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Financial Implications of Rooftop Solar Penetration in Sri Lanka from Utility Point of View

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Abstract: Solar is one of the fast growing and economical renewable power generation sources. The intention of development of solar power generation is to promote clean energy while addressing the basic requirement of uninterrupted and reliable electricity supply.

The Sri Lankan government decided to adopt a policy that would use subsidies to encourage the growth of solar PV-based electricity. As a result, the market developed with a large number of customers eager to install solar rooftop systems, and they received strong assistance from solar power service providers. Hence, the utility is required to absorb the solar energy produced and this study focuses on the impact of solar penetration to the utility.

System dispatch data for year 2019 and rooftop solar generation data for a period of 6 months of year 2019 were considered for the analysis in this paper. The model compares the financials of two scenarios to estimate the impact to the utility. The base case scenario, which is business as usual with the already installed solar generation in the system and No solar scenario which assumes that there is no solar in the system and therefore the demand is met by other available generation capacities in the system.

This paper examines the two scenarios with careful calculations of how the system can still run without solar in the system. Daily demand patterns were also analysed and then expanded to months and summarized for the year. This research focuses the financial impact of solar electricity penetration to the national grid and how everyone can still be benefitted.

Keywords: Renewable energy, Solar rooftop, Subsidy, Distributed generation, Financial sustainability

1. Introduction

It is important to have an uninterrupted, economical, and reliable electricity supply contributing to economic and social development of a country. Due to the environmental impacts of fossil fuel based conventional power generation, the world is moving towards power generation from renewable sources like wind, solar, bio-mass etc.[1]. Solar is one of the fast growing and economical renewable power generation sources. The intention of development of solar power generation is to promote clean energy while addressing the basic requirement of uninterrupted and reliable electricity supply [2].

Going with world trend, the Government of Sri Lanka promotes the development of solar PV based electricity through subsidies. Hence, the market graduated with many consumers willing to install solar rooftop and they were ably supported by solar power service providers. On the other hand, the utility is obliged to absorb the solar power generated as per the different subsidized schemes available. The benefit for the utility is that the expensive oil-fired generation during the day demand can be reduced. However, in contrast, the utility needs to maintain sufficient capacity to compensate the intermittent and non-dispatchable electricity generation [3].

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Despite the numerous initiatives introduced by the Government of Sri Lanka and the Ceylon Electricity Board(CEB), there is enormous potential to develop more solar energy to support the growing energy demand[4]. CEB has been criticized for been slow in absorbing renewable energy and having many barriers. Reasons for slow progress emphasized by CEB are the technical constraints and the higher tariff of renewable energy.

Although, extensive research had been carried out on challenges and opportunities due to the technical constraints of solar power generation, a few studies have been carried out examining the financial and economic impact of solar penetration to the national grid [5][6][7].

The question of whether the solar generation can resolve the energy demand at the lowest cost and at the minimum burden to the economy is unanswered.

This research focuses on to assess the financial impact of solar electricity penetration to the national grid. The study discusses the direct impact to CEB due to solar penetration and the impact to CEB revenue from the solar generating consumers. The study recommends changes required to the solar tariff and also the changes required to the tariffs of Rooftop Solar (RTS) consumers.

2. Methodology

This study is focused on to estimate the financial impact to the national utility, CEB in Sri Lanka, due to penetration of solar generation in the system. The study contains two parts:

- Financial impact due to the cost of generation.
- Financial impact due to the loss of revenue from solar rooftop customers.

To estimate the financial impact to CEB due to the cost of generation, the study compares two scenarios of the typical demand curve.

Base case scenario

Base case scenario is the typical demand curve of a day as shown in Figure 1. The supply is dominated by hydro, coal and other thermal which includes CEB as well as Individual Power Plants(IPP). There is a considerable solar generation meeting the demand during the day.

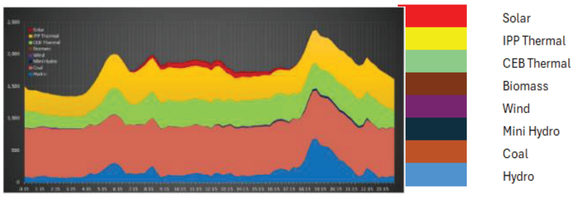

Figure 1 - Base Case Scenario (Typical Demand Curve)

No solar scenario

The contribution from the solar generation is displaced using the other sources of generation in the "No solar scenario" as shown in Figure 2. Merit order dispatch of CEB is used to displace the solar generation.

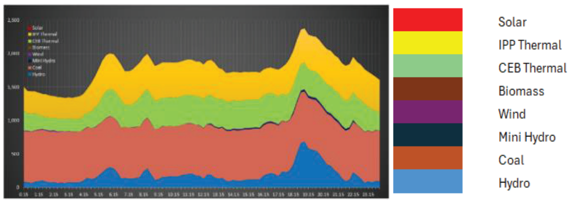

Figure 2 - Solar is Replaced by other Generation

Financial Impact due to the cost of generation

Analysis for a day

The financial impact is calculated for a day based on the following methodology.

Actual generation data of each 15-minute interval from each generator is tabulated and categorized under different generation type (hydro, coal, other thermal, mini hydro, biomass, wind, solar and rooftop solar) and also according to the ownership (CEB or IPP). Actual data of rooftop solar generation for 15-minute interval is not available, therefore an assumption-based calculation is used.

For base case scenario, the total cost of generation of the day is calculated as a product of energy from different types of generators multiplied by unit cost of each generator.

For no solar scenario, the generation of solar is displaced from other available generators (the generators which are not fully dispatched), based on the merit order dispatch. The displacement methodology (displacement calculation) is explained in the next section. After the solar generation (ground mounted solar and rooftop solar) is displaced from other generators, a revised generation for each 15-minute for each generator is tabulated. The total cost of generation for no solar scenario is then calculated as product of energy from different types of generators multiplied by unit cost of each generator.

The costs of two scenarios are compared to assess the impact to the utility. Flowchart in Figure A1 in Appendix A depicts the basic aspects of the methodology.

Displacement calculation
The displacement calculation is only relevant to the no solar scenario. The model considers each 15-minute interval for the solar displacement calculation. The main purpose of the model is to see how the demand can be met if solar generation is displaced. This displaced generation from solar will be loaded to thermal and hydro power plants based on the merit order and the available capacity of each generator in the merit order. The following steps are used in the displacement calculation. Figure A2 in Appendix A flow chart shows the methodology of displacement calculation.

- The maximum capacity for each generator (thermal and hydro) is disregarded, and the maximum generation within the day for each plant is considered. This is to factor in any technical limitations in loading generators up to the maximum capacity for that particular day. These limitations could be the technical capacity constraints in the generator itself or network constraints.

- Generation plants which were not dispatched during the day were not considered to displace solar generation. It is assumed that there could have been technical reasons for not loading these plants during the particular day.

- If a generation plant is loaded up to 95% of the maximum generation capacity during the 15-minute interval, these plants are not used to allocate additional load. It is assumed that there could be technical or unavoidable reasons for not to load up to 100%. Only the generation plants loaded below 95% are considered to displace the solar generation.

- Once these filters are completed, the rest of thermal generators are loaded according to the merit order up to the maximum generation of the day.

- If the full solar capacity cannot be allocated using thermal generators, dispatchable hydro plants are also considered for loading.

- When hydro plants are considered for additional loading, the marginal cost of the system at that 15-minute interval is considered as the cost of hydro, but not the real cost of hydro.

Analysis for a month
The model considered weekdays, Saturdays, Sundays and holidays to get a probable sample of demand types. Based on the sample days selected, the financial impact is extrapolated for a month. The comparison of the two scenarios is presented as the impact to the utility. This methodology is repeated for 12 months of 2019.
Assumptions

- Maximum generation of a particular generator during the day is considered the maximum possible capacity.
- If the generators are loaded up to 95% of the maximum capacity, the generators are not loaded further for "no solar scenario".
- Actual solar rooftop data for each 15-minute interval is not available to be fed into the model. However, the total monthly rooftop solar energy generation data is available. Therefore, generation curve of ground mounted solar generation is assumed as similar to the rooftop generation curve and the monthly total solar rooftop energy generation is matched with actual data.
- The priority to dispatch generators will be based on the type of month.
- For thermal dominant months, thermal generators are displaced on the "base case scenario" to absorb solar before hydro generators are dispatched.
- For hydro dominant months, hydro generators will be dispatched before thermal generators are considered for replacement.

Financial impact due to the loss of revenue from rooftop solar consumers

There are three schemes: Net metering, Net accounting and Net Plus.

Net metering: This model allows customers to offset the consumed electricity with the electricity they generate from their rooftop solar systems. At the end of monthly billing cycles, if the customers consume more than they have generated from their rooftop solar systems, they are billed at the electricity tariff rates based on their net consumption level. If the customers generate more electricity than they consume, the electricity surplus balance is carried over to the next month. The surplus balances can be kept for up to 10 years.

Net accounting: This model allows customers to be paid in cash for any surplus they generate at the end of their monthly billing cycles at the following rates: (a) year 1 to year 7 at LKR 22.0/kWh, and (b) year 8 to year 20 at LKR 15.5/kWh.

Net plus: This model allows customers to separate electricity consumption and electricity generation. The customers pay for the electricity they consume based on the existing tariff structure. At the same time, the customers can also sell whatever electricity they generate from their rooftop solar photovoltaic systems at the following rates: (a) year 1 to year 7 at LKR 22.0/kWh, and (b) year 8 to year 20 at LKR 15.5/kWh.

The study considered a sample of 168 consumers of net metering and net accounting schemes, using available data for 2019, to calculate the revenue impact to the utility from the rooftop solar consumers.

The electricity bill, based on the net consumption is compared with the electricity bill, if the total consumption is billed without considering the solar generation. This difference is averaged to the number of units generated for all the 168 samples. Average revenue loss per unit generated has been used to calculate total revenue loss for the utility.

Monthly actual bill, actual number of units imported, and actual number of units exported are considered to calculate this average revenue loss per unit generated.

Distribution network loss factor for rooftop solar generation was obtained from the utility and factored into the model. Inhouse consumption from the self-generation during the day, is also factored in the calculation and was assumed as 25%. It is also assumed that 40% of the solar rooftop capacity as net plus scheme. Therefore only 60% of the total solar energy is considered to calculate the revenue loss to CEB from the rooftop solar consumers. Figure A3 in Appendix A flow chart presents the methodology of revenue loss calculation.

3. Analysis

There are two parts to this analysis.

1. The impact on generation cost due to solar penetration.
2. The impact due to revenue loss from solar rooftop customers

The Impact of Solar in the Generation

Data sheet

Data sheet changes monthly and consists of the variable data for the daily and monthly analysis. It gives the details such as, type of month of the hydro generation, estimated hydro capacity, unit cost of the rooftop solar[8], rooftop solar distribution loss, average rooftop solar capacity for the month, etc. Table 1 is a sample of data sheet in the model.

Table 1 - Data Sheet

Month	January
Year	2019
Loading Factor	0.95
Type of Month	Average Hydro
Hydro Max Capacity (MW)	1000
Rooftop Solar Unit Cost (LKR/kWh)	22.00
Rooftop PV Capacity (MW)	60

Other important data of the data sheet is the merit order of the thermal plants and the cost of unit generated for the particular month for each thermal plant obtained from CEB, given in Table 2[9]. It is visible that the merit order starts with low-cost thermal generators and gradually ends up with high-cost thermal generators. The merit order derived based on the lowest marginal costs.

Table 2 - Merit Order per a Sample Month

Merit Order	Type	Complex	Plant Name	Max Capacity (MW)	Unit Cost (LKR/kWh)
1	Coal	CEB	Lakvijiya 03	270	7.82
2	Coal	CEB	Lakvijiya 02	270	7.86
3	Coal	CEB	Lakvijiya 01	270	8.17
4	Thermal	CEB	Sapugaskanda B	72	20.80
5	Thermal	CEB	Barge	60	21.31
6	Thermal	CEB	KCCP (GT)	110	22.15
7	Thermal	CEB	KCCP (ST)	55	22.15
8	Thermal	IPP	Sapugaskanda A	72	22.21
9	Thermal	CEB	Uthuru Janani	24	22.41
10	Thermal	CEB	Sojitz	163	22.83
11	Thermal	IPP	West Coast	270	24.43
12	Thermal	IPP	ACE Embilipitiya	90	24.84
13	Thermal	IPP	KPS(GT7)	115	36.84
14	Thermal	IPP	KPS (GTT)	51	48.10

According to the analysis for year 2019, CEB would have spent additional 603 million LKR for generation in the year 2019, if solar was not available in the system. However, revenue loss to the CEB due to shifting their high paying customers to prosumers is 4 billion LKR. Thus, there is a net financial loss to CEB due to rooftop PV customers of 3.4 billion LKR.

Sensitivity Analysis

A sensitivity analysis was carried out to analyze the capacity variation, cost variation, net plus ratio variation and the distribution loss variation.

Sensitivity analysis for solar capacity changes

Sensitivity analysis was conducted to observe the impact if the solar rooftop capacities are changed. An additional 25% and 50% of solar rooftop capacities were considered, but a negative change is not considered for obvious reasons. Additional solar rooftop capacities result in an increase in the profit from the generation, but also increases the revenue loss from the solar rooftop customers. The net negative impact (loss) increases when the solar rooftop capacity increases. The specific impact is presented in Table 3 and Figure 3.

Table 3 - Sensitivity Analysis for Solar Capacity

	Base Case	Solar RT Capacity (+25%)	Solar RT Capacity (+50%)
Generation Profit / Loss (LKR)	603,121,992	907,666,664	1,241,837,434
Revenue Loss (LKR)	(4,038,504,815)	(5,048,131,018)	(6,057,757,222)
Total Benefit / Loss (LKR)	(3,435,382,823)	(4,140,464,354)	(4,815,919,788)

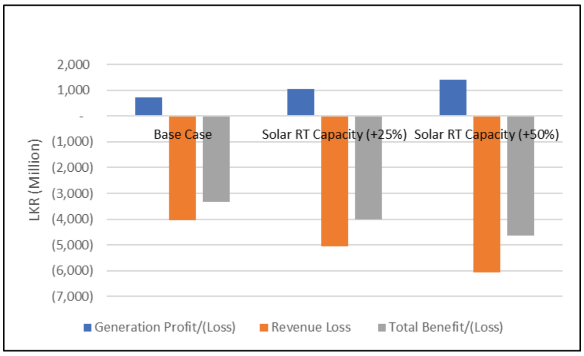

Figure 3 - Sensitivity Analysis for Capacity

Sensitivity analysis for costs

Sensitivity analysis was conducted to observe the impact if the solar rooftop costs are changed. Cost increase of 10% and 20% and cost decrease of 10% and 20% from the base case were considered. Decrease of unit cost decreases the generation cost and overall loss to the utility reduces. The specific impact is presented in Table 4 and Figure 4.

Table 4 - Sensitivity Analysis for Solar Costs

	Base Case	Cost -20%	Cost -10%	Cost +10%	Cost +20%
Generation (Profit/Loss)	603,121,992	1,441,964,996	1,022,543,494	183,700,490	(235,721,012)
Total (Benefit/Loss)	(3,435,382,823)	(2,596,539,819)	(3,015,961,321)	(3,854,804,325)	(4,274,225,827)

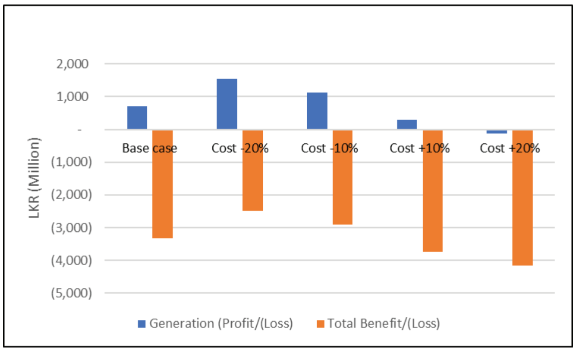

Figure 4 - Sensitivity Analysis for Costs

Sensitivity analysis for net plus scenario

A sensitivity analysis was conducted to see the impact of net plus capacity ratio. For the base case scenario, considered 40% as the net plus customers (60% other two schemes) from the total rooftop generation (based on the received data from the utility). Then conducted the sensitivity analysis for 20% to 80%. It was observed that increasing net plus ratio minimized the overall loss to the utility and the impact is presented in Table 5 and Figure 5.

Table 5 - Sensitivity Analysis for Net Plus Ratio

	Net plus 20%	Base case Net plus 40%	Net plus 60%	Net plus 80%
Revenue Loss (LKR)	(5,384,673,086)	(4,038,504,815)	(2,692,336,543)	(1,346,168,272)
Total Benefit / Loss (LKR)	(4,672,570,497)	(3,326,402,225)	(1,980,233,954)	(634,065,682)

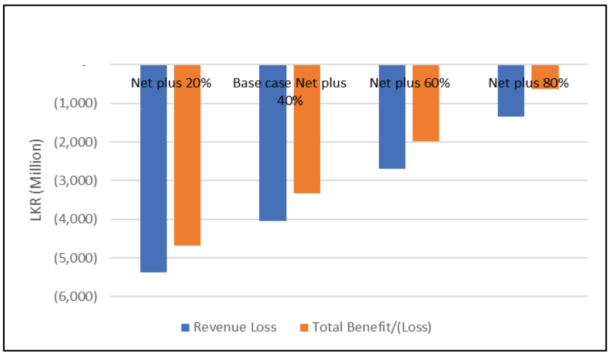

Figure 5 - Sensitivity Analysis for Net Plus Ratio

Sensitivity analysis for Network loss

A sensitivity analysis was conducted to observe the impact from the possible network losses. It was assumed that the network losses would be 2% in the base case scenario and varied the network loss up to 6% and calculated the total benefit or loss to the utility. The results are presented in Table 6 and Figure 6.

Table 6 - Sensitivity Analysis for Network Loss

	Base case (2%)	Network loss 4%	Network loss 6%
Generation Profit/Loss (LKR)	603,121,992	494,257,479	385,700,341
Total Benefit/Loss (LKR)	(3,435,382,823)	(3,544,247,335)	(3,652,804,474)

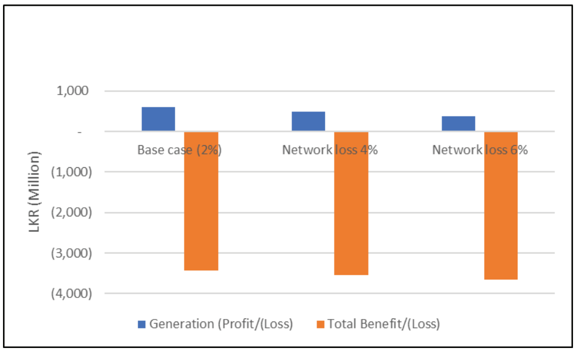

Figure 6 - Sensitivity Analysis for Network Loss

4. Conclusion

The conclusion from the study mainly highlights that solar penetration is beneficial to the utility to displace the existing high-cost generation. However, CEB loses revenue from the existing consumers once they move onto solar rooftop with net metering or net accounting schemes. As a summary of the study, CEB would have spent additional Rs. 603 million for generation in year 2019, if solar was not available in the system. The revenue loss to the CEB due to consumer transitioning to rooftop solar is Rs. 4 billion and the net loss therefore for CEB is Rs. 3.4 billion in year 2019.

From the sensitivity analysis for changes in the installed solar capacity, the results confirm higher penetration of rooftop solar benefits CEB in reducing the generation cost.

It can be recommended to allow solar rooftop with net plus scheme, as it does not alter revenue from the consumption, and to impose a service charge and impose mandatory Time of Day tariff for net metering and net accounting consumers to overcome the negative impact to the utility.

The current net accounting scheme facilitates offsetting energy imports against exports rather than the monetary value of imports and exports. In order to create a win-win for both the utility and prosumers, this scheme can be amended to offset just the actual consumption within the facility and generate revenue for the total exported energy to the grid at the present net plus rates. Accordingly, the imports will be charged at the standard electricity tariff applicable to the facility. At the end of the billing cycle the net value of cost of imports and income from exports will be the payment pending to/from the utility.

It can be further recommended that if Net Metering scheme is to continue, CEB needs to impose a service charge. For example, rather than crediting the net balance of units to a net metering customer, CEB can retain 25% of the units as their network operating costs.

However, with the present economic situation of the country, there are many reasons to promote distributed roof top solar generation, however the tariff regime needs to carefully consider the impact to the utility and to minimize the revenue loss to the utility and also to consider the escalations of capital expenditure.

(Note: All the costs and tariffs used in the study are those of year 2019)

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Appendix A

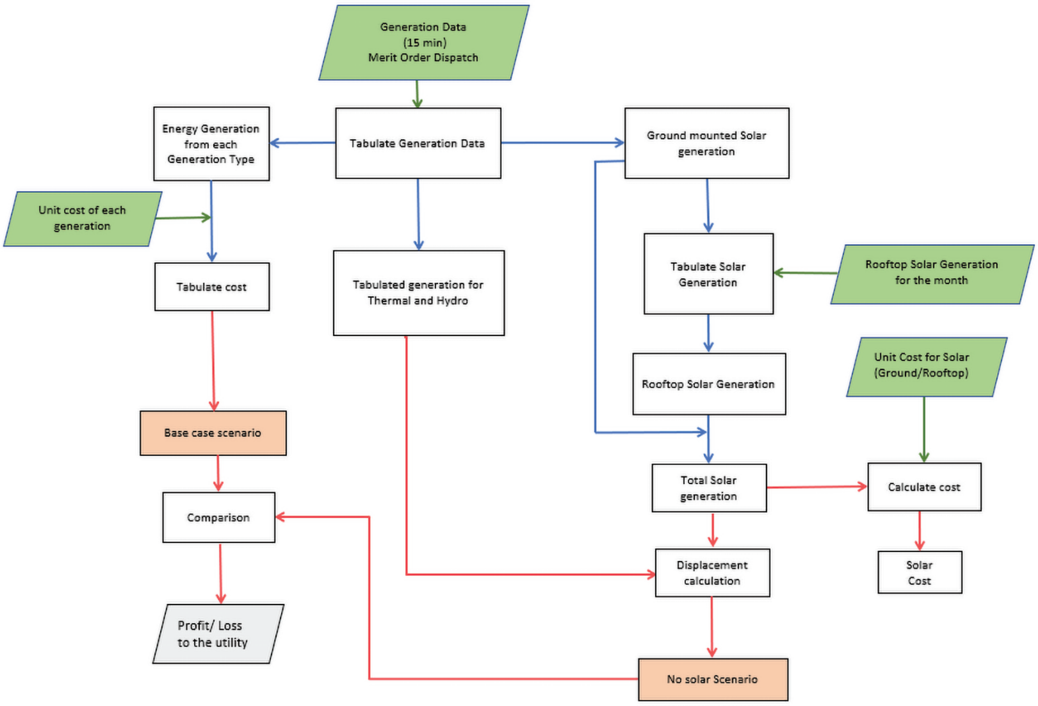

Figure A1- Flow Chart - Analysis for a Day

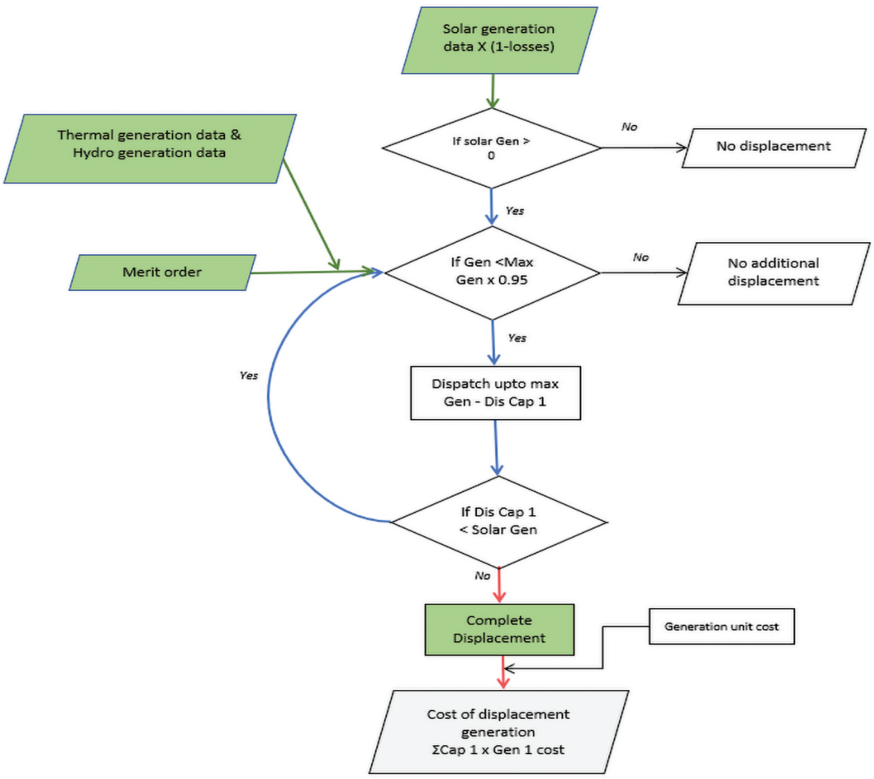

Figure A2 - Flow Chart - Displacement Calculation

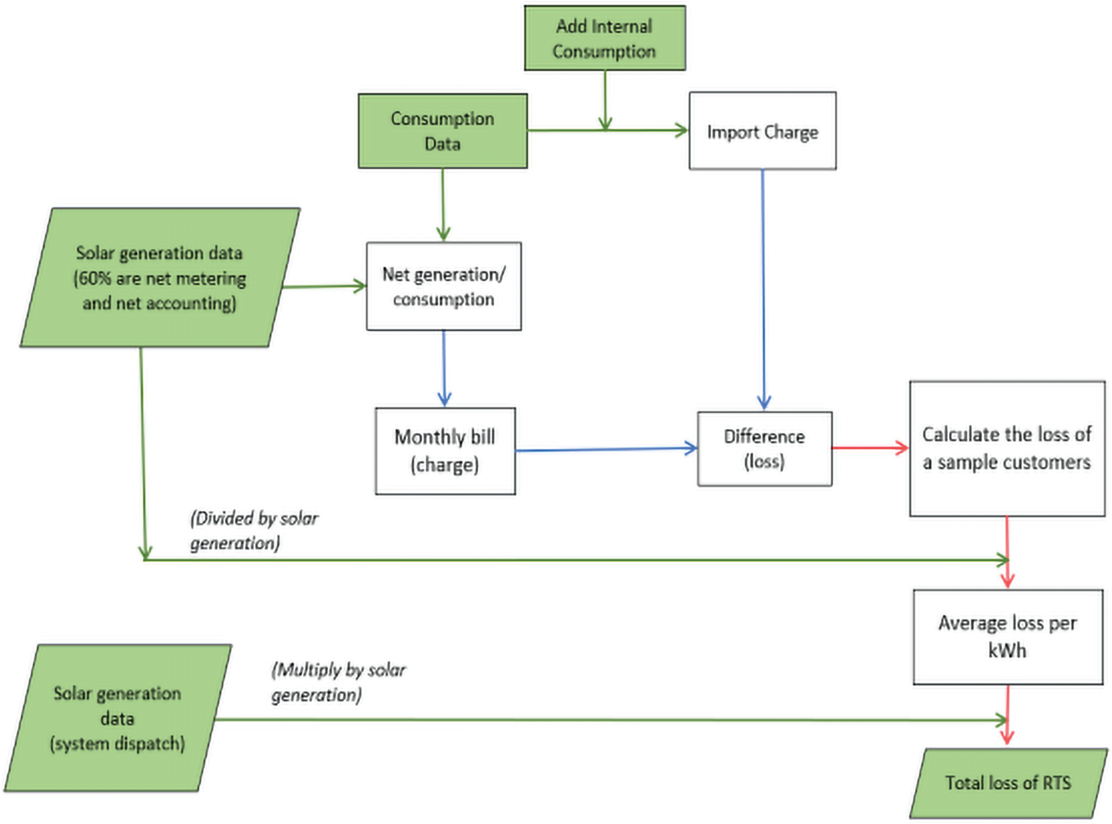

Figure A3 - Flow Chart - Revenue Loss Calculation