it has been revealed through stakeholder discussions with RTPV consumers (existing and prospective) and DISCOMs, that in the residential sector, households with annual incomes greater than Rs. 20 lakhs and independent plots are more inclined to invest in RTPV systems. The average sanctioned load of existing RTPV installations in Bengaluru, Karnataka is taken as 5 kW. This is also the cap on maximum installed capacity for domestic LT consumers with single phase supply. For others with three phase supply (5 kW to 50 kW sanctioned load) this is either equivalent to or less than 100% of their sanctioned load [22]. The average rooftop area for these installations is taken to be 80 m2. 1 kWp of RTPV is allocated 10 m2 of rooftop area taking Balance of System (BoS) into account [38][39]. The average monthly consumption is taken as 600 units out of which 40 units are from captive diesel generators [40].

These representative numbers and the parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for residential consumers (LT category) in the five states. HT consumers (large apartments or complexes) are not considered for this analysis. The roofs of these buildings are usually quite small compared to the number of floors and thereby households. There are also social barriers surrounding ownership and sharing of electricity and revenue generated from solar panels.

Commercial RTPV Systems

Typically, commercial establishments pay the highest tariffs amongst the gamut of consumers catered to by Indian DISCOMs. With global solar PV prices on the decline, the Levelized Cost of Electricity (LCOE) of RTPV systems is now cheaper than the rates paid by commercial consumers in most Indian states. Two representative cases in the LT and HT segments in the commercial space are considered in this research article:

1. Independent mini-supermarket with a sanctioned load of 40 kW, available rooftop area of 800 m2; monthly consumption of 8,000 units out of which 500 units are from a captive diesel generator during power cuts.
2. A shopping mall with a sanctioned load of 250 kW, available rooftop area of 3500 m2; monthly consumption of 60,000 units out of which 4,000 units are from a captive diesel generator during power cuts.

These representative numbers, parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for commercial consumers (LT and HT category) in the five states.

Industrial RTPV Systems

Two representative cases in the LT and HT segments in the industrial consumers' category are considered in this research article:

1. A packaging warehouse with a sanctioned load of 50 kW, available rooftop area of 2000 m2; monthly consumption of 9,000 units out of which 800 units are from a captive diesel generator during power cuts.
2. A ball bearing manufacturing unit with a sanctioned load of 300 kW, available rooftop area of 5,000 m2; monthly consumption of 85,000 units out of which 8,000 units are from a captive diesel generator during power cuts.

These representative numbers and the parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for industrial consumers (LT and HT category) in the five states.

Institutional RTPV Systems

Two representative cases in the LT and HT segments in the institutional consumers' category are considered in this research article:

1. A government primary school with a sanctioned load of 30 kW, available rooftop area of 500 m2; monthly consumption of 2,000 units out of which 200 units are from a captive diesel generator during power cuts.
2. A government arts college with a sanctioned load of 200 kW, available rooftop area of 4,000 m2; monthly consumption of 45,000 units out of which 4,000 units are from a captive diesel generator during power cuts.

These representative numbers and the parameters and restrictions listed in Table 14 and Table 15 are used to calculate the installed capacity and associated capital costs of RTPV systems for industrial consumers (LT and HT category) in the five states.

Techno-economic Assessment

LCOE is calculated by determining the total amount of electricity generated by the RTPV system over its lifetime (taking degradation into account) i.e. 25 years and all numbers being discounted to Present Value (PV) and the total cost of the RTPV system over its lifetime being divided by the total amount of electricity generated [41][42].

Where,

$$LCOE = \frac{\sum_{t=1}^{n} \frac{(I_t+M_t+F_t)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t = *Investment expenditures in the year t*

M_t = *Operations and maintenance (O&M) expenditures in the year t*

F_t = *Fuel expenditures in the year t (considered to be 0 in case of solar PV)*

E_t = *Electricity generated in the year t*

r = Discount rate

n = Lifetime of the system (25 years in case of solar PV)

The revenue model has then been calculated by taking into account the savings of the consumer due to displacement of grid-based electricity and diesel, and revenue from electricity sales through NM/GM scheme to the DISCOM. This analysis is based on Discounted Cash Flows (DCF) over the useful life of the plant, taking into consideration the time value of money. The cash flows are discounted over the lifetime and Net Present Value (NPV), internal rate of return (IRR) for project as well as equity, and payback period for each system are calculated. In this, future monetary earnings are discounted back to get their present value using a discount rate that varies across states since the opportunity cost of capital is different. These relationships and equations form an integral part of CSTEP's in-house CSTEM tool [43] which is used for all these calculations.

Assumptions used in the model are as follows:

- Long-term equity gains are tax free in India which is why income tax on RoE is assumed to be zero
- For average retail tariff calculation, the component of fixed costs is not embedded in the overall billing cycle and is assumed to be constant during the useful life of the system
- After 10 years, inverter replacement costs are added to the calculations along with the salvage value of the plant and inverter, a parameter not considered in the Commission's analysis in all the five states. Salvage value therefore, is assumed at 10% while the annual escalation in the cost of the inverter is taken to be 2%
- Retail tariff is assumed to rise at an annual rate of 3%
- Only half of diesel-based consumption is assumed to be replaced by RTPV generation since power cuts occur after sunset as well
- Some SERCs do not define every financial parameter required for techno-economic assessments of RTPV systems. In these cases, CERC prescribed parameters are considered

Results & Discussion

Results based on the aforementioned methodology are presented and discussed in the following sub-sections.

Residential RTPV Systems

The installed capacities and corresponding capital costs of residential RTPV systems with and without MNRE subsidy in the five states are depicted in Table 12.

A summary of the techno-economic assessment of residential RTPV systems in the five respective states is presented in Table 1.

Table 1: Techno-economics for residential RTPV systems

State	LCOE (Rs./kWh)	FiT (Rs./kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Without Subsidy							
Karnataka	5.55	7.08	6.5	21.38	34.12	1.16	8
Rajasthan	5.75	5.4	6.3	20.45	30.69	1.38	7
Gujarat	5.45	APPC	4.5	14.96	17.42	0.32	22
Maharashtra	7.14	APPC	5.6	14.25	18.12	0.76	12
Tamil Nadu	5.97	-	3.77	7.38	6.04	-0.41	-
With Subsidy							
Karnataka	3.92	7.08	6.5	35.39	76.67	1.99	4
Rajasthan	4.21	5.4	6.3	32.51	66.69	2.06	4
Maharashtra	5.39	APPC	5.6	23.53	43.18	1.62	6
Gujarat	4.54	APPC	4.5	20.69	30.31	0.58	7
Tamil Nadu	4.64	-	3.77	12.05	13.39	0.45	15

In spite of a reduction in NM/GM rates in Karnataka and a restriction of sanctioned load being imposed on the capacity of an RTPV installation, the state still performs the best amongst the five states in terms of techno-economics of residential RTPV systems. With reducing capital costs, the move to switch to GM along with a capping the installed capacity to 100% of the sanctioned load reflects a fine balance between consumer expectations on RoE and the ability of DISCOMs to pay for rooftop electricity. This has overall improved the market for domestic households in Karnataka, which is stated as one of the objectives of the present policy.

Rajasthan is another state with favourable techno-economics for residential RTPV systems. Although the FiT is lower than the calculated LCOE of an RTPV system, the higher retail tariffs which are offset because of electricity savings and NM lead to equity IRR crossing 30% in the state with a payback period of only 7 years.

In Gujarat and Maharashtra, surplus energy at the end of billing cycle is purchased at APPC by DISCOMs. Apart from this, the retail rates in these two states are much lower than the LCOE of RTPV systems. Hence, equity IRRs hover in the range of 17%-18% and payback periods are more than ten years. Stakeholder consultations in these two states revealed that residential consumers are more likely to invest in other market instruments rather than RTPV systems because of the lukewarm financial performance.

Tamil Nadu is the state where there is no FiT scheme which lead towards the poor performance. Any excess generation at the end of a billing cycle is not considered for monetary compensation. Apart from this, the retail tariffs are also significantly lower than the LCOE of RTPV systems. Hence, residential RTPV installations in this state has a negative NPV and the payback period is never reached. Therefore, a further capital cost reduction or introduction of a FiT up to Rs. 5.5/kWh for net export will be needed to achieve a minimum equity IRR of 16% to create a viable business model.

Except Tamil Nadu, availing the MNRE subsidy leads to highly profitable business cases in the rest states with equity IRRs greater than 30% as shown in Table 2. Even with the subsidy in Tamil Nadu, residential consumers obtain payback periods of more than 15 years in the residential RTPV sector.

Commercial RTPV Systems

The installed capacities and corresponding capital costs of commercial RTPV systems without MNRE subsidy in the five states are depicted in Table 13.

A summary of the techno-economic assessment of commercial RTPV systems – LT and HT consumers – in the five states is presented in Table 2 and Table 3 respectively.

Table 2: Revenue Model for LT commercial RTPV systems (supermarket)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Rajasthan	5.34	5.4	8.75	32.86	66.61	24.08	4
Karnataka	5.11	6.61	8.49	32.54	66.33	20.64	5
Maharashtra	6.64	APPC	7.59	24.92	45.71	20.96	6
Tamil Nadu	5.56	-	8.01	23.25	38.15	26.15	6
Gujarat	5.08	APPC	4.5	19.12	26.18	4.72	8

Table 3: Revenue Model for HT commercial RTPV systems (shopping mall)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Karnataka	4.68	5.67	8.45	37.03	80.38	142.35	4
Rajasthan	4.87	5.4	8.35	36.32	77.57	154.48	4
Maharashtra	6.08	APPC	8.3	31.97	66.99	173.49	4
Tamil Nadu	5.06	-	8	26.93	48.45	183.9	5
Gujarat	4.71	APPC	4.35	22.84	35.28	38.67	6

In all four states (except Gujarat), commercial RTPV consumers (both LT and HT) have achieved grid-parity making RTPV installations viable projects for investors. Apart from LT consumers in Gujarat, all other business cases have equity IRRs greater than 30% and positive NPVs. Higher retail tariffs have also contributed in improving the business model for these consumers under NM wherein self-consumption is offset by cheaper source of electricity using RTPV. Rajasthan and Karnataka are the states with the most favourable business cases in the commercial RTPV sector followed by Maharashtra and Tamil Nadu.

In case of Gujarat where grid parity has still not been achieved, the major factor for longer payback periods and lower NPVs is the low retail tariff rate. At electricity tariffs comparable to other states (above Rs. 7.00/kWh), the bill savings create adequate revenue to render the model economically viable. Therefore, low tariffs may continue to act as a barrier for commercial consumers (both LT and HT) towards further adoption of RTPV in the state.

For consumers making use of diesel generators to compensate for power shortages, RTPV adoption holds significant importance as solar based electricity holds potential to offset diesel consumption and also turns out to be a cheaper source of electricity than diesel. The results show that the net income for prospective commercial RTPV consumers is directly proportional to the quantity of diesel abated which thereby improves business cases. The results also show that the equity IRRs for commercial consumers is much higher than that of residential and industrial consumers because of the higher retail rates in this sector.

Industrial RTPV Systems

The installed capacities and corresponding capital costs of industrial RTPV systems without MNRE subsidy in the five states are depicted in Table 14.

A summary of the techno-economic assessment of industrial RTPV systems – LT and HT consumers – in the five states is presented in Table 4 and Table 5 respectively.

Table 4: Revenue Model for LT industrial RTPV systems (packaging warehouse)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Karnataka	5.11	6.61	6.48	25.41	45.14	15.93	6
Rajasthan	5.34	5.4	6.45	24.99	43.1	18.9	6
Maharashtra	6.64	APPC	6.49	21.41	35.82	19.65	7
Gujarat	5.08	APPC	4.89	22.21	33.52	8.31	7
Tamil Nadu	5.56	-	5.98	17.56	24.12	18.8	8

Table 5: Revenue Model for HT industrial RTPV systems (ball bearing factory)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Rajasthan	4.87	5.4	7	32.88	66.64	160.79	4
Maharashtra	6.08	APPC	7.9	31.86	66.47	209.06	4
Karnataka	5.11	5.67	6.65	27.68	51.52	115.46	6
Gujarat	4.71	APPC	4.35	27.78	48.11	68.86	5
Tamil Nadu	5.06	-	6.35	22.97	37.36	170.07	6

Apart from LT industrial consumers in Tamil Nadu, all industrial consumers in the other four states have viable business cases with equity IRRs more than 30% and payback periods less than 7 years. This is again because in Tamil Nadu, any excess generation from RTPV systems at the end of the billing cycle is not considered to be eligible for monetary compensation.

Although the equity IRRs are lesser compared to commercial consumers, the business cases in all five states for industrial RTPV consumers are favourable enough considering the amount of capital involved in setting up larger RTPV systems and reducing dependency on diesel based generation.

Institutional RTPV Systems

The installed capacities and corresponding capital costs of institutional RTPV systems without MNRE subsidy in the five states are depicted in Table 15.

A summary of the techno-economic assessment of institutional RTPV systems – LT and HT consumers – in the five states is presented in Table 6 and Table 7 respectively.

Table 6: Revenue Model for LT institutional RTPV systems (govt. primary school)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Karnataka	5.11	6.61	7.61	26.82	51.31	9.86	6
Rajasthan	5.34	5.4	7	24.18	42.25	9.92	6
Gujarat	5.08	APPC	4.72	17.41	22.54	2.73	9
Maharashtra	6.64	APPC	5.9	15.75	22.47	5.08	9
Tamil Nadu	5.56	-	5.75	13.92	17.03	5.61	21

Table 7: Revenue Model for HT institutional RTPV systems (govt. arts college)

State	LCOE (Rs./kWh)	FiT (Rs./ kWh)	Retail Tariff (Rs./kWh)	IRR (%)	Equity IRR (%)	NPV (Lakhs)	Payback period (Years)
Rajasthan	4.87	5.4	7	31.62	62.94	99.97	5
Karnataka	4.68	5.67	6.4	29.11	56.12	74.54	5
Maharashtra	6.08	APPC	6.5	25.4	47.31	96.64	6
Gujarat	4.71	APPC	4.35	24.73	40.05	36.55	6
Tamil Nadu	5.06	-	6.35	22.03	34.98	104.38	6

The representative govt. primary school has a high sanctioned load compared to the actual consumption. This is because in most govt. primary schools there are hardly any heavy loads with lights and fans being the primary electrical appliances. However, the sanctioned load is kept high with the provision of allowing computers and other appliances to be installed in the near future. However, as of today, the large rooftop areas allow for larger RTPV installations and the subsequent generation significantly exceeds the consumption. Hence, Karnataka and Rajasthan have excellent business cases because of the higher NM/GM rates. However, Gujarat and Maharashtra have longer payback periods and lower equity IRRs since excess electricity is bought back by DISCOMs at APPC that is invariably lesser than the LCOE of RTPV systems. Tamil Nadu is the worst performer with payback periods crossing 20 years and equity IRRs less than 20%. This is because the excess generation at the end of the billing cycle is not considered for monetary compensation. In these three states, the FiT needs to be increased to more than Rs. 5.5/kWh to make competitive business cases for LT institutional consumers to adopt RTPV systems.

In case of the HT institutional consumer sector, the representative case is taken to be a govt. arts college which has large rooftop area and consumption commensurate to the sanctioned loads. Since the generation from RTPV systems in this sector does not exceed consumption and there is also a heavy dependence on diesel based generation which can be partially offset by RTPV, the business cases for RTPV in all the five states for HT institutional consumers is very good with best and worst equity IRRs being ~63% and ~35% respectively.

Conclusions & Recommendations

Of the 40 GW RTPV target for 2021-22, only ~1.7 GW is installed in India so far. Apart from the technical constraints, the financial aspects of RTPV systems are a concern for implementing agencies in many states in the country. The techno-economics of RTPV systems for various consumer categories in the five leading states are the focus of this research article. Conclusions and subsequent recommendations are presented in this section.

RTPV systems in urban areas reduce system congestion because of localized generation and self-consumption. Residential consumers contribute heavily to the electricity demand and a majority of the 40 GW target for India is expected to come up on domestic rooftops. However, the results of this study show that the business cases for residential RTPV systems in India are the least favourable amongst all consumer categories. Without the MNRE capital subsidy, amongst the five representative states in this study, Karnataka has the best equity IRR (~34%) with a payback period of 8 years. Rajasthan has a similar scenario with an equity IRR of ~31% and a payback period of 7 years. These are the only two states which have FiTs announced for DISCOMs to procure RTPV-based generation from consumers. Gujarat and Maharashtra DISCOMs procure excess RTPV-based generation at APPC which is lower than the LCOE of residential RTPV systems. Hence, these two states have long payback periods and lower equity IRRs. Tamil Nadu has the worst business case for residential RTPV systems (payback is not reached and NPV is negative) because there is no provision for DISCOMs to procure excess RTPV-based generation in the state. Availing the 30% MNRE capital subsidy leads to better business cases in Karnataka, Rajasthan, Gujarat and Maharashtra with payback periods dropping to less than 8 years and equity IRRs becoming more than double of what they were without the subsidy. In spite of this, Tamil Nadu still has a payback period of 15 years and equity IRR ~13%, thereby highlighting the need for a revision of the state's RTPV policy.

In order to make viable business cases for residential RTPV systems across India, states like Gujarat, Maharashtra and Tamil Nadu need to fix FiTs above Rs. 5.50/ kWh for DISCOMs to purchase excess RTPV-based generation. However, considering the poor financial health of most DISCOMs in the country, determination of a suitable FiT needs thorough analyses of the DISCOMs' finances, accurate demand forecasts, Annual Revenue Requirements (ARRs) and average realisation rates. These exercises provide the authors of this research article with future scope of work continuing from the present research on RTPV penetration in India.

Capital subsidies are usually provided to enhance the adoption rate of commercial technologies in the nascent phase of market introduction. Although the solar industry is witnessing tremendous growth in India, ~1.7 GW of RTPV installations suggest that the rooftop segment is still in its infancy and some consumer categories need the capital subsidy. However, stakeholder consultations revealed that availing the subsidy is a tedious process and prospective consumers would rather rely on attractive NM/GM rates and timely payments from DISCOMs. To make the MNRE subsidy a more effective instrument, measures need to be taken to streamline the processes to avail the subsidy and reduce the complexities which deter prospective consumers today.

Commercial, industrial and institutional consumers have lucrative business cases for RTPV adoption in most cases. The aforementioned determination of a suitable FiT for NM/GM is key to bridging the gap for LT commercial consumers in Gujarat and LT industrial and institutional consumers in Tamil Nadu.

The results of this study show that Tamil Nadu has the least favourable RTPV policy regime with no provisions for DISCOMs to procure excess RTPV-based generation. However, the maximum amount of RTPV installations in India till date are in the state, contradicting the results of this study. Stakeholder consultations revealed that 90% of these installations are installed by HT industrial consumers in the state. This shows that contrary to popular opinion, consumers who are aware of their business cases have an appetite for RTPV systems in India. The results of this study show that Karnataka's tiered FiT structure based on capacity of the RTPV system – which takes economies of scale into account – is responsible for the state having favourable business cases for all categories of consumers. This model can be replicated in other states in India to foster RTPV growth in the country.

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APPENDIX I

Table 12: Comparison of RTPV policies in different states

State	RTPV policy	Restrictions	Salient features
Karnataka [22]	Shifted to GM for domestic consumers, hospitals and educational institutions while retaining NM for industrial and commercial consumers	Not more than sanctioned load	1. Energy Accounting and Settlement: *For domestic category, hospitals and educational institutions:* GM *For industrial and commercial consumers:* NM as per the following rates:
Gujarat [23][24]	NM	Up to a maximum of 50% of consumer's sanctioned load	1. Energy Accounting and Settlement: *For net importer*: net consumption billed at existing tariff *For net exporter*: surplus energy after adjustment of consumption at the end of billing cycle shall be purchased by the DISCOM at the Average Pooled Power Purchase Cost (APPC) rate of the year in which the SPG was commissioned. Provided the consumer is not an obligated entity under RPO and does not take credit under REC mechanism. If so, then purchase price at which DISCOM buys further reduces to 85% of APPC 2. Residential & government installations qualify for DISCOM's RPO For industrial and commercial consumers, installations are credited towards meeting the consumer's RPO (if REC is not availed) and surplus credited towards DISCOM's RPO 3. CDM benefits: 100% retained by consumer
Rajasthan[25][26]	NM with FiT for exporting more than 50 units	80% of Sanctioned Load Cumulative capacity of all solar systems installed shall not exceed 30% of distribution transformer capacity.	1. Energy Accounting and Settlement *For net importer*: net consumption billed at retail tariff *For net exporter*: this is accompanied with a Feed-in-tariff of Rs.5.40/unit (without AD Benefit) and Rs. 4.85/unit (with AD Benefit) 2. RPO benefits are credited towards meeting DISCOM's RPO if eligible consumer is not an obligated entity 3. CDM benefits are retained by DISCOM provided that are passed on to the consumers through Annual Revenue Requirement (ARR)
Tamil Nadu [27]	NM with Generation Based Incentive (GBI) for domestic households	Not more than sanctioned load	1. Energy Accounting and Settlement *For net importer*: net consumption billed at retail tariff *For net exporter*: Surplus electricity fed into the grid shall be capped at 90% of the electricity consumption at the end of the settlement period. Excess energy beyond 90% cap shall be treated as lapsed 2. No CDM benefits

State	RTPV policy	Restrictions	Salient features
Maharashtra [28]	NM	Not more than sanctioned load (in kW) or contract demand (in kVA), subject to the cumulative capacity of the relevant Distribution Transformer (DT) (with a provision of ±5%)	1. Energy Accounting and Settlement: *For net importer*: net consumption billed at retail tariff *For net exporter*: Surplus electricity credits are passed on to the next billing period and purchased by the DISCOM at APPC at the beginning of the next settlement period 2. If consumer is an Obligated Entity, the solar energy generated shall be accounted to meet the consumer's RPO. If not, accounted for the DISCOM's RPO 3. RTPV systems under NM shall not be eligible for REC 4. CDM benefits are retained by the consumer

Table 13: Parameters prescribed by different SERCs for RTPV installations

Parameters	Gujarat [24]	Rajasthan [29]	Maharashtra [30]	Tamil Nadu [27]	Karnataka [31]
Capital cost (lakhs/kW) – Domestic [32]	0.47	0.54	0.54	0.65	0.50
Capital cost (lakhs/kW) – LT (Commercial, Industrial, Institutional)	0.42	0.49	0.49	0.59	0.45
Capital cost (lakhs/kW) – HT (Commercial, Industrial, Institutional)	0.38	0.43	0.43	0.52	0.40
Assumption:*Capital cost for Commercial, Industrial and Institutional consumer is assumed on the basis of the capital cost assigned for Domestic consumers. For LT category the capital cost is 90% of the cost of Domestic category and for HT category the cost is 80% of the cost of Domestic category.*					
Operation & Maintenance (O&M) (in lakhs/kW_p)	0.01075	0.007	0.01378	0.007	0.007
Annual escalation in O&M	5.72%	5.85%	5.72%	5.72%	5.72%
Insurance cost (% of net asset value)	0.35%	0.35%	0.35%	0.35%	0.35%
Capacity Utilization Factor (CUF)	19%	20%	19%	19%	19%
Degradation Factor	1%	0.8%	0.8%	0.8%	0.8%
Useful life	25	25	25	25	25
Debt : Equity	70 : 30	70 : 30	70 : 30	70 : 30	70 : 30
Loan tenure (years)	10	12	12	10 (+1)	12
Interest rate on loan	12.85%	12.76%	11%	11%	12%
Working Capital (WC) requirements	O&M for 1 month + 1-month receivables	O&M for 1 month + 2 months receivables	O&M for 1 month + 2 months receivables	O&M for 1 month + 2 months receivables	O&M for 1 month + 1 month receivables
Interest on WC	11.85%	12.26%	11.00%	11.50%	12.50%
Rate of depreciation	6% (first 10 years) 2% (next 15 years)	5.83% (first 12 years) 1.54% (next 13 years)	5.83% (first 12 years) 1.54% (next 13 years)	5.83% (first 12 years) 1.54% (next 13 years)	5.83% (first 12 years) 1.54% (next 13 years)
Salvage value	10%	10%	10%	10%	10%
Return on Equity (RoE)	14%	16%	20% (Pre-tax)	20% (Pre-tax)	16%
Discount factor	10.65%	10.78%	10.81%	9.24%	13.20%
FiT (Rs./kWh)	APPC	5.4 (without AD) 4.85 (with AD)	APPC	No FiT	Refer to Table 12

Table 14: DISCOMs chosen for analysis

State	DISCOM chosen for analysis
Karnataka	Bangalore Electricity Supply Company (BESCOM)
Gujarat	Torrent Power Limited (TPL)
Rajasthan	Jaipur Vidyut Vitran Nigam Limited (JVVNL)
Maharashtra	Reliance Energy Limited
Tamil Nadu	Tamil Nadu Generation and Distribution Corporation (TANGEDCO)

Table 15: Comparison of retail tariffs in the selected states (electricity charges per kWh)

		Karnataka [33]	Gujarat [34]	Rajasthan [35]	Maharashtra [36]	Tamil Nadu [37]
Domestic	LT	0-30 units: Rs. 3.25 31-100 units: Rs. 4.70 101-200 units: Rs. 6.25 201-300 units: Rs. 7.30 301-400 units: Rs. 7.35 401-500 units: Rs. 7.40	0-50 units: Rs. 3.20 50-200 units: Rs. 3.90 >200 units: Rs. 4.90	0-50 units: Rs. 3.85 51-150 units: Rs. 6.10 151-300 units: Rs. 6.40 301-500 units: Rs. 6.70 >500 units: Rs. 7.15	0-100 units: Rs. 1.90 101-300 units: Rs. 5.40 301-500 units: Rs. 6.80 >500 units: Rs. 8.60	0-100 units: Rs. 0 101-200 units: Rs. 3.50 201-500units: Rs. 4.60 >500 units: Rs. 6.60
Commercial	LT	0-50 units: Rs. 7.50 >50 units: Rs. 8.50	Rs. 4.50 (<15 kW)	1-100 units: Rs. 7.55 100-200 units: Rs. 8.0 200-500 units: Rs. 8.35 >500 units: Rs. 8.80	0-20 kW: Rs. 6.80 20-50 kW: Rs. 6.95 >50 kW: Rs7.60	0-100 units: Rs. 5 >100 units: Rs. 8.05
	HT	0-1 lakh units: Rs. 8.45 > 1 lakh units: Rs. 8.55	1-400 units: Rs. 4.45 >400 units: Rs. 4.35	Rs. 8.35	Rs. 8.30	Rs. 8.0
Industrial	LT	0-500 units: Rs. 5.25 >500 units: Rs. 6.50	Rs. 4.70 (<50 kW) Rs. 4.90 (>50 kW)	0-500 units: Rs. 6 >500 units: Rs. 6.45	0-20 kW: Rs. 6.0 >20 kW: Rs. 6.50	0-500 units: Rs. 4.0 >500 units: Rs. 6.0
	HT	0-1 lakh units: Rs. 6.65 >1 lakh units: Rs. 6.95	1-400 units Rs. 4.45 >400 units: Rs. 4.35	SSI: Rs. 7 MSI: Rs. 7.30	Rs. 7.90	Rs. 6.35
Institutional	LT	0-200 units: Rs. 6.50 >200 units: Rs. 7.75	0-200 units: Rs. 4.10 >200 units: Rs. 4.80	Rs. 7	Rs. 5.90	Rs. 5.75
	HT	0-1 lakh units: Rs. 6.40 >1 lakh units: Rs. 6.80	1-400 units Rs. 4.45 >400 units: Rs. 4.35	Rs. 7	Rs. 6.50	Rs. 6.35

Table 16: Installed capacities and capital costs for typical RTPV systems (LT residential consumers)

State	Maximum installed capacity (kWp)	Capital Cost (Rs. Lakhs)	
		Without subsidy	With subsidy
Karnataka	5	2.50	1.75
Gujarat	2.5	1.18	0.83
Rajasthan	4	2.16	1.51
Maharashtra	5	2.70	1.89
Tamil Nadu	5	3.25	2.28

Table 17: Installed capacities and capital costs for typical RTPV systems (LT and HT commercial consumers)

State	LT (supermarket)		HT (shopping mall)	
	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)
Karnataka	40	18.00	250	100.00
Gujarat	20	8.46	125	47.00
Rajasthan	32	15.55	200	86.40
Maharashtra	40	19.44	250	108.00
Tamil Nadu	40	23.40	250	130.00

Table 18: Installed capacities and capital costs for typical RTPV systems (LT and HT industrial consumers)

State	LT (packaging warehouse)		HT (ball bearing factory)	
	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)
Karnataka	50	22.50	300	120.00
Gujarat	25	10.57	150	56.40
Rajasthan	40	10.44	240	103.68
Maharashtra	50	24.3	300	129.60
Tamil Nadu	50	29.25	300	156.00

Table 19: Installed capacities and capital costs for typical RTPV systems (LT and HT industrial consumers)

State	LT (government primary school)		HT (government arts college)	
	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)	Maximum installed capacity (kW_p)	Capital Cost (Rs. Lakhs)
Karnataka	30	13.50	200	80.00
Gujarat	15	6.34	100	37.60
Rajasthan	24	11.66	160	69.12
Maharashtra	30	14.58	200	86.40
Tamil Nadu	30	17.55	200	104.00