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Gajjar, Jaymin; Raizada, Swasti; Kumar, Vikash et al.

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Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/econis-archiv/

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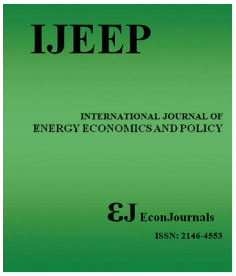

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Economic Effect of Rooftop Photovoltaic Penetration on Retail Rates of Bangalore Electricity Supply Company

Jaymin Gajjar*, Swasti Raizada, Vikash Kumar, Nikhil Abraham, Saptak Ghosh

Renewable Energy (RE) and Energy Efficiency (EE) Domain, Center for Study of Science, Technology and Policy, Bangalore, India.*Email: jaymin@cstep.in

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ABSTRACT

India has a target of achieving 100 GW of installed solar capacity by 2021-2022. Of this, 40 GW will be in the form of rooftop photovoltaic (RTPV) systems. Karnataka has an RTPV target of 2.3 GW, with its largest distribution utility – Bangalore Electricity Supply Company Limited (BESCOM) – expected to contribute 1 GW by 2021-2022. This research article focuses on the impact of this capacity addition on BESCOM's retail rate for downstream consumers considering the present RTPV policy which includes both net-metering and gross-metering mechanisms for specific consumer categories in the state. In order to conduct this exercise, the annual revenue requirement (ARR) of BESCOM has been calculated for the years 2015-2016 to 2021-2022. The projected energy demand for BESCOM in this timeframe has been estimated based on a compounded annual growth rate of 5.13%. Power purchase costs including annual capacity additions of RTPV have been obtained and these have been observed to rise from Rs. 11,750 Cr. to Rs. 19,100 Cr. in the control period. Subsequently, the average realisation rate has been computed after the ARRs for each year have been determined. The difference between average realisation rates with and without RTPV has been shown to be the impact of RTPV on BESCOM's retail rates. It has been quantified that with RTPV penetration, the increase in average realisation rate rises by Rs. 0.68/kWh to Rs. 2.32/kWh during the timeframe of seven years. In order to reduce this economic burden across consumer categories, BESCOM needs to improve its distribution network and reduce losses. Apart from this, it has been seen from global energy market dynamics that there has been a decline in PV prices and an increase in the prices of fossil fuel-based electricity. The results that have been presented in this article are likely to be offset marginally owing to these trends.

Keywords: Rooftop Photovoltaic, Distribution Companies, Net-metering, Gross-metering, Annual Revenue Requirement, Average Realisation Rate
JEL Classifications: G18, C30, Z18, H41 & H50

1. INTRODUCTION

Solar photovoltaic (PV) systems have become one of the most economically competitive renewable energy technologies in the world today. Most countries striving to combat climate change have formulated strong solar programmes with a view to curbing emissions from the electricity sector. The rapidly declining prices of PV modules and balance of system (BoS) components, the rising costs of fossil fuels and supportive policy measures to increase global demand have, for instance, led to large utility-scale ground-mounted PV reaching grid parity in Africa (IRENA 2015, 2016) and in some states in India (Moallemi et al., 2017). In developed countries in Europe, America and Australia, grid parity is expected to be attained between 2017 and 2020 as suggested by reports (Deutsche Bank, 2015; Frost and Sullivan, 2016).

However, rooftop PV (RTPV) systems continue to be more expensive than ground mounted counterparts because they lack economies of scale. Researchers have shown that without policy incentives – such as subsidies and net-metering (NM) or gross-metering (GM) in the USA (Hagerman et al., 2016), Feed in Tariff (FiT) in Germany (Renn and Marshall, 2016; Wittenberg and Matthies, 2016) and capital subsidies and GM/NM in India (Goel, 2016) – grid parity for RTPV systems is unlikely to be achieved before 2020. However, RTPV systems have the following advantages which outweigh their economic disadvantage (Ghosh et al., 2015):

- No requirement of ground-level land and a reduced gestation period
- Energy security for the consumer
- Reduced system congestion and transmission and distribution (T and D) losses because of the decentralised nature of power generation and usage
- Environmental benefits from the displacement of small-scale diesel generator sets
- Potential to drive policy changes such as time-of-use pricing.

Most countries leading globally in terms of installed PV capacity took cognisance of the aforementioned advantages of RTPV systems and modified their respective solar policies to support their growth. In Germany, for instance, more than 74% of the 40 GW solar installed capacity is on building rooftops, of which 70% are <10 kW in size and installed on residential rooftops (Indo-German Development Cooperation, 2016). In the USA, more than 11 GW of the 28 GW installed solar capacity is in the form of RTPV systems in the residential, commercial and industrial sectors (Bloomberg New Energy Finance, 2016). In Australia, more than 5.1 GW of the 5.7 GW solar installations is in the form of small-scale RTPV systems (Australian Energy Council, 2016). Other countries with significant installed RTPV capacity include Japan, Italy and China. In each of these countries, NM or FiT and/or capital subsidies formed the policy pillars for the growth of RTPV. Researchers have shown that a combination of such policies is essential to promote RTPV growth (Jacobs and Sovacool, 2012; Jenner et al., 2013; Moosavian et al., 2013). It has been shown that FiT along with other combinations has more pros than cons in terms of aiding RTPV growth while safeguarding the interests of all stakeholders (*viz*., consumers, distribution companies (DISCOMs) and government-designated nodal agencies) (Yamamoto, 2012).

However, as RTPV installations pick up pace around the globe, these policies have come under criticism because of the impacts on DISCOMs and ratepayers (Comello and Reichelstein, 2017). Through a financial model adapted from a tool called the Benefits Calculator, it has been found that because of RTPV systems, the average retail rates increase and the resulting dip in revenue for the electric utility is more than the decrease in costs, leading to a revenue erosion effect (Satchwell et al., 2015a). Regulators are considering alternative regulatory and rate-making approaches to mitigate these financial impacts, and it has been found that incremental changes to utility regulatory and business models can help in this regard (Satchwell et al., 2015b). It is thus important to first study the regulatory model being used by the concerned government agency to measure the revenue erosion effect, if any, due to RTPV penetration on the distribution utilities.

Today DISCOMs lose revenue because of addition of RTPV consumers, and in order to recover fixed costs, retail rates for non-RTPV consumers are increased. Such increases in retail rates incentivise further adoption of RTPV systems, creating a feedback loop (Darghouth et al., 2016). This feedback loop has been modelled by researchers, and it has been shown that the main factors that affect future RTPV penetration and recovery costs are the willingness of the consumers to adopt RTPV systems because of bill savings and the prevalence of existing RTPV consumers and those switching to RTPV in that particular year (Cai et al., 2013). It has also been shown that there exists an equally strong and opposing negative feedback loop to offset this domino effect. The increased PV penetration causes shifts in the timing of peak-period electricity prices leading to reduction in bill savings under NM where time-varying retail electricity rates are used, thereby hindering further PV adoption (Darghouth et al., 2016). A case study of 226 residential RTPV consumers in California – a state in USA with more than 3.5 GW of installed RTPV capacity – showed that real-time/time-of-use pricing makes it difficult to predict bill savings because of RTPV systems and adds varying retail rate structures to the list of important factors which determine RTPV adoption in the near future (Darghouth et al., 2014).

The electricity tariff along with a lump sum subsidy provided by the government also includes cross-subsidies among different consumer segments which are also affected by NM. A tariff model constructed for Southeast Queensland – a region which has witnessed one of the highest uptake rates of RTPV in the world – demonstrated that a peak capacity-based "demand tariff" is more efficient, cost-reflective and has an equitable pricing structure. This improves the stability of tariffs given a rate-of-return regulatory constraint. In case DISCOMs do not introduce these time-of-use tariffs while promoting RTPV, non-trivial cross-subsidies shall rapidly emerge leading to wealth transfers within various segment of consumers (Simshauser, 2016). The effects of NM on cross-subsidies, cost recovery and policy objectives have been highlighted in another study where it has been shown how more number of prosumers combined with NM results in reduced incomes for many DISCOMs worldwide – a reason DISCOMs might be more inclined to shift towards GM with reduced tariffs. Consequently, this transition pushes DISCOMs to increase the charges per kWh in order to recover costs. For non-RTPV owners, this could result in inequality issues due to the fact that they also have to pay higher chargers for their electricity consumed to make up for electricity exported under NM to DISCOMS by RTPV consumers. It is therefore preferable to use more explicit incentives for RTPV like GM instead of current implicit incentives like NM (Eid et al., 2014).

This paper aims to estimate the impact of RTPV penetration on the financial structure of one of India's largest DISCOMs, Bangalore Electricity Supply Company (BESCOM) in Karnataka. While much of the literature deals with how RTPV adoption rate will vary in the future because of changes in retail rate structures and positive and negative feedback loops, there is a gap in terms of available research or literature on changing retail rates based on annual RTPV targets set beforehand by the state or central government. This paper shows how retail rates will change based on the achievement of the annual RTPV capacity targets set by the Karnataka Electricity Regulatory Commission (KERC) while taking into account the existing policy regime of a combination of GM, NM and capital subsidy. The results obtained in this study have significant importance in policymaking for RTPV penetration and roadmap strategies for DISCOMs in developing countries.

2. BACKGROUND

In India, RTPV programmes are essentially state-driven, wherein state nodal agencies, State DISCOMs and state electricity regulatory commissions (SERCs) are the designated agencies for implementation along with support from ministry of new and renewable energy (MNRE) and Solar Energy Corporation of India (SECI). More than 90% of the installed 1.2 GW of rooftop installations in India till date have come through state channels. Only recently has SECI floated tenders for an additional 1.5 GW on government buildings across the country (SECI, 2016a, 2016b) with the option for vendors to avail capital subsidy from the Centre. In the states, SERCs have been given the latitude to prescribe tariff rates for RTPV systems – be it GM/NM or FiT – depending on the retail tariff structures prevalent in the state along with the financial health of the DISCOMs, the initial success of the RTPV scheme in the state and inputs from key stakeholders in industry and society.

2.1. RTPV Scenario in Karnataka

In 2013, KERC fixed the NM rate at Rs. 9.56/unit without MNRE subsidy and Rs. 7.2/unit with MNRE subsidy for RTPV system owners for excess energy being exported to the grid (BESCOM, 2014). While these rates were commensurate with the market prices for PV in 2014, they did not account for the sharp reductions in global PV module rates in subsequent years. This led to applications crossing 1.5 GW in the state in 2016 since consumers realised that their return on investment could cross 20% if planned properly. Also, there was no restriction on system size based on sanctioned load and only a cap of 1 MW per installation was imposed. The state's official target at that time was 400 MW by 2021-2022. KERC noted the discrepancies and revised the scheme, shifting domestic households, hospitals and educational institutions to a GM regime, whereas other consumers continued to be under the NM scheme with revised rates. The rates have been reduced (Table 1) based on the present market rates and a restriction has been imposed on the system size equal to the sanctioned load of the consumer (KERC, 2016b). This order makes Karnataka the only state in the country to have set in motion a policy with different rates for specific kW segments in the RTPV space. The RTPV target for the state has also been revised to 2.3 GW by 2021-2022. BESCOM has been one of the frontrunners in the state with a present installed RTPV capacity of 37 MW (BESCOM, 2017). Out of the 2.3 GW target, around 1 GW is allocated to be installed within BESCOM's service area. This research article focusses on BESCOM's RTPV targets and what will the subsequent impact on retail rate be to achieve these targets.

2.2. Preparedness of DISCOMs: A Case Study on BESCOM

BESCOM is responsible for power distribution in eight districts. It covers an area of 41,092 sq. km. and serves 1,01,46,567 consumers (a 7.43% increase over the previous year). On the demand side for FY 2015-2016, the energy sales for BESCOM was reported at 24,538.18 Million Units (MUs) out of which 18,348.38 MUs were under the metered category and the remaining 6,189.80 MUs were accounted for under the unmetered category. The distribution of sales for different types of consumers suitable for RTPV systems is given in Tables 2 and 3 summarises BESCOM's energy procurement and sales data for FY 2015-2016.

Table 1: Revised tariffs for RTPV systems in Karnataka

Capacity of RTPV and small PV power plants	Revised tariff (Rs./kWh without MNRE subsidy)	Revised tariff (Rs./kWh with MNRE subsidy)
1<kW≤10	7.08	6.03
10<kW≤50	6.61	5.63
50<kW≤100	6.14	5.23
100<kW≤500	5.67	4.83
500<kW≤1,000	5.20	4.43

On the procurement side, the total energy available for distribution stood at 29,161.67 MUs with overall T&D losses of 15.86%. Overall, this means that 4,624.08 MUs of energy did not generate any sales revenue for the DISCOM. These losses are manifested in the form of demands for retail tariff hikes sought by BESCOM from KERC (BESCOM, 2016) (Table 4).

As more domestic households shift to solar, BESCOM will have to request the regulatory commissions to allow them to raise the electricity rates to be able to recover their fixed costs. This higher electricity tariff would further incentivise more consumers to adopt RTPV systems. Since grid parity is achieved earlier for consumers falling under the higher tariff category, the utility may lose a significant fraction of their revenue share (Cai et al., 2013). This article attempts to quantify how these dynamics and feedback loops will affect BESCOM's retail rate tariff design while achieving the 1 GW RTPV target by 2021-2022.

3. METHODOLOGY

The objective of this research activity is to study the impact of RTPV penetration on retail rate design for BESCOM. This will enable the distribution utility to not only assign tariffs to its various consumer segments without giving them sudden tariff shocks, but also take into consideration the profitable operation of the utility. The demand for electricity has been increasing across all consumer segments currently served by BESCOM. Hence, the quantum of energy which will have to be purchased by BESCOM to meet the growing demand will also increase annually. This paper presents an analysis of the increase in the annual revenue requirement (ARR) for BESCOM if RTPV is incorporated in to the current power purchase mix. Also, the increase in average realisation rate, which gives the tariff increase required by BESCOM across all consumer categories for meeting the revenue gap, can be calculated from the increased ARR. A pictorial description of the methodology used in this paper is shown in Figure 1.

3.1. Tariff Determination using ARR

ARR is computed by adding the various annual costs incurred by the distribution utility (KERC, 2015). The various heads of expenditure which are added to calculate the ARR are:

- Power purchase costs
- Operation & Maintenance (O&M) expenditures
- Depreciation
- Interest & finance charges
- Regulatory assets
- Carried forward expenses from previous years, if any.

Every year BESCOM submits its petition to KERC to review the prevailing tariffs with projected expenses for the future years

Table 2: Category-wise distribution for FY 2015-2016

Type of consumer	Tariff Schedule category	Number of consumers	Percentage of total consumers (%)	Sales (in MUs)	Percentage of total sales (%)
Domestic	LT-2	68,08,445	67.1	6,027.37	24.56
	HT-4	272	0.003	96.59	0.39
Commercial	LT-3	9,44,611	9.31	1,754.07	7.15
	HT-2 (b)	5,827	0.057	2,614.90	10.66
Industrial	LT-5	1,89,452	1.87	1,150.39	4.69
	HT-2(a)	6,286	0.061	4,593.22	18.72
Institutional	HT-2(c)	533	0.005	232.53	0.95
Other Consumers		21,91,141	21.59	8,069.11	32.88
Total (inclusive of other consumers)		1,01,46,567	-	24,538.18	-

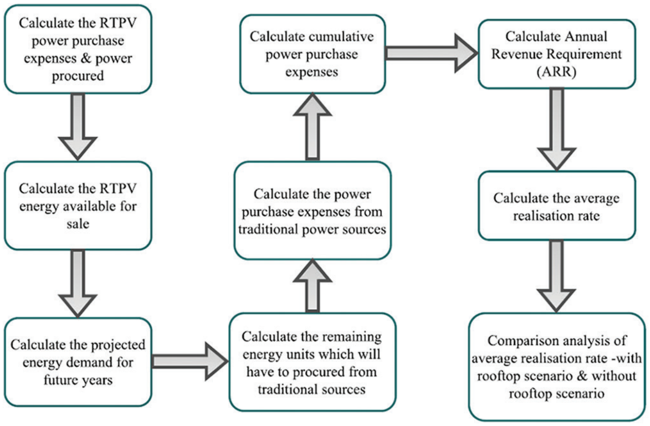
Table 3: Summary of energy procurement and sales data of BESCOM for FY 2015-2016

Total energy purchased	29,161.67 MUs
AT&C losses	4.35%
Total energy at interface point	27,893.14 MUs
Distribution losses	12.03%
Energy available for sales	24,537.59 MUs
Revenue foregone (energy in units)	4,624.08+6,189.80 (unmetered)=10,813.88 MUs

Table 4: Hike sought by BESCOM

Year	Hike Sought (Rs./kWh)	Hike Granted by KERC (Rs./kWh)
2016-2017	102 paise	48 paise
2015-2016	80 paise	13 paise
2014-2015	66 paise	32 paise

Figure 1: Overview of the followed methodology



conforming to the provisions of the Electricity Act 2003. KERC then carries out an extensive analysis of the various expenses based on the submissions of BESCOM and other letters of objections from third party (consumers) and approves acceptable expenses of each head and subsequently computes the approved ARR for the future years. KERC has approved BESCOM's ARR for the next 3 years – 2016-2017, 2017-2018 and 2018-2019 – where power purchase expenses have been calculated after taking into account conventional sources but not considering RTPV.

In order to study the impact of RTPV penetration in the retail rate design of BESCOM, a model has been developed which accounts for a certain quantity of energy units being generated from RTPV systems and the remaining demand being met through conventional sources of energy such as hydel, thermal, renewable sources, etc. Since it is safe to assume that RTPV penetration will affect the power purchase costs only, the variation in the ARR is analysed for both cases, i.e., ARR with RTPV and ARR excluding RTPV. In this article, conventional power purchase schedule in a year has been used to first find the average realisation rate for consumers for that particular year based on the approved ARR for FY 17 to FY 19 presented in the Tariff Order 2016 (KERC, 2016a) for BESCOM. At the same time, the same values of power purchase have been reduced in the aforementioned model to incorporate RTPV capacity addition. Using this second scenario, the ARR and average realisation rate have been calculated again. The difference between the two for a particular year has been shown to be the impact of RTPV on revenue realisation for BESCOM.

3.2. Calculation of ARR with RTPV

As mentioned earlier, KERC executed a mid-course revision of the 2013 tariff for RTPV and small PV power plants due to the declining costs of solar panels and its associated equipment by balancing the interests of the investors and the financial stability of the distribution utilities. The norms and tariffs decided in the new policy are applicable to all solar RTPVs and small PV power plants commissioned on and after 02.04.2016 and up to 31.03.2018 and entering into a formal power purchase agreement with state DISCOMs. BESCOM's ARR has been calculated taking this revision and the previous policy regime into account. The following steps have been taken in this research activity to build the model required to arrive at the final ARR for BESCOM:

1. Projections for annual capacity addition of RTPV till 2021-22 have been made for BESCOM after stakeholder discussions with BESCOM, KERC and Karnataka Renewable Energy Development Limited (Figure 2). These capacity addition estimates have been used in this research to enable apportionment of targets to various categories and segments of consumers.
2. Out of the 37 MW installed till date by BESCOM, 26 MW fall under the previous NM scheme, whereas 11 MW are under the present revised scheme. This distinction has been considered in the model that has been used for this analysis. Under the new policy, GM is applicable only to homes, hospitals and educational institutes, whereas NM still applies to industrial, commercial and all other categories of consumers in addition to the ones under GM. It has been envisaged that the trend of 70% of RTPV installations will come under the previous NM regime of 2016-17 based on the applications database maintained by BESCOM. Out of these installations under

the NM scheme, only 30% of the power generated has been considered for sale to BESCOM because of the restrictions on sanctioned load which prevent the consumer from exporting more electricity into the local distribution network. Henceforth, a GM-to-NM ratio of 50:50 has been assumed for these years under analysis with reference to the new policy. This assumption has been made taking into account that hospitals, educational institutions and domestic consumers contribute more than 50% to BESCOM's demand. The 30% restriction on the power exported to the grid from RTPV systems under the NM scheme has been applied to future installations as well.

3. To calculate the aggregate cost from multiple segments of consumers as mentioned under the new policy, projections have been made in terms of numbers of RTPV systems under installed capacities. Multiple scenarios of this projected capacity have been built to analyse how the aggregate cost varies in response to the different portions assigned to different segments. Data from existing installations commissioned by BESCOM in the first 2 years (2015-2016 and 2016-2017) have been used to build the base scenario. These data have then been extrapolated for other scenarios in the future. One such scenario is depicted in Figure 3. To perform a sensitivity analysis on the final results, this sample distribution has been varied by ± 10% (with steps of 5% in either way) for each size range and the corresponding ARRs have been obtained.
4. In terms of *transmission losses*, KERC's approved numbers of 3.47% for FY 17 and further reduction of 0.1% each for FY 18 and FY 19 have been considered in the calculations.

Figure 2: Annual capacity addition of rooftop photovoltaic by Bangalore Electricity Supply Company Limited

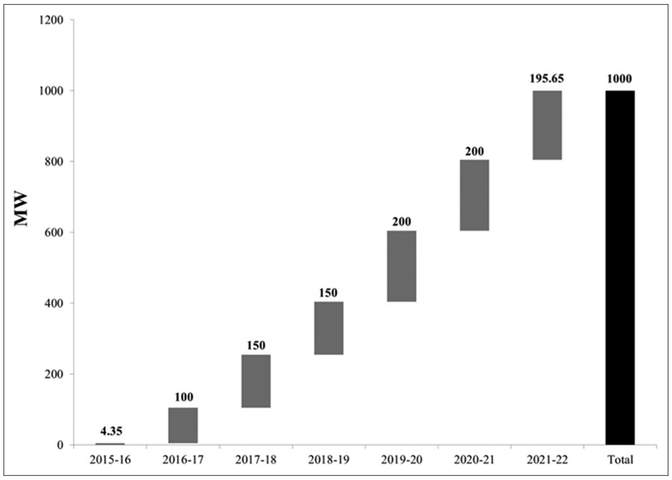
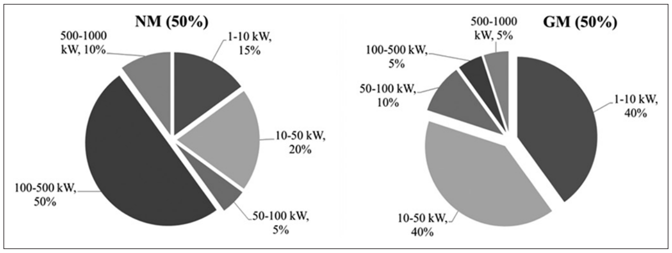


Figure 3: Scenario for distribution of rooftop photovoltaic systems based on installed capacities



Distribution losses for BESCOM have been reducing in the recent past owing to investments to strengthen the local distribution infrastructure and have dropped to 13% for FY 17 and further reduction of 0.25% each for FY 18 and FY 19 have been considered (KERC, 2016a). Total T&D losses approved by KERC have been tabulated in Table 5 and have been considered for calculating total BESCOM expenses in this article.

Since RTPV is a form of distributed generation and the final point of sale lies within the jurisdiction of the nearest substation, it has been assumed that the distribution losses for the energy generated using RTPV will reduce by a factor of 2 when compared to the overall distribution losses. This assumption has been validated by actual field data obtained from existing RTPV plants across DISCOMs in Karnataka. In this article, the net energy available for sale from RTPV systems has been calculated after deducting the T&D losses from the total generation from all projected RTPV systems in the concerned years based on the aforementioned assumption.

5. In order to calculate the *projected energy demand* from FY 17 to FY 19, forecasting has been done using compounded annual growth rate (CAGR) with the help of total number of installations and quantum of energy sold to each consumer category from FY 12 to FY 15. It has been found that the CAGRs for number of installations and energy sales in the timeframe of FY 12-FY 15 were 7.61% and 5.13% respectively (Table 6).

With the above values of CAGR, the energy demand for FY 17-FY 22 has been calculated. The energy available for sale from RTPV has then been deducted from the projected energy demand. The rest of the energy demand has been assumed to be procured from the traditional sources from which BESCOM has been purchasing in the past. In order to calculate the power purchase expenses for this power, the remaining quantum of power has been multiplied with the average pooled power purchase cost (APPC).

The total power purchase expenses have been calculated by adding the power purchase expenses for procuring RTPV-based generation and power purchase expenses for procuring other sources of energy. As the power purchase mix has been changing every year due to limited availability of hydel resources, the costs of power purchase would vary year on year depending upon the mix of power purchase from different sources. This variation has been kept out of the scope of this article.

6. Other expenses which have been considered for ARR calculations include O&M expenses, depreciation, other

Table 5: KERC-approved T&D losses for BESCOM

Year	2015-2016	2016-2017	2017-2018	2018-2019
Distribution Loss (%)	13.40	13	12.75	12.50
Transmission Loss (%)	3.80	3.47	3.37	3.27
Total T&D Loss (%)	17.20	16.47	16.12	15.77

Table 6: CAGR for total number of installations and energy sales from FY 12-FY 15

Category of consumers	Tariff	No. of Consumers (%)	Energy Sold (MUs) (%)
Bhagya Jyothi	LT1a	3.15	5.35
Domestic lighting & heating	LT2	6.98	5.83
Commercial	LT3	7.48	5.68
IP set	LT4	8.51	2.58
Industries	LT5	6.22	2.09
Water works & street light	LT6	9.56	−1.24
Temp	LT7	43.88	11.32
Water supply	HT1	15.73	7.83
Industrial	HT2A	11.25	2.15
Commercial	HT2B	9.46	1.38
Lift irrigation	HT3	13.19	30.17
Residential apartments	HT4	7.23	1.86
TOTAL		7.61	5.13

income, interest and finance charges, regulatory assets and gaps in revenues in previous years which have been carried forward for relevant financial years. These numbers have been taken from KERC's approved tariff order.

7. In terms of RTPV systems availing the central government subsidy, BESCOM databases show that <5% of the existing installations used the 30% capital subsidy because the profit margins are higher without it. This trend has been applied to future installations as well.
8. The capacity utilisation factor for RTPV plants has been taken as 19% for Bengaluru (CSTEP, 2015).

The ARR, which is the amount BESCOM needs for its cost recovery, has then been calculated by summing all the expenses. The average realisation rate has been calculated using the following formula:

$$Average\ Realisation\ Rate = \frac{ARR}{Total\ Energy\ Sold}$$

This has then been compared with the ARR for BESCOM as approved by KERC without RTPV.

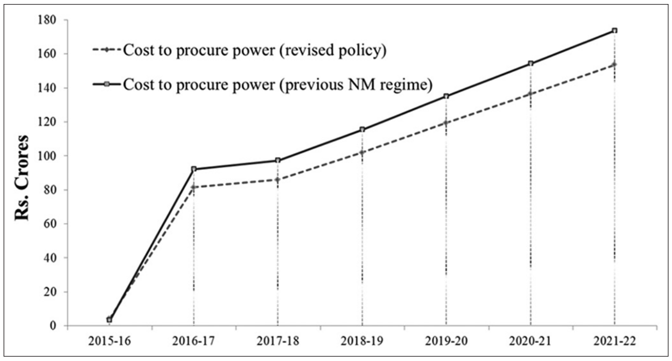
4. RESULTS AND DISCUSSION

Based on the steps described in the Methodology section, the data sets required for this article have been populated and required computations have been performed. The significant results that have been obtained in this analysis are the following:

1. With the new rates under the revised policy, it has been found that there is a reduction in the financial burden on BESCOM for achieving the same 1 GW target capacity addition when compared to the previous NM regime. This is because the NM/GM rates were reduced considering the declining prices of PV modules in the global market.

There is also a decrease in the impact of percentage of power exported to the grid from RTPV systems because of the restrictions on sanctioned load. Figure 4 shows the difference in cost to BESCOM to achieve the 1 GW target under the two regimes on an annual capacity addition basis. The findings vindicate KERC's decision to revise the state's RTPV policy to a certain extent since the difference does not exceed Rs. 20 Cr. in any year.

Figure 4: Annual costs to procure 1 GW rooftop photovoltaic -based generation for Bangalore Electricity Supply Company Limited



2. Figure 5 shows the total projected installed capacity additions of RTPV systems based on the distribution trend under NM and GM categories from 2016-2022. In these capacity additions, there is further distribution in terms of sizes of systems since the revised policy has different rates for different sizes of RTPV systems. Figure 3 shows one such distribution which has been considered for this analysis. The resultant detailed capacity additions under each size category have been depicted in Figure 6. The sensitivity analysis has been performed for these distributions in different size ranges in order to check the validity of the model used in this research activity. For the sake of representation and lucidity, all the results shown below correspond to this sample distribution. The final average realisation rates have been represented as a range taking the sensitivity analysis into account.
3. ARR with RTPV: Following the steps mentioned in the Methodology section, the power purchase costs have been computed and depicted in Table 7.

After obtaining the total power purchase cost for BESCOM, the other parameters have been applied following the steps described in the Methodology section to arrive at the ARR as shown in Table 8.

4. The average realisation rate has then been calculated by dividing the ARR by BESCOM's total energy sold to consumers. The average realisation rate for this sample case has been computed for the control period and shown in Table 9.
5. Based on the sensitivity analysis performed on the system sizes, the average realisation rate for each combination has

Figure 5: Annual capacity additions under NM/GM schemes

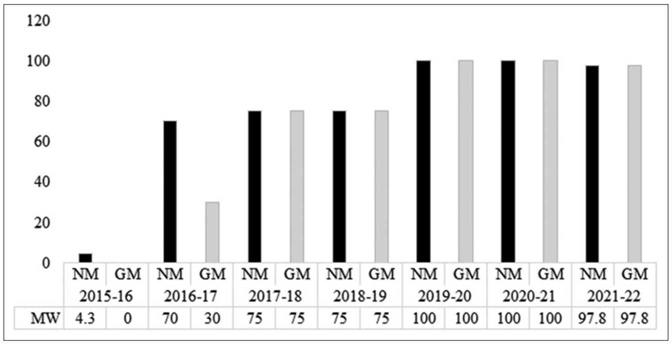


Figure 6: Sample distribution of rooftop photovoltaic annual capacity additions in different size ranges

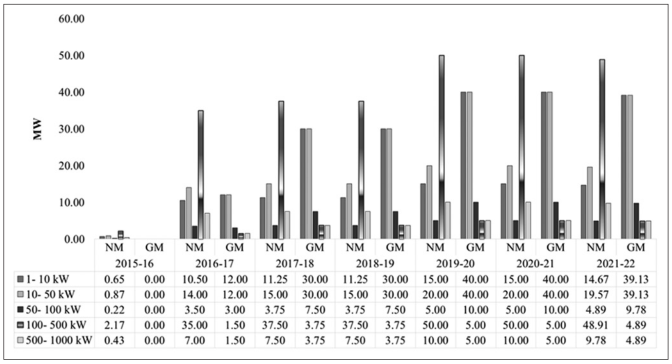


Figure 7: Average realisation rates with rooftop photovoltaic for Bangalore Electricity Supply Company Limited

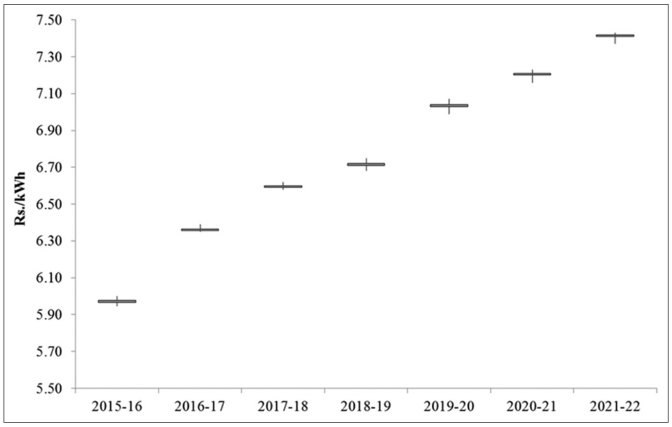
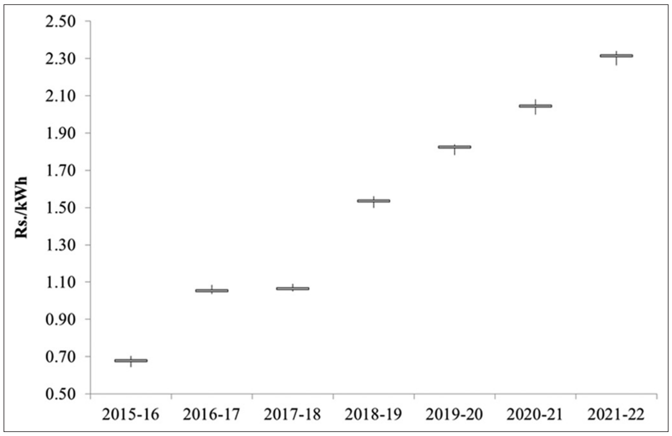


Figure 8: Differences between average realisation rates with and without rooftop photovoltaic for Bangalore Electricity Supply Company Limited



been obtained along with the difference between average realisation rates with and without RTPV. The variance between the maxima and minima has been observed and the mean value has been computed. The resultant average realisation rates and differences with and without RTPV for BESCOM have been depicted in Figures 7 and 8, respectively.

6. It can be seen from Figure 8 that there is a significant increase in the average realisation rates with increasing penetration rates of RTPV in BESCOM. It has been calculated to rise from Rs. 0.68/kWh in 2015-16 to around Rs. 2.32/kWh in 2021-22 when 1 GW RTPV systems have been installed by BESCOM (Table 10). These calculations show that the hike required in 2021-2022 will be almost 50% of the APPC of BESCOM in that year. This will translate to BESCOM seeking higher hikes in tariff from KERC and subsequently distributing the granted hikes across its consumer categories.

5. CONCLUSIONS

It has been inferred from the results from the previous section that the cumulative capacity addition of RTPV systems under BESCOM will lead to significant increases in the retail rate structure for consumers. The salient conclusions of this article have been elucidated below:

1. During 2016-22, the projected energy demand for BESCOM is expected to increase from around 26,000 MUs today to 34,750 MUs, while the total power purchase costs are expected to rise from Rs. 11,750 Cr. to 19,100 Cr. in the same time period. Assuming that the RTPV targets are met and the NM/GM ratio is adhered to, the retail rates paid by the consumer categories will increase every year with annual RTPV capacity additions. BESCOM will be purchasing only 2.17 MUs from RTPV systems today and this will go up to around 1,056.03 MUs in 2021-2022. This proves that in spite of 1 GW capacity addition of RTPV in the electricity mix, BESCOM will still be heavily dependent on conventional power sources such as thermal and hydro.
2. In order to reduce the impact of RTPV on retail electricity rates, BESCOM will need to improve its distribution network infrastructure in terms of reducing distribution losses and upgrading distribution transformers. Reduction in losses will lead to BESCOM purchasing lesser amounts of electricity in order to meet the project demands in the control period (2016-22), thereby reducing the financial burden on itself and end users.
3. Costs of fossil fuel-based electricity generation are dependent on the global market prices of coal. These costs are expected to rise in the near future (Foster et al., 2017), which means that BESCOM's APPC is likely to increase as well. On the other hand, global PV prices are declining rapidly because of the dynamics in China's module manufacturing industry (Zou et al., 2017). This trend should reflect in the reduction of the prices of RTPV systems in India, which will further encourage the adoption of RTPV systems in all consumer

Table 7: Sample power purchase cost calculations for BESCOM

Particulars	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022
Projected energy demand (MUs)	25,694.77	27,018.32	28,410.06	29,873.48	31,412.29	33,030.36	34,731.77
Electricity exported from RTPV (MUs)	2.17	87.06	249.33	411.61	627.99	844.36	1,056.03
%T&D loss for RTPV (%)	6.70	6.50	6.38	6.25	6.13	6.00	6.00
T&D loss for RTPV (MUs)	0.15	5.66	15.90	25.73	38.46	50.66	63.36
Net energy available from RTPV (MUs)	2.03	81.40	233.44	385.89	589.52	793.70	992.66
Units self-consumed by prosumer (MUs)	5.07	81.56	87.38	87.38	116.51	116.51	113.98
Energy requirement to be met through other sources (MUs)	25,687.68	26,855.37	28,089.24	29,400.21	30,706.26	32,120.15	33,625.13
Energy to be purchased (considering T&D losses) (MUs)	30,105.96	31,278.45	32,617.22	34,036.63	35,441.16	36,960.66	38,692.44
Approved cost per kWh (Rs.) (KERC, 2016a)	3.90	3.97	4.30	4.35	4.56	4.66	4.79
Power purchase cost for other sources (Rs. Cr.)	11,741.32	12,417.55	14,025.41	14,805.93	16,170.08	17,210.52	18,517.35
Power purchase cost from RTPV (Rs. Cr.)	2.08	68.90	173.56	278.23	417.78	557.34	693.86
Total power purchase cost for BESCOM (Rs. Cr.)	11,743.40	12,486.44	14,198.97	15,084.16	16,587.86	17,767.86	19,211.21

Table 8: Sample ARR calculation for BESCOM

Particulars (amount in Rs. Cr.)	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022
Expenditure							
Power purchase cost	11,743.40	12,486.44	14,198.97	15,084.16	16,587.86	17,767.86	19,211.21
Transmission charges	1,022.49	1,496.39	1,635.78	1,796.28	2,059.24	2,301.27	2,543.29
SLDC charges	14.29	11.20	9.17	13.20	14.29	15.10	16.33
O&M expenses	1,205.01	1,348.61	1,510.01	1,688.27	1,845.39	2,007.09	2,168.80
Depreciation	167.31	272.29	300.20	314.54	368.57	414.21	459.86
Interest & finance charges							
Interest on capital loans	261.59	282.24	319.09	337.99	367.38	393.83	420.27
Interest on working capital loans	287.77	306.00	323.77	342.08	360.07	378.15	396.22
Interest on consumer security deposits	244.89	257.45	280.70	303.95	323.34	343.52	363.71
Other interest & finance charges	7.63	10.19	10.19	10.19	11.12	11.85	12.58
Less interest & other expenses capitalised	50.00	80.00	82.00	86.00	98.37	109.04	119.70
Total interest & finance charges	751.88	775.88	851.75	908.21	963.53	1,018.30	1,073.08
Other debits	1.00	-	-	-	-	-	-
Less other income	219.44	191.80	213.00	223.00	209.16	210.77	211.96
Deficits for previous year	367.33	11.21	-	-	-	-	-
Regulatory asset	305.50	541.97	-	-	-	-	-
Annual Revenue Requirement	15,358.77	17,199.00	18,759.42	20,074.49	22,111.13	23,811.92	25,776.05

Table 9: Sample average realisation rate calculations

Particulars	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022
ARR (with Rooftop Solar) (Rs. Cr.)	15,358.77	17,199.00	18,759.42	20,074.49	22,125.42	23,811.92	25,776.05
Energy sold (MUs)	25,694.77	27,018.32	28,410.06	29,873.48	31,412.29	33,030.36	34,731.77
Average realisation rate (Rs./kWh)	5.98	6.37	6.6	6.72	7.04	7.21	7.42

Table 10: Sample increase in average realisation rate because of RTPV penetration

Average revenue realisation rate (Rs./kWh)	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	202120-22
With RTPV	5.98	6.37	6.60	6.72	7.04	7.21	7.42
Without RTPV	5.29	5.31	5.53	5.18	5.21	5.16	5.10
Difference	0.68	1.06	1.07	1.54	1.83	2.05	2.32

categories. Although it has not been considered in the scope of this research article because of the volatility of prices of both coal and PV modules, it is expected that the combined effects of these two trends will lower the ARRs and subsequently the average realisation rates (Table 10) for BESCOM with RTPV under the current policy regime.

4. The present RTPV policy regime in Karnataka with the revised NM/GM rates is valid till March 2018 after which the state's solar policy will be revised based on market conditions and targets. It is envisaged that the tariffs will fall in alignment with global PV prices, which means that the power purchase costs for procuring RTPV-based electricity will reduce for BESCOM. This means that the ARRs and average realisation rates will reduce further, making RTPV systems a viable option for BESCOM as well as consumers. Hence, the estimates of increasing ARRs and average realisation rates with RTPV for BESCOM will be offset by a certain extent because of global market dynamics of both conventional and renewable energy sources, as well as revisions in state-level RTPV solar policy.

5. The trends observed in this article in terms of RTPV penetration leading to increased ARRs and average realisation rates for BESCOM are applicable to all other public DISCOMs in India as well. It is expected that there will be an increase in both, which will be abated by rising coal prices and declining PV prices, and the additional costs will be passed on to the consumers by the respective DISCOMs. This essentially means that non-RTPV consumers (both society and industry) will have to pay in terms of increased tariffs instead of the upfront capital investments borne by RTPV consumers. The policy framework within which this transition into cleaner sources of energy – in this case RTPV – will occur needs to ensure equitable distribution of the financial burden among all categories of consumers as well as DISCOMs in the near future.
6. Our future work concerning RTPV solar policy in Karnataka involves the preparation of a roadmap for achieving the 1 GW target for BESCOM taking into account the impact on retail rates as studied in this article. A tool to accurately assess the potential and techno-economics of BESCOM consumers is being developed, which will also consider BESCOM's distribution network and provide recommendations for upgradations wherever required. Policy aspects such a revision of sanctioned load and NM/GM restrictions are also being explored in this context.

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