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Estimating the economic potential of PV rooftop systems in South Africa's residential sector: a tale of eight metropolitan cities

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Abstract: The cost of producing electricity with solar photovoltaic (PV) has decreased drastically in the past 10 years, so much that the installed PV capacity has increased exponentially between 2010 and 2018. South Africa is endowed with a technical potential of 72 GW for PV rooftop systems, but the economic potential is largely unknown. As a result, the integrated resource plan assumes that an annual installation of 200 MW of distributed generation will be made between 2018 and 2030. This study evaluates the economic potential of rooftop PV systems in the residential sector within metropolitan cities in South Africa using financial metrics. The important financial metrics used to qualify an investment are net present value, internal rate of return (IRR) and payback period. An investment is expected to pay itself back in less than 10 years with a high rate of return (IRR). Households are classified into living standards measure so that it is easier to map customers to related tariffs. Using this method, the eight metropolitan municipalities will have PV economic potential of 11 GW in 2019 and 22.7 GW by 2030 if the current tariff grows at 5% and the tariff structure does not change.

1 Introduction

Solar photovoltaic (PV) is one of the most promising electricity-producing technologies [1]. Globally, PV installed capacity has reached over 509 GW by the end of 2018 and is projected to reach the highest level of 1600 GW by 2023 if current policies in different regions of the world continue [2]. Relative to the world, South Africa has an installed PV capacity of 1.5 GW at utility-scale as of 2018, and at the distribution level (decentralised systems – feeding power into distribution grid), 0.3 GW is installed [3].

Despite the fact that the low levels of installed distributed PV, a study conducted by the Council for Scientific and Industrial Research (CSIR) and Fraunhofer estimated that there is a technical rooftop potential of 72 GW in South Africa [4]. This technical potential capacity was estimated using population density, irradiance levels, space requirement of the installations and settlement areas suitable for fixed tilted PV rooftop systems. A similar method was applied to estimating the PV potential in China [5–8]. The examples of rooftop PV systems that were included as part of the study are presented in [9, 10].

The technical capacity or potential of PV rooftop systems found in [4] does not give an indication of how much capacity households and or businesses can install on their rooftops. To understand the installable capacity of rooftop systems, further studies are required. Similar to conducting the integrated resource planning (IRP) when planning for inclusion of PV systems at utility-scale as shown in [11–14], there is also a need to conduct optimal or economic capacity that is deployable for distributed PV rooftop systems. Estimating the economic potential for rooftop systems is crucial to inform policymakers so that conducive policies can be drafted if this capacity is significant and can be used to contribute to the emission reduction targets.

At the utility-scale, the process of estimating economic potential is through IRP planning process, which determines techno-economic electrical capacity that can be deployed in a country or region [11–13]. Assessing theoretical energy resource potential serves as a critical input for IRP planning together with technical limitations and costs (investment and operating) for any technology that is considered as a part of the mix. The theoretical resource is usually shown in energy resource maps such as solar and wind atlas maps [4, 6–9]. In estimating the economic or optimal capacity deployment, tools like PVSyst are used to assess solar resource potential.

For individual customers, the IRP process does not apply unless a customer has a significant demand, which can be met with a diverse mix of technologies. Senatla and Mushwana [14] used IRP to assess the electrical capacity mix for a commercial entity because this specific customer had a peak load of 7 MW, which can be met with diverse energy resources. Usually, customers develop business cases to understand the economics and financial flows of energy projects in which they can invest. This is to make sure that the investments make economic and financial sense and there is a return on the investment made.

Given that Massachusetts Institute of Technology (MIT) in 2011, predicted that the future grid would be more and more decentralised [15]; this is currently a reality as regions such as South Africa experienced ten times more growth for distributed/decentralised PV systems from 2011 to 2018 [3]. In 2011, about 30 MW of decentralised PV was installed [3], and by 2018, this capacity had increased to around 300 MW. This transition is occurring all over the world as presented in [8, 16–22]. Therefore the role of distributed technologies within the grid can no longer be ignored anymore. To make sure that countries, utilities and regulators are prepared for the surge of distributed technologies, proper planning must take them into consideration. The most prominent distributed technology is PV rooftop systems [19, 23].

Several customers are currently making individual decisions on whether to install PV rooftops or not. This behaviour is likened to that of autonomous agents within the ecosystem [24]. The common determining factor amongst all these customers is the good financial performance of the investments [25]. The collective decisions of these customers and agents will result in the aggregated distributed capacity of rooftop PV systems. This aggregated capacity is called economic potential of PV rooftop systems in a given area, because it is the capacity that makes economic sense to be installed. Instead of tracking these installations as an ex-post analysis, consistent effort must be made to plan for them before they occur (ex-ante analysis), given the

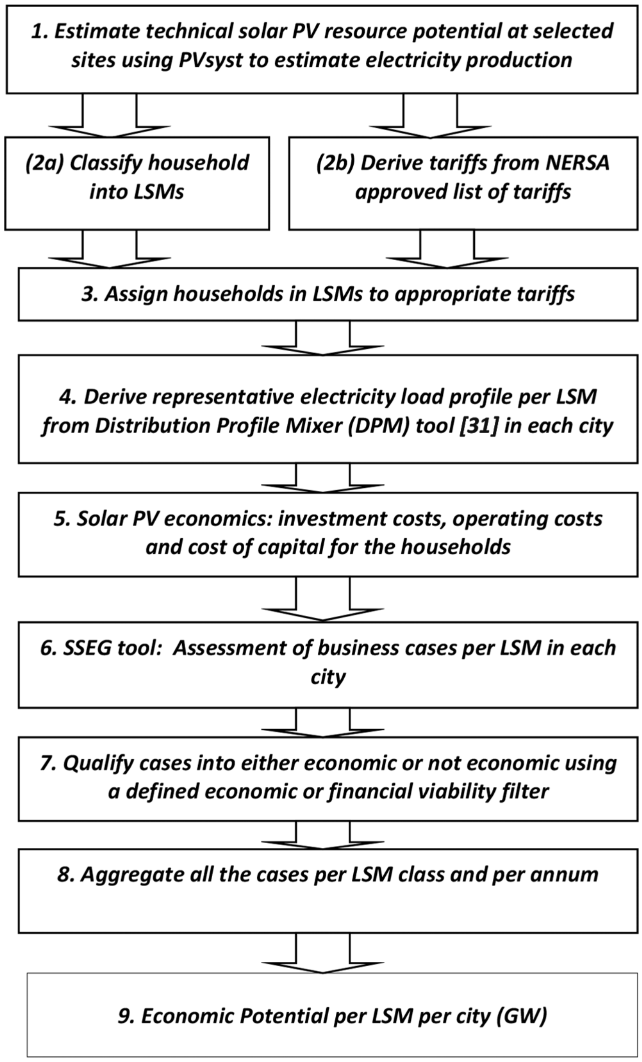


Fig. 1 *Methodological framework for estimation of solar potential*

effects that the aggregated installed PV rooftop systems have on distribution grids.

Several studies have come up with methodologies for estimating the economic potential of PV rooftop systems [3, 18, 20–22, 24, 25]. Each study used a slightly different methodology depending on the type of data that is available. The common thread amongst all these differing studies is the use of households as agents/customers whose decisions are aggregated using common characteristics between them. Brown *et al.* [25] performed a geospatial analysis to estimate the economic potential of several renewables energy resources in the US, while in Suphahitanukool *et al.* [18] used only financial metrics such as net present value (NPV) and internal rate of return (IRR) to assess the status of economic potential of a region. Mainzer *et al.* [26] used image recognition so that the characteristics of buildings (captured in the 3D map) can be captured during the estimation of the economic potential.

For South Africa, knowing the economic potential of rooftop PV systems is crucial as it helps not to overestimate the PV capacity at utility-scale when conducting the IRP for the country. Senatla *et al.* [3] have conducted a high-level assessment of economic potential of PV rooftop systems in some cities in South Africa's residential sector for 2018. This was done using tariffs as approved by the National Energy Regulator of South Africa (NERSA). This research only highlighted a snapshot of economic potential in just 1 year. In reality, economic potential increases every year, as tariffs increases, the cost of PV systems decreases and the economic situation of households change over time.

In the current planning process of the Integrated Resource Plan (IRP), distributed technologies are allocated 200 MW of installation rate per annum until 2030 [12]. This allocation is not linked to any study and it is of great importance to understand what is realistic to implement out of the 72 GW rooftop PV capacity estimated in [4].

With the economic assessment of 1 year in [3], and an uninformed allocation of 200 MW from the IRP draft report [12], there is a need to have a longer view of the economic potential that exists within South Africa. Given that a sector with high potential to hold decentralised rooftop systems is the residential sector, this study assesses the economic potential of PV rooftop systems for households in eight metropolitan cities in South Africa.

The contribution that this research will do is threefold:

i. Conducting an in-depth analysis of the economic potential in eight metropolitan cities in South Africa by taking into consideration the impacts of increasing tariff and decreasing PV investment costs, hence indicating how much distributed PV can be included in the IRP for residential sector in urban areas.
ii. Defining economic potential using financial metrics of IRR and payback period (PBP) for households classified into living standard measure (LSM) (LSM 1–LSM 10) within the eight metropolitan cities.
iii. Unlike the cases in [3], where only LSM 8–LSM 10 were analysed, the analysis in this work considers all households across all LSM categories.

The remaining sections of this paper will focus on the methodology, data used, results together with discussion and conclusions. Section 2 elaborates on the methodology used to estimate economic rooftop PV systems for residential sector in South Africa's 8 metros and explains the data used for the analysis. Section 3 presents the results together with their discussions and concludes with Section 4 which summarises the findings of the paper.

2 Methodology of estimating economic potential of PV rooftop systems

The methodology in [3] is static because it considers the economic potential of PV rooftop systems only at a particular point in time based on electricity tariffs from the municipalities, technical potential, cost of using PV rooftop systems to produce electricity and the interest that households will incur. Every year electricity tariffs increase and as a result, a new economic potential will be realised. The framework presented in Fig. 1 is used to estimate economic potential within the residential sector of the metropolitan cities in South Africa.

2.1 Schematic diagram of the methodology

The analysis involves a series of steps. The methodology employs nine distinct process steps as shown in Fig. 1.

2.2 Technical solar resource assessment

In Fig. 1, the first step (1), in the process of quantifying resource potential, is to estimate the technical solar resource potential of the area/s under consideration. This assessment will give an indication of how the solar resource performs over the year. The data used in this study was generated by Fraunhofer for the CSIR aggregation study [4], and for areas where CSIR did not generate the solar resource, PVsyst was used to derive the solar resource assessment.

2.3 Classification of households into LSMs

The second step (2a) involves categorisation/classification of households within municipalities/metros under consideration into LSMs. LSM is a measure used to classify households into their standard of living and inherently disposable income. Data recorded by South African Audience Research Foundation (SAARF) [27] was used to classify population and households by LSM in respective municipalities. For the eight municipalities under consideration, the number of households in each municipality is presented in Table 1.

It is highly likely that only households that own their property can install PV rooftop systems. Households that rent or stay in other people's property will be limited in deciding on a rooftop PV system investment due to ownership dynamics involved. Therefore, it is crucial to estimate the ownership levels of households in those regions. The number of households that own houses was taken from the municipality database [28] and the levels of ownership are presented in Fig. 2. This study assumes that this ownership level will stay constant up until 2030.

Table 1 Total number of households in each municipality (million)

Cities	2018	2020	2025	2030
Buffalo city	0.37	0.38	0.41	0.45
Ekurhuleni	1.17	1.21	1.30	1.41
EThekwini	1.14	1.17	1.26	1.35
City of Cape Town	1.34	1.38	1.49	1.61
City of Johannesburg	1.30	1.36	1.54	1.74
City of Tshwane	1.13	1.16	1.26	1.35
Manguang	0.27	0.28	0.30	0.32
Nelson Mandela Bay	0.38	0.39	0.43	0.48
total	**7.10**	**7.34**	**8.00**	**8.71**

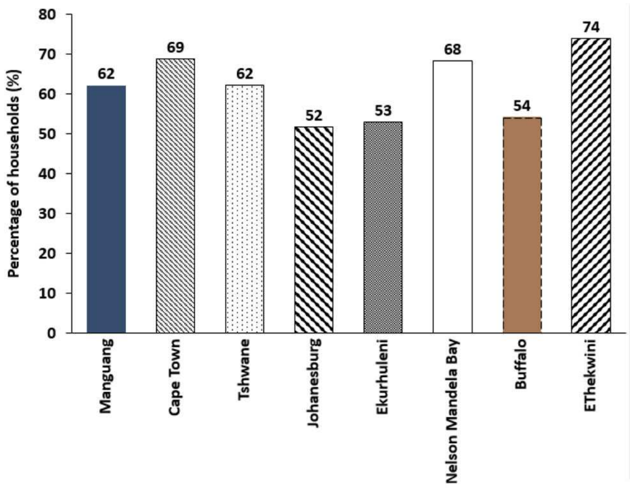


Fig. 2 *House ownership levels in different cities [27]*

Table 2 Number of households that own houses (million)

Cities	2018	2020	2025	2030
Buffalo city	0.20	0.21	0.22	0.24
Ekurhuleni	0.62	0.64	0.69	0.74
EThekwini	0.84	0.87	0.93	1.00
City of Cape Town	0.92	0.95	1.02	1.11
City of Johannesburg	0.67	0.70	0.80	0.90
City of Tshwane	0.70	0.72	0.78	0.84
Manguang	0.19	0.19	0.21	0.22
Nelson Mandela Bay	0.26	0.27	0.30	0.33
total	**4.41**	**4.56**	**4.95**	**5.39**

House ownership levels shown in Fig. 2 result in 4.4 million households owning houses in the four metros in 2018 (see Table 2). Table 2 also shows that the number of households that will own houses will increase to 5.4 million by 2030, as a result of the increasing population. The households presented in Table 2 have the potential to install a rooftop system if it becomes financially and economically feasible to do so.

The wealth of households differs and the distribution of households by their living standard measure (wealth) is presented in Table 3. As shown, the City of Cape Town and all the metros found in Gauteng province have a higher share of households in LSM 5–LSM 10. In other municipalities, the higher share of households is found in LSM 3–LSM 7. It can then be concluded that the big metros have wealthier households, which have been shown to be the first adopters of PV rooftops systems in other economies.

2.4 Assigning households in respective LSM categories into appropriate tariffs

After assigning all the households to the appropriate LSMs, it is important to align them to appropriate and relevant tariff types that the households can be charged from the municipalities. Municipal tariffs within the residential sector are diverse, even within a single municipality. The common parameter amongst the different municipalities is that almost all municipalities use inclined block tariffs as presented in Table 4. Table 4 presents the residential sector tariffs charged by Manguang municipality.

Under Manguang, there are two types of tariffs: domestic incline block tariff (IBT) and high domestic IBT. These two tariffs are applied differently for both summer and winter seasons, with winter charges being higher than summer charges. The base year tariff data is taken from NERSA [29].

Since municipalities do not give details of how they classify their residential sector customers, this study assigned low tariffs to lower LSMs and higher tariffs to higher LSMs. This inference is made based on a study that was conducted by Senatla [30], which discovered that electricity consumption in households is correlated to income level. As a result, households in lower LSMs are assigned tariffs in lower inclined block tariff levels. An example of how households within each LSM are assigned to respective tariffs within each municipality is shown in Table 4 (giving Manguang municipality as an example).

On domestic IBT, there are three types of tariff blocks. These are for households that consume low electricity (between 0 and 100 kWh on a monthly basis) are charged a lifeline tariff of R1.01/kWh and R1.28/kWh in summer and winter, respectively. Households in this category of consumption are classified as LSM

Table 3 Share of households by LSM in each municipality

Municipalities	Manguang, %	Cape Town, %	Tshwane, %	Johannesburg, %	Ekurhuleni, %	Nelson Mandela Bay, %	Buffalo City, %	EThekwini, %
LSMs								
LSM 1	—	0	0	0	0	10	10	2
LSM 2	2	0	0	0	0	9	9	8
LSM 3	3	1	1	1	1	12	12	10
LSM 4	10	3	3	3	3	16	16	16
LSM 5	23	7	10	10	10	13	13	16
LSM 6	35	28	32	32	32	18	18	17
LSM 7	9	20	18	18	18	8	8	9
LSM 8	6	14	13	13	13	5	5	7
LSM 9	8	17	14	14	14	6	6	8
LSM 10	4	9	10	10	10	3	3	8

1 and LSM 2 households for the purposes of this study. Households that consume electricity above the lifeline level, but use electricity below 350 kWh in a month, fall in block 2 and the charges are presented in Table 4. All households that consume electricity above 350 kWh monthly are charged R1.46/kWh and R1.62/kWh is summer and winter, respectively.

Higher-income households are assumed to be placed on high domestic IBT and only two tariff blocks exist in this type of tariff. Block 1 customers (households) consume between 0 and 350 kWh of electricity per month and all other customers consuming above 350 kWh fall into block 2 customers. Customers in block 1 are charged R1.20/kWh and R1.50/kWh in summer and winter, respectively. Customers in block 2 are charged R1.29/kWh and R1.55/kWh in summer and winter, respectively.

Given the current energy transition process that is occurring in South Africa and worldwide, tariffs are currently evolving and changing as more and more customers are installing generation assets on their premises and reduce buying electricity (volume–kWh). The most common move is to increase the fixed tariff charges as municipalities are losing revenue from reducing volumetric charges (*R*/kWh). This tariff change is already happening in South Africa, as the City of Cape Town has already changed its tariff structure in the 2018 tariffs [29]. In the 2018 approved regulator tariffs, the City of Cape Town charged its customers (including residential customers), higher fixed charges (*R*/month) and lower energy charges (*R*/kWh) so that installations do not affect the City's finances/revenue collection from electricity sales. Despite tariff structure changes being a reality, this study assumes that the current tariff structures within each municipality will not change.

As a result, the tariff structures assumed for each municipality in 2018 will still be applied by the respective municipalities in 2030. However, the tariffs presented in Table 5 are assumed to grow by 2% on an annual basis up to 2030. The analysis excludes the dynamic feedbacks that the tariffs will experience as more households increase their solar PV rooftop deployment.

The assumed tariff trajectories are shown in Fig. 3 for two municipalities under study. Tariffs for complexes were excluded in this analysis because investing in PV systems for the community of property (COP) schemes might be a challenge given the way these schemes are managed currently in South Africa.

2.5 Economic parameters: PV cost, interest rate

To do the assessment, the cost of PV, and the cost of financing the system (which is captured through the interest rate) are assumed. The unit cost for every kWp that is installed is R22 000 across all the LSMs. The interest rate of 10% is assumed for all households and all households are assumed to finance their systems via debt such as a bank loan. This is the usual average prime rate level in South Africa. With these assumptions, the levelised cost of producing electricity (LCOE) with PV systems ranges from R1.01/kWh to R1.42/kWh in 2018 in the studied municipalities.

Table 4 Example for assigning tariffs into respective tariffs

Manguang

Domestic IBT summer	Consumption block, kWh	Price, c/kWh	LSM categories
lifeline	0–100	100.50	LSM 1 and LSM 2
block 2	101–350	106.96	LSM 3 and LSM 4
block 3	>350	145.95	LSM 4 and LSM 5

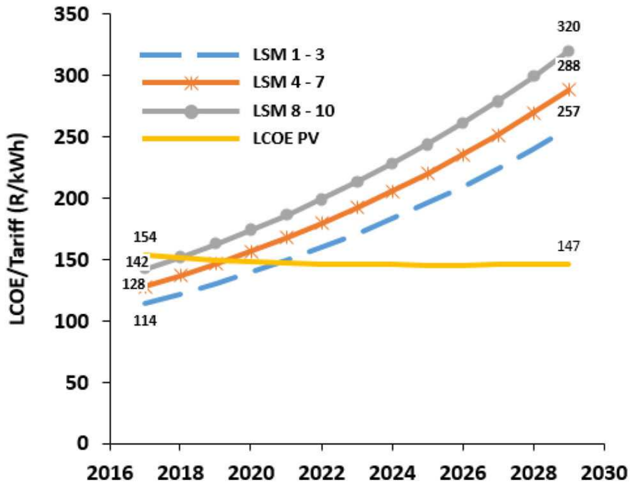
Domestic IBT winter	Consumption block, kWh	Price, c/kWh	LSM categories
lifeline	0–100	127.66	LSM 1 and LSM 2
block 2	101–350	136.31	LSM 3 and LSM 4
block 3	>350	161.70	LSM 5 and LSM 6

High domestic IBT summer	Consumption block, kWh	Price. c/kWh	LSM categories
block 1	0–350	120.00	LSM 7–LSM 9
block 2	>351	129.00	LSM 10

High domestic IBT winter	Consumption block, kWh	Price, c/kWh	LSM categories
block 1	0–350	150.00	LSM 7–LSM 9
block 2	>351	155.00	LSM 10

Table 5 Average tariffs per LSM category in 2018

LSM	Buffalo City	Ekurhuleni	EThekwini	Cape Town	Johannesburg	Tshwane	Manguang	Nelson Mandela Bay
LSM 1	128	117	99	104	127	142	114	138
LSM 2	128	117	99	104	127	142	114	138
LSM 3	128	117	99	104	127	142	122	138
LSM 4	128	117	99	159	141	142	122	138
LSM 5	178	117	151	159	151	166	154	166
LSM 6	178	117	151	190	151	166	154	166
LSM 7	178	117	151	190	171	181	135	184
LSM 8	180	166	151	197	171	181	135	184
LSM 9	180	166	151	197	172	195	135	191
LSM 10	180	166	151	197	186	195	142	191
average	**159**	**132**	**130**	**160**	**152**	**165**	**133**	**164**



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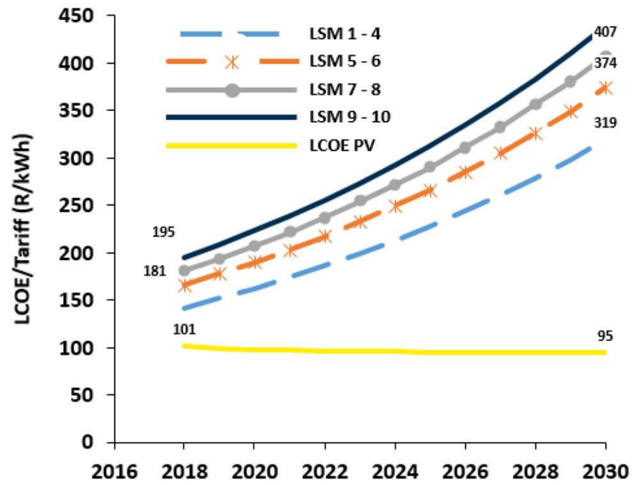

b

Fig. 3 *Tariff and cost relationship per LSM category*
(a) Tariff growth trajectory in Manguang from 2018 to 2030 in comparison to the PV cost trajectory during the same period, ***(b)*** Tariff growth trajectory in Tshwane from 2018 to 2030 in comparison to the PV cost

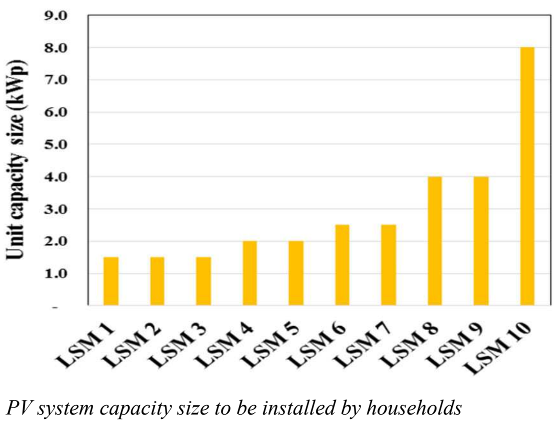

Fig. 4 *PV system capacity size to be installed by households*

The declining costs of producing electricity with PV are presented in Fig. 3 for both Manguang and Tshwane municipalities. The differences in both the LCOE are the PV resource potentials in each municipality.

2.6 Load estimation for classes of households

To do business cases, the representative loads for the households considered are required. There were real households load data for at least two municipalities. In the other six municipalities, the load had to be assumed. Given the differing climatic conditions and the resulting differing loads, loads from the two municipalities could not be used to estimate the load in other municipalities. Therefore, the load from the Distribution Profile Mixer (DPM) tool as developed from the load research database, was used. DPM is a software application for estimating the aggregate hourly load profile for consumers from different domestic consumer classes [31].

2.7 Description of the tool used for the analysis of business cases

To assess business cases, a Microsoft Excel spreadsheet-based model developed by Genesis [32] was used to assess the business cases for small-scale embedded generation (SSEG). The SSEG impact model is an open-source excel based tool which assesses business cases for PV investments and also assesses the impacts the certain penetration of PV installation has on the municipal finances. All the inputs described above are used to assess business cases for households in respective LSMs within the specified municipalities. The parameters of interest are NPV, IRR and PBP.

A positive NPV means that the investment makes economic sense, but it must also meet a certain rate of return and PBPs [33]. The aim of the study is to also assess the differential levels at which the LCOE and grid parity must be there to make the rooftop systems economical. It is well known that reaching grid parity does not automatically mean positive business case. However, it is not currently known at what level the two parameters must differ in order to make an investment economic.

To calculate NPV and LCOE, there is a need to know the PV resource potential and likely output so that the cost of generating electricity with the PV can be calculated. If the NPV indicates that there is a breakeven point with the current tariffs within the lifetime of the investment, then it means that the investment is worth pursuing with current tariff. Since tariffs and the environment in which they operate are highly unpredictable due to the ongoing energy transition, a negative NPV now does not really make an investment and not worth pursuing. Equations (1)–(4) are used to calculate NPV

$$\mathrm{NPV} = \mathrm{PRV} - C \tag{1}$$

$$\mathrm{PRV} = \sum_{t=1}^{N} \frac{S_t * (1+f)^{t-1}}{(1+L)^t} \tag{2}$$

where C is the capital cost (CAPEX), PRV is the present value of the installation. N is the economic life of the PV system, f is the inflation rate, L is the loan interest, S_t is the annual savings and t is the time in years in which savings are enjoyed. It is assumed that customers use their respective interest rates, which tends to be higher for private entities compared to the national discount rate of 8.4%. Therefore, for residential customers an interest rate of 10% is assumed on their loan amounts.

To calculate the S_t in (2), the energy yield from the system must be calculated. The energy yield depends on the installed capacity, performance ratio (PR) and solar irradiance of a chosen location. The energy yield in year 1 is calculated using the following equation:

$$Y_{e1}(\mathrm{kWh}) = \mathrm{PR} * S_i * \mathrm{PV_{cap}} \tag{3}$$

Y_{e1} is the annual energy yield in year 1, $S_i$is the historical average global horizontal irradiance for a selected site, PR is the performance ratio and $\mathrm{PV_{cap}}$ is the installed capacity of the rooftop PV system. The $\mathrm{PV_{cap}}$ for households in each LSM is presented in Fig. 4. The performance ratio from the eight case studies (or sample household designs are done) ranges between 67 and 87%. The lower PR was experienced in cities around the coastal areas while inland areas showed higher PR ranging from 70 to 87%.

This energy yield is affected by degradation factor (d). In this study, d of 0.7% is assumed for the PV modules. Starting from the second year of operation, a degradation factor will be added to the energy yield, resulting in

$$Y_{et}(\text{kWh}) = Y_{e1} * (1 - d)^{t-1} \quad (4)$$

Y_{et} is the energy yield in the subsequent years. The discounted IRR is calculated using (5) and LCOE using (6)

$$\text{IRR} = \frac{\text{NPV}}{C} \quad (5)$$

$$\text{LCOE} = \frac{\text{NPV}}{\text{Discounted } Y_{et}} \quad (6)$$

2.8 Screening for economical and non-economical PV potentials

In terms of financial viability, a single metric cannot be used on its own; a mixture of metrics are required. An IRR is usually used in conjunction with PBP to validate the financial viability of a project. The desired IRR is specific to individual investors and varies from country to country. In [33] an acceptable IRR is 14%, but in [17] an IRR of 4% was assumed acceptable if it was without subsidies in 2009.

Given that this analysis concentrates only on the residential sector, households that can invest in PV rooftop systems and obtain an IRR at 5% and aboveare assumed to have reached an economically viable level for the installation of PV. With respect to PBP, this work PBP below 15 years is assumed economical.

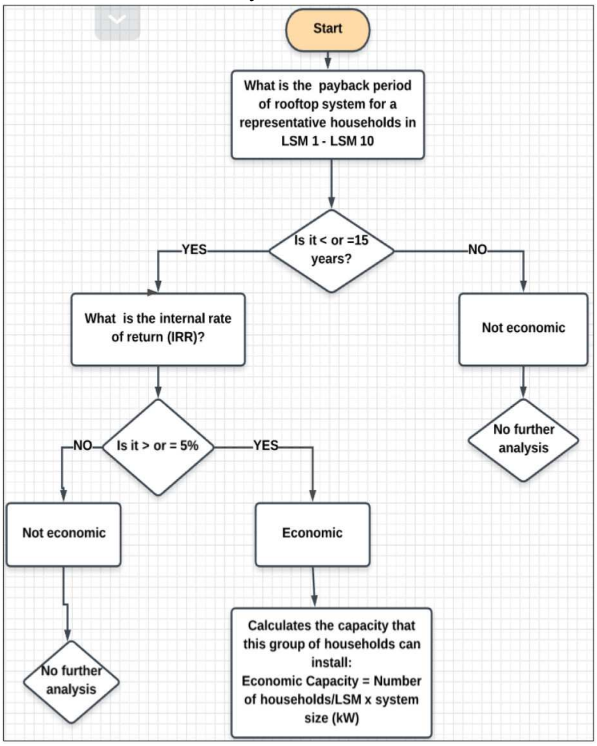

Fig. 5 *Screening for economic and not economic installations*

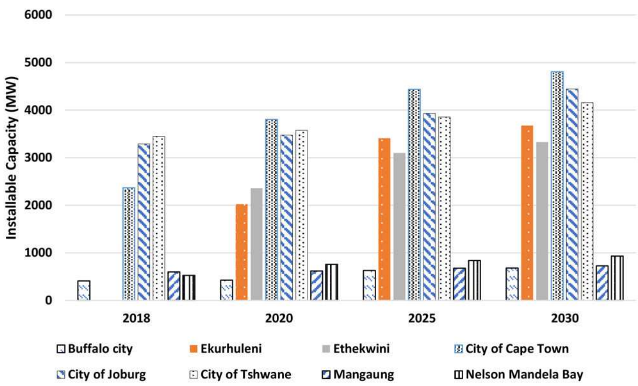

Fig. 6 *Economic potential by city up to 2030*

After assessing the business cases for the households in each LSM in each municipality, all the results are passed through a filter mechanism, as shown in Fig. 5, to determine households that have good business cases and those that do not have good business cases for their installations to fall under economical capacity.

Given their economic and wealth status, households in different LSMs will install different sizes of PV systems. Without a favourable feed-in tariff, most households will install systems that will match their daily load as much as possible so that they do not oversize their systems. The assumed PV rooftop system sizes for each LSM group is presented in Fig. 4.

3 Results and discussion

3.1 Overall economic potential of PV in eight municipalities in South Africa

The modelling in this study depicts the potential that makes financial business sense for households to tap into from 2018 until 2030, given increasing tariffs and falling PV costs. Given the definition of economic viability as described in Section 2.8, the economic potential within the eight metropolitan municipalities is at 10.6 GW in 2018. It will increase to 17 GW in 2020, with a significant share of the growth coming from EThekwini and Ekurhuleni. Respectively, by 2025 and 2030, 21 and 23 GW will be economic to install in these metros. Potential economic capacity in each metro is presented in Fig. 6.

The three big metros that have higher economic potential (City of Cape Town, City of Johannesburg and City of Tshwane) have two common characteristics. These two characteristics are that they have a high level of wealthy households (households in LSM 6–LSM 10) (see Table 3), and those households are charged high electricity tariffs (see Table 5). The co-existence of these two parameters within a single group of households serve as determinants of investing into PV rooftop systems because even though Ekurhuleni has wealthy households, the PV economic potential is very low in 2018 because the tariff is very low in comparison to the cost of PV system in that year. As the tariff increases and it exceeds the cost of PV systems, the PV potential in Ekurhuleni increases. As the cost of PV decreases the economic potential in other cities starts to increase.

In 2018, 85% of the economic potential resided in the City of Cape Town, City of Johannesburg and City of Tshwane, as shown in Table 6. This potential mainly comes from high-income households as shown in Fig. 7. Even though Ekurhuleni and EThekwini have no PV economic potential in 2018, by 2030, these two cities economic potential will constitute 31% of the total installed rooftop PV capacity within the eight metros.

To get to the economic potential of 23 GW in 2030, about 1.92 GW per annum becomes economic to install in these cities. Given that the IRP assumes 200 MW annual installation rate for all distributed generation capacities, this study shows that such an assumption must be reviewed. This study shows that potential is likely higher than the assumed conservative assumption of 200 MW per annum up until 2030.

Table 6 Share of potential capacity by municipality/city

City name	2018, %	2020, %	2025, %	2030, %
Buffalo City	4	2	3	3
Ekurhuleni	0	12	16	16
EThekwini	0	14	15	15
City of Cape Town	22	22	21	21
City of Johannesburg	31	20	19	20
City of Tshwane	32	21	18	18
Manguang	6	4	3	3
Nelson Mandela Bay	5	4	4	4
total	100	100	100	100

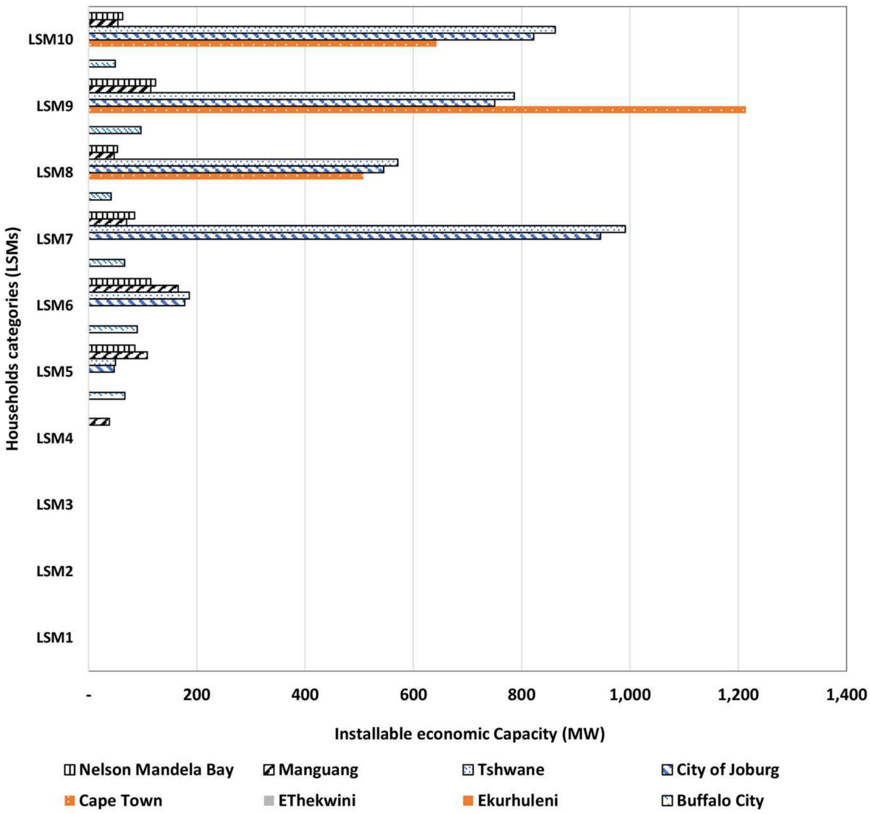

Fig. 7 *Economic PV potential by LSM and city in 2018*

3.2 Economic potential of municipality and LSM in 2018 and 2030

Fig. 7 shows that the economic potential is higher in households in the higher LSM bands (LSM 8–LSM 10) in Cape Town. In Johannesburg and Tshwane, significant potential starts from LSM 7 upwards. In Cape Town, the new SSEG tariff delays the rooftop PV systems to be economical in lower LSM bands. Even though the tariffs of LSM 6–LSM 7 in the City of Cape Town are similar to tariffs in Tshwane and Johannesburg, PV is not economic in the city.

The tariff in Cape Town has a higher fixed tariff and lower volumetric charges with reasonable feedback. The service charge (cost of being connected to the grid) in the city increases by 177% for households that install rooftop PV systems, while at the same time, their volumetric charge (*R*/kWh) from the grid reduces by a mere 30% for households in LSM 6–LSM 7 and no decrease for households in higher LSMs (LSM 9–LSM 10).

Before installation of SSEG, households on higher LSMs pay a monthly service fee of R130 in 2018/2019 financial year. After SSEG installation, the monthly service fee increases to R370 per month while the electricity cost (*R*/kWh) reduces by 30% to a range of (R1.37/kWh–R0.96/kWh) for LSM 5–LSM 8 and is R1.98/kWh for LSM 9–LSM 10. Therefore, it becomes clear that the change in the structure of the tariff has impact on the economic potential of PV within an LSM.

In both Ekurhuleni and EThekwini, Fig. 7 shows that there is no economic potential owing to the fact that their tariff levels are comparatively low when compared to the cost of PV within the EThekwini's region in 2018. Across all cities, 69% of economic potential in 2018 sits in higher LSMs (LSM 8–LSM 10), and the remaining potential is realised within LSM 5–LSM 7. There is no economic potential in the lower LSMs given the low tariff they are charged. It is important to note that these tariffs are low because households in these categories are usually subsidised through the Free Basic Electricity policy [34].

By 2030, when the PV investment cost has declined from R22.000/kWp (2018) to R17,000/kWp (2030) and tariffs have increased by 12%, PV starts to be economic in lower LSMs as well as shown in Fig. 8. In 2030, both Ekurhuleni and EThekwini have increased their combined potential to 7.00 GW from 0 GW (in 2018), as shown in Fig. 8. In EThekwini, PV rooftop systems start to be economic for even households in LSM 2.

The low levels of economic potential in Buffalo City, Manguang and Nelson Mandela Bay are due to the low number of households in these municipalities relative to the big metros such as Cape Town, Tshwane and Johannesburg.

3.3 Sensitivity analysis

Given that there is no universal way of deciding which investment is economically or financially viable, a sensitivity analysis was done. The sensitivity is used to determine the economic potential of rooftop systems when the IRR ≥10% and the PBP is less than 10 years. In South Africa, the prime lending interest rate is 10%, so it is crucial to do sensitivity analysis with the IRR set at least be at the prime interest rate.

If the IRR is expected to be at least 10% and PBP less than 10 years, there is no economic potential in 2018 in all the eight metros (see Fig. 9). In 2020, it starts to be economic to install about 7.2 GW and by 2025, 19 GW of rooftop PV systems are economic to install until about 23 GW is economic to install by 2030.

3.4 Grid parity implication

Out of this analysis, it was discovered that reaching grid parity is not enough to result in a positive business case for individual rooftop systems. Grid parity is the level at which the electricity cost from the grid is the same as the cost from a specific technology (in this case the PV rooftop systems).

Throughout this analysis, it was observed that for the rooftop PV systems to have a positive business case, this was attained when the LCOE was lower than the grid electricity by 40% of more. Given the criteria used to determine a positive and a negative business cases, once LCOE exceeds the tariff by 40%, households can invest in PV rooftop systems with a probability of breaking even in less than 15 years.

4 Conclusion

As early as 2018, it was economic to install about 11 GW of PV rooftop systems. By 2030, it is economic to install about 23 GW of

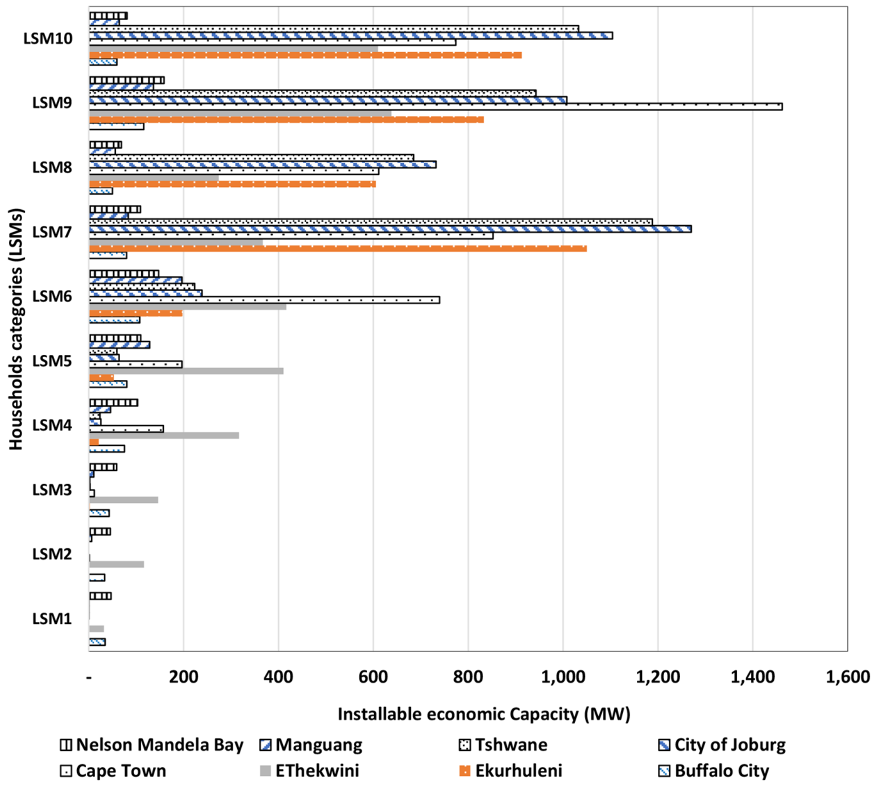

Fig. 8 *Economic PV potential by LSM and city in 2030*

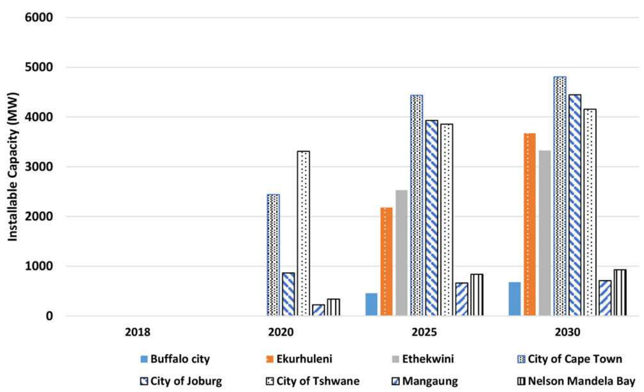

Fig. 9 *Economic potential if IRR above 10% and PBP below 10 years are expected*

rooftop systems in South Africa's eight metros. It was found that households in higher LSMs are more financially stable and are better positioned to install PV rooftop systems given the tariff they are charged is higher than the LCOE of PV. In 2030, as the tariffs have increased and PV CAPEX cost has dropped by 22% due to the assumed learning curves, PV starts to be economic in lower LSM bands.

Unlike what the draft IRP (IRP2018) says about small scale embedded generation, this study has shown the metros have an economic potential to install solar rooftop systems at a rate of 1.92 GW per annum from 2018 to 2030 in the residential sector in cities alone, not at 200 MW as is suggested by the draft IRP2018. This highlights that the assumed installation rate of 200 MW per annum up to 2030 is a very low and conservative assumption. If the PV rooftop economic potential is realised at the scale that this study has shown, it is fundamental that its impacts on IRP can be quantified and known.

The next modification of this study will have to deal with households that have rooftop space available to install PV rooftop systems. This is important because, in this analysis, owning a household assumes that you are able to install a rooftop system. In reality, it is difficult or impossible for households that own multi-storey buildings or sectional title units to install some rooftop systems yet their potential is currently accounted for in this study. For example, households within community share schemes (sectional title units) are not allowed to make a decision alone on the investment of the PV system without collective agreement of the body corporate (all owners) or the trustees of the scheme, therefore ownership of a house alone does not translate to an available space to install PV.

Since the modelling applied is static, the authors acknowledge that it does not include feedback of tariff and costs impacts and it is very important to model the uptake of these systems with a model that allows for feedback of such impacts. To incorporate this aspect into future studies, the market related technological uptake modelling concept – called 'Bass diffusion modelling' can be applied across the LSMs so that realistic adoption can be estimated going into the future.

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