ORIGINAL RESEARCH

Exploiting the rooftop solar photovoltaic potential of a tropical island state: case of the Mascarene Island of Mauritius

Jay Rovisham Singh Doorga[1] · Ryan Tannoo[2] · Soonil D. D. V. Rughooputh[1] · Ravindra Boojhawon[3]

Abstract

Mauritius relies heavily on fossil fuel imports to satisfy the energy requirements of its population. Urged by policies to address climate change at the national and international levels, the government is committed to promote sustainable development, with emphasis laid on reducing greenhouse gas emissions. Consequently, we provide an assessment of rooftop PV potential at the national level. A sampling strategy is used to acquire reduction coefficients, which are thereafter applied to energy-based equations. The result suggests that the rooftop PV potential at the country-scale is estimated at 20.04 GW with an annual energy output of 32,512 GWh. A novel architectural layout for a Solar City to be located at an identified optimum site is proposed. A shading analysis is conducted to verify the appropriateness of the city's structural design to harness energy from the sun. An energy analysis performed, reveals that the Solar City has a solar power potential of 13.55 MW and an annual energy generation capacity equivalent to 21.99 GWh. Construction of the Solar City would help avert the emissions of 13,744 tons of CO_2 annually.

Keywords Rooftop PV · Solar energy modelling · Solar city · GIS · Urban architecture · Mauritius

Introduction

Strategic energy management plays a vital role in urban development, prompting cities around the globe to shift towards low-carbon economies through the optimal management of their resources while ensuring high quality of life to inhabitants. The increasing population dynamics coupled with higher income thresholds are primarily responsible in the rising energy demand faced by the global community.

Efforts being made through the integration of sustainable policies and energy-focused initiatives contribute significantly towards the efficient management and exploitation of sustainable energy resources while promoting measures coordinated on climate protection. Considerable number of cities are integrating renewable energy technologies in their electricity generation grid in view of reducing dependence on fossil fuel resources and mitigating the irreversible effects of climate change.

Recognizing the potential threats posed by climate change on the economic, environmental and social aspects of vulnerable Small Island Developing States (SIDS) like Mauritius, the government of the island has ratified a number of conventions on national and international grounds. As from 1992, the country has been actively engaged in consortiums determined to reduce the emissions of greenhouse gases (GHGs) through the endorsement of the United Nations Framework Convention on Climate Change (UNFCCC) and later, in 2001, by signing the Kyoto Protocol [1]. The COP22 meeting held in Marrakech in 2016 has seen the operationalization of the Paris Climate Change Agreement which aims at preventing the rise of global temperatures [2]. The island also faces the challenge of having to implement safe, inclusive, resilient and sustainable cities, as part of its Sustainable Development Goal (SDG 11) agenda.

✉ Jay Rovisham Singh Doorga
  jay.doorga927@gmail.com

  Ryan Tannoo
  ryantnn@hotmail.com

  Soonil D. D. V. Rughooputh
  rughooputh.sddv@gmail.com

  Ravindra Boojhawon
  r.boojhawon@uom.ac.mu

1 Department of Physics, Faculty of Science, University of Mauritius, Reduit, Mauritius

2 Kent School of Architecture, Faculty of Humanities, University of Kent, Canterbury, UK

3 Department of Mathematics, Faculty of Science, University of Mauritius, Reduit, Mauritius

Consequently, the country has a moral obligation to maintain GHGs at a safe level through the promotion of 'greener' and more sustainable projects.

In Mauritius, there has been a noted progression towards the development of sustainable cities that focus on solar energy. For instance, the Moka Smart City currently has at least five photovoltaic farms, generating 2353 kWp annually and conserving about 3500 tons of carbon-dioxide emissions [3]. The grid emission factor of the island is estimated at 1.01 tonnes CO_2/MWh mainly due to the high importations of coal (39%) and fuel oil (38%) in the electricity generation mix [4]. In view of reducing reliance on fossil fuels, Mauritius aims to reach 40% renewable energy in its energy mix by 2030 from its current value of 21.7% [5]. Consequently, a series of measures have already been formulated by the Government and includes: The setting up of a 2 MW floating solar farm at Tamarind Falls Reservoir, Scaling up the Henrietta solar farm from 2 to 10 MW, Installation of 1000 solar PV panels on the rooftops of low-income households [5].

However, sustainable development on the island needs to factor in the problem of land constraint. With an annual sea-level rise of 4–6 mm reported over the past 30 years, Mauritius is faced with the problem of diminishing land space [6]. Consequently, development on the island needs to be carefully planned to save as much vegetation and green spaces as possible. The increasing pace of urbanisation, arising from the necessity of constructing more cities to satisfy the social needs of the population, results in the reduction of the amount of available space for other developments, such as improving the energetic situation of the country through the investments in renewable energy technologies. Incorporating renewable energy technologies in the urban fabric would circumvent the spatial constraints posed by limited land space in small island states whilst satisfying both the social and environmental needs of a growing population.

The current study investigates the potential for installing PV systems on the rooftops of existing buildings in Mauritius. We also explore how the implementation of rooftop PV project at the city-scale in a hotspot in Mauritius can contribute in significantly decarbonising the energy mix. To the author's knowledge, this work represents the first assessment of rooftop PV potential in the country and would be of utmost importance to the Government and other relevant authorities in making an informed decision pertaining to strategic energy investments and in designing energy policies in the country.

Methodology

Study area

The main island of Mauritius (20° 10′ S, 57° 30′ E), situated to the east of Africa and near the edge of the tropic of Capricorn Fig. 1a, forms part of the Mascarene islands. Of volcanic origin, the island is roughly elliptical in shape with a major axis measuring about 60 km long and a 45 km wide minor axis. Comprising of an elevated central plateau about 500 m above sea level, believed to be a caldera of origin, the geology of Mauritius is a beautiful ensemble of isolated peaks, mountain chains and variable land slopes decreasing towards the coast Fig. 1b.

In 2017, the population of Mauritius stood at 1,265,309, representing a registered growth of 0.1% as compared to the previous year [7]. The settlement patterns of the country are governed by three main mechanisms: Administrative policies for land development, Socio-economic and ecological factors which encompass economic, cultural, topological and climate-induced considerations, location of main facilities within the island [8]. An overview of the settlement distributions around the country is illustrated in Fig. 1b. One of the most densely populated districts of Mauritius is Plaines Wilhems, with roughly 30% of the population and situated in the central plateau of the island [8] Fig. 1c.

The solar potential of Mauritius

The distinct spatial variations of the insolation regime of the island is attributed to the variations in the sky conditions prevailing at different parts of the island. As mentioned by Doorga et al. [9], the forced uplift of moist warm air from the South-East Trade Winds, due to being obstructed by the rising topographic relief of the south-eastern region, results in condensation and the formation of clouds in the southern part of the central plateau. It can be observed from Fig. 2a that the southern part of the central plateau is the highest region of the island and is characterised by higher cloud cover resulting in less penetration of sun rays. However, in contrast, the north-western region of the island witnesses higher solar potential Fig. 2b attributed to lower cloud cover since the descending air in the leeward side has been stripped off of its moisture content due to condensation and formation of clouds on the higher plains of the central plateau. Installation of ground-mounted PV panels in the high potential northern region of the island could generate as much as 202.9 kWh annually per square metre [10].

Literature review

Inspection of research conducted to determine the rooftop photovoltaic potential of several regions around the world is presented in Table 1. The data used, GIS technique employed and key findings of the studies are explored in view of gearing the present study to achieve accurate results.
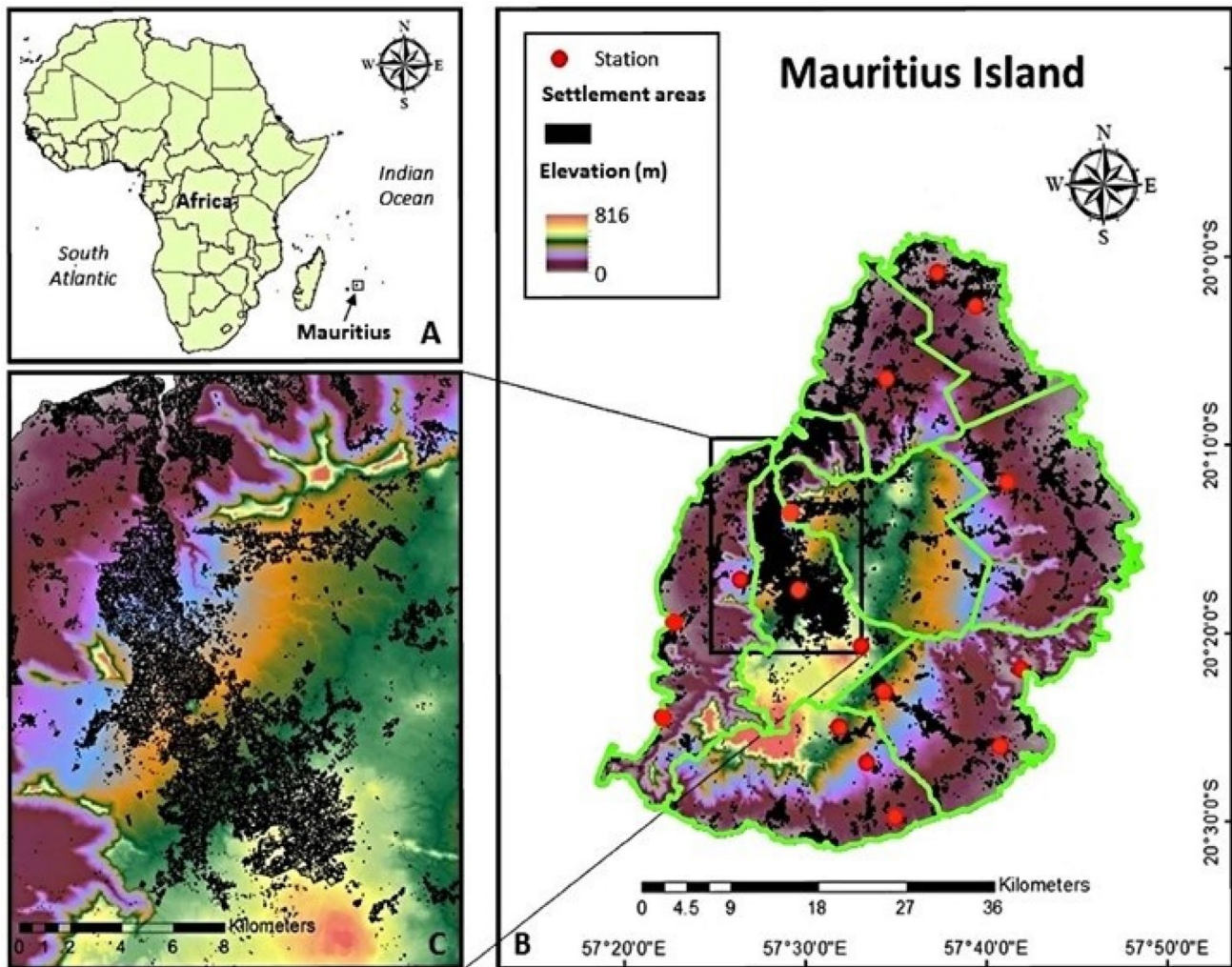
Fig. 1 a Geographical position of Mauritius in the south-west Indian Ocean, off the eastern coasts of Africa. **b** Digital Elevation Model (DEM) of Mauritius island superposed with the settlement areas of the country. Also present are the locations for the recording stations measuring global solar radiation data. The green borders represent the main districts of the country. **c** Magnified view of the built-up areas for the district (Plaines Wilhems) which contains the most rooftops in Mauritius

Methodological framework

The methodological framework adopted in the present study is shown in Fig. 3. The study is divided into two phases. Phase 1 is concerned with estimating the rooftop PV potential of existing buildings. To do that, a digitized shapefile of built-up areas in Mauritius is acquired and the validity of the extracted rooftop areas is tested using on-site measurements. Sampling of buildings according to geographic districts and categories is thereafter performed, prior to obtaining estimations for obstruction, shading, aspect and PV panel racking coefficients. Extrapolation of the results is then carried out to determine the net energy contribution from rooftop PV deployment. Phase 2 of the study involves proposing a novel Solar City. First, the optimum site for the construction of a city that will host buildings with rooftop PV systems is identified. After which, a proposal for a design of a Solar City to be constructed in that optimum zone is presented. In the final stage of the study, an estimation of energy potential of the city is made, alongside practical considerations pertaining to the generation and transmission of the intermittent energy source in the grid.

Theoretical background

The solar power potential and energy output of installed PV panels on the rooftops of buildings in Mauritius may be quantified. The relevant equations employed in literature to perform these computations are presented below.

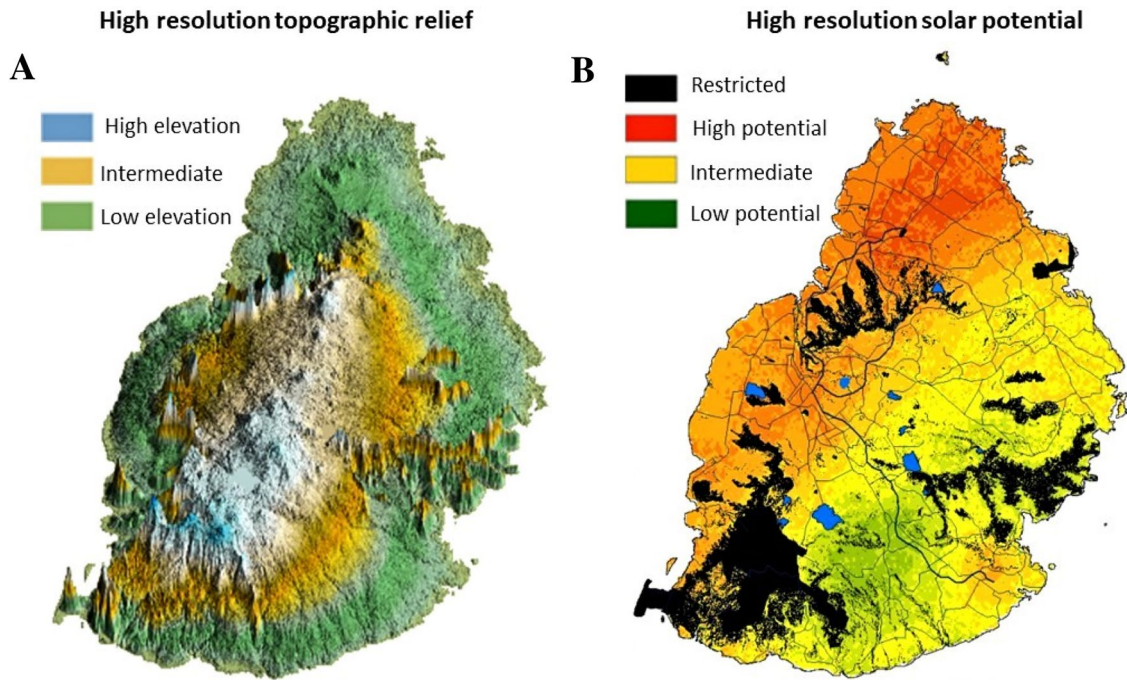The solar power potential is computed as:

High resolution topographic relief

A

- High elevation
- Intermediate
- Low elevation

High resolution solar potential

B

- Restricted
- High potential
- Intermediate
- Low potential

Fig. 2 **a** High resolution topographic relief of Mauritius. **b** High resolution solar potential mapping of Mauritius [9]

$$P = \text{Ig} \times \eta_{\text{PV}} \times A_{\text{PV}}, \tag{1}$$

where Ig represents the global solar insolation recorded under global air mass 1.5 spectrum of 1000 W/m^2. The efficiency of the PV module (η_{PV}) chosen depends on the manufacturing technology and material employed for its construction, as presented in Table 2.

The total annual energy output is given by:

$$E = I_{\text{md}} \times 365 \times \eta_{\text{PV}} \times A_{\text{PV}}, \tag{2}$$

where I_{md} is the mean daily global solar irradiation and is equivalent to 4.444 kWh/m^{2}day (16 MJ/m^{2}day) for Mauritius as computed via modelling by [17] and derived from the stations in Fig. 1b. This conservative value is used since there is not much variations in mean daily solar irradiation in Mauritius when viewed over long time frames.

The available area per capita, $A_{\text{PV/capita}}$, is a function of roof obstructions (C_o), shading (C_s), aspect (C_a) and PV panels racking (C_r). The different factors in Eq. (3) are computed using the spatial measurement tool available in ArcGIS. The available area per capita is computed from the total rooftop area per capita ($A_{\text{roof-area/capita}}$) as follows:

$$A_{\text{PV/capita}} = A_{\text{roof-area/capita}} \times C_o \times C_s \times C_a \times C_r. \tag{3}$$

The available area for PV deployment on rooftop, A_{PV}, can be deduced through extrapolation as follows:

$$A_{\text{PV}} = A_{\text{PV/capita}} \times \text{Population}. \tag{4}$$

Field validation and rooftop situation

The digitized rooftop shapefile provided by the Ministry of Housing and Lands (MOHL) was used in the current study. The MOHL digitized all built-up areas in the country using a high-resolution aerial image. Sample rooftops feature extractions for the region of Montagne Longue is presented in Fig. 4a. Consequently, it was necessary to assess the accuracy of the rooftop polygons extracted. For that purpose, a sample residential building is selected as shown in Fig. 4b which is located at 31, Labourdonnais Avenue, Quatre-Bornes (20.266265° S, 57.473987° E). Also, a detailed rooftop map of the selected residential unit was constructed using AutoCAD software as shown in Fig. 4c.

Using the area calculator available in ArcGIS software, the polygon of the selected residential unit measured about 170.97 m^2. However, field validation work of the sample building rooftop revealed that the actual rooftop area was about 161.91 m^2. Therefore, an accuracy of 94.40% was registered for the sample rooftop chosen for validation. Since satisfactory results were obtained, the digitized rooftop shapefile was used for further processing.

Table 1 Summary of GIS-based rooftop PV potential as applied to different study areas

References	Data and GIS technique	Key findings	Study Area
[11]	Satellite imagery acquired from Google Earth and processed using ENVI EX software	Mono-crystalline silicon-based rooftop PV can contribute about 12.24 MW (122.4%) of peak power demand	Pakistan
[12]	Satellite solar data and weather data from MeteoSwiss are used as input in a Support Vector Machine (SVM) and GIS system	Annual PV electricity generation of 17.86 TWh from urban areas (28% of Switzerland's electricity consumption in[2]	Switzerland
[13]	High resolution satellite images, GIS models and building audits are combined with PVSOL for specific building type analysis	For about 33,000 residential units, annual rooftop PV electricity potential is 797 GWh for tilted and 757 GWh for flat solar PV panels	Saudi Arabia
[14]	Census data and DRAPE orthophotos analysed using ArcGIS software	Capable of meeting about 30% of Ontario's energy demand through province-wide rooftop PV deployment	Canada
[15]	Combination of GIS-based technique, lidar data and statistical modelling employed to estimate rooftop PV potential	8.13 billion square metres of available roof area could generate about 1432 TWh of electricity annually from the deployment of about 1118 GW rooftop PV solar panels	United States
Doorga et al. (Proposed model)	High resolution satellite images and census data analysed using ArcGIS software and ground-truthing performed via on-site measurements		Mauritius

In general, rooftops of built-up areas in Mauritius are mostly flat, unoccupied Fig. 4e and due to its location in the tropical belt, buildings are mostly equipped with solar water heaters and overhead water tanks. According to an audit report, about 73,480 households and businesses had solar water heaters representing about 22% of total number of household and business units by 2016 [18]. Consequently, the major obstructions to rooftop PV deployment for residential and business units are overhead water tanks and solar water heaters which take up significant amount of roof space as depicted in Fig. 4d.

Sampling strategy

To come up with appropriate factors for roof obstruction, shading and roof orientation as applied to the test case of Mauritius, rooftop samples of various buildings around the island need to be analysed. To account for the variations in rooftop building characteristics, samples of different building types was taken from various districts across the island. However, sample selection was primarily based on the population density of the nine districts Fig. 1b.

The population density census carried out for the year 2017 [7] revealed that the northern districts of Pamplemousses and Riviere du Rampart had population densities of 785 population/km^2 and 700 population/km^2, respectively. The southern districts of Savanne and Grand Port had population densities of 278 population/km^2 and 432 population/km^2, respectively. The eastern district of Flacq recorded a population density of 464 population/km^2 whilst the western districts of Black River and Port Louis had population densities amounting to 321 population/km^2 and 2946 population/km^2, respectively. The central plateau districts of Plaines Wilhems and Moka had population densities of 1875 population/km^2 and 357 population/km^2, respectively.

The number of rooftop building samples chosen per district was dependent on the ratio between the population density in a given district and the sum of population densities in all nine districts. A total number of 30 rooftop building samples per category was regarded as a fairly good representation of the overall number of existing buildings in Mauritius. Out of the 30 buildings per category, the number of samples per district selected for analysis is presented in Table 3.

Due to the fact that the rooftops of different building types (residential, industrial, commercial, …) would *apriori* be obstructed by different extents, have different degrees of orientation and experience distinctive shading effects, the survey was conducted separately for each building type [19] found the various restriction coefficients separately for apartment and villa. In this study, we choose to study the main building types as classified by Wikipedia [20] and which are relevant to the country. These are categorised into residential (single-family detached/attached, apartment, villa

Methodological Structure of the Study

Phase 1

Rooftop PV potential of existing building

Acquisition of digitized building rooftop areas and field validation of built-up areas

↓

Sampling of buildings according to geographic districts

↓

Sampling of buildings according to category (residential, industrial & commercial, specialty)

↓

Estimation of coefficients for obstruction, shading, aspect and PV panels racking

↓

Extrapolation of results to determine the net energy contribution from rooftop PV deployment

Phase 2

Proposal of a novel Solar City

Identification of an optimum site for the construction of a solar city

↓

Proposal of a design for a city to be operated from rooftop PV systems

↓

Estimation of PV rooftop electricity generation potential of the solar city
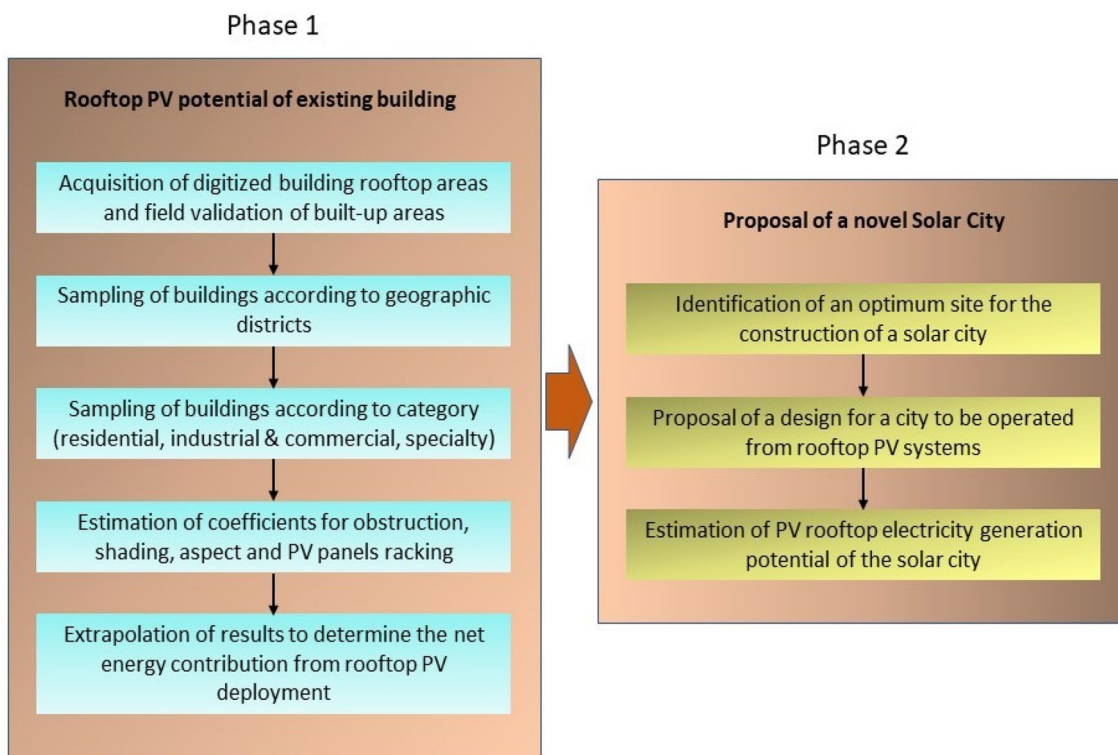
Fig. 3 Proposed methodological framework to perform a full-scale assessment of rooftop PV potential on existing buildings and the construction of a novel Solar City

Table 2 Selected PV technologies from [16] as investigated under global air mass 1.5 spectrum (1000 W/m^2) at 25 °C

PV technology	Module efficiency (%)	Panel output (W/m^2)	Module description
Si (mono-crystalline cell)	26.7	267	Kaneka, n-type rear IBC
Si (poly-crystalline cell)	22.3	223	FhG-ISE, n-type
Si (thin film mini module)	10.5	105	CSG solar (< 2 μm on glass)
Si (amorphous cell)	10.2	102	AIST

and flats),commercial (office, retail and hotels),industrial (manufacturing and warehouse/distribution); specialty (educational, hospital and airport). After thorough inspection of the rooftops of some commercial and industrial buildings of the country and noticing similar characteristics in terms of their rooftop occupancy and shadings, we decided to group them under a single category. Sample selection of residential, commercial and industrial, and specialty units are presented in Figs. 5, 6 and 7, respectively.

Sampling of residential units

See Fig. 5.

Sampling of commercial/industrial units
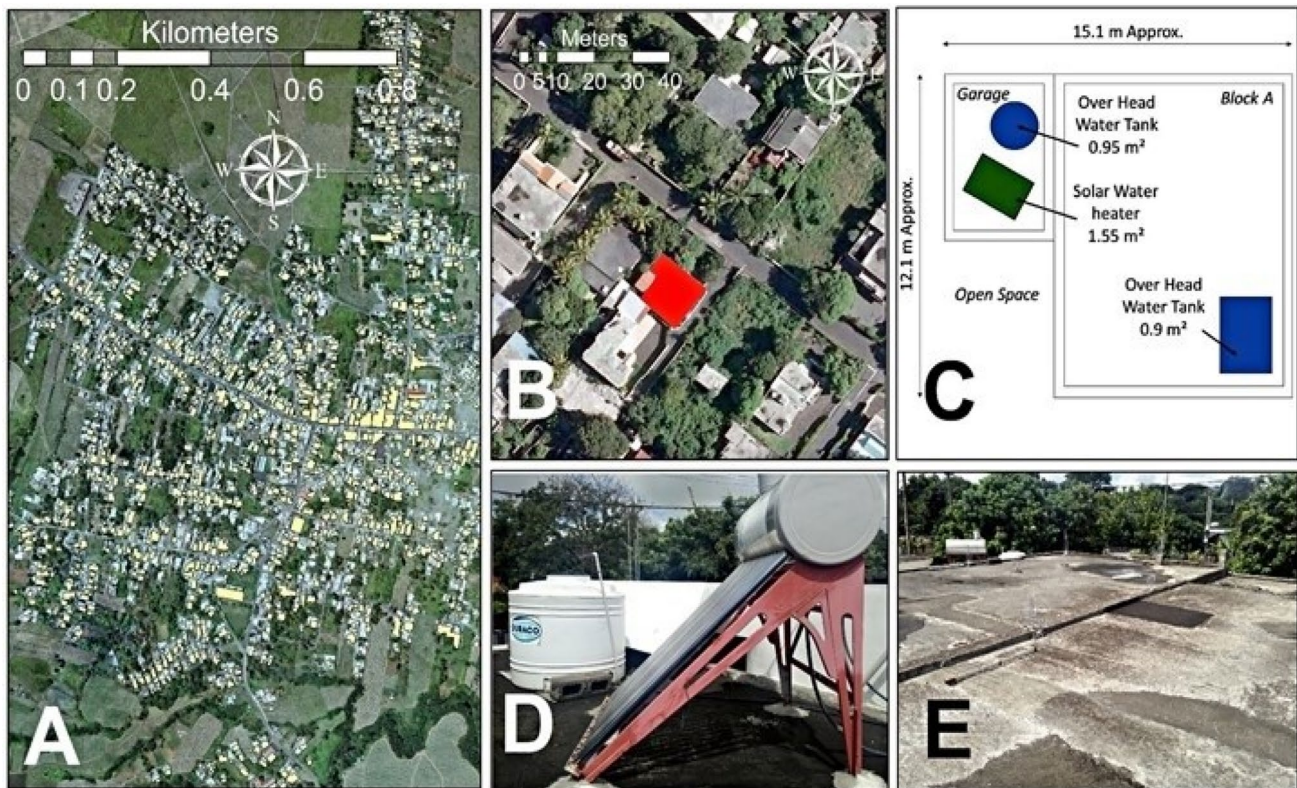
See Fig. 6.

Sampling of specialty units

See Fig. 7.

Fig. 4 a Sample rooftops feature extractions (depicted as yellow roofs) for the region of Montagne Longue, Mauritius. **b** One of the sample rooftop (depicted as red roof) for field validation work (Location: 31, Labourdonnais Avenue, Quatre-Bornes, Mauritius). **c** Detailed map of sample rooftop for computing actual rooftop area. **d** Rooftop PV obstructions on typical residential unit in Mauritius. **e** Availability of rooftop space for PV deployment on sample residential unit

Results and discussions

Reduction

The available roof space for PV deployment is reduced due to (1) obstructions such as overhead water tanks and solar water heaters which are present; (2) effects of shadows cast by neighbouring tall trees or building structures; (3) orientation of peaked rooftop with respect to the sun; (4) racking of PV panels so as to maintain an appropriate inter-row spacing to prevent unwanted shadows on PV modules. We investigate the contributions of each aspect towards the reduction of overall roof space in the following subsections.

To come forward with appropriate coefficients for the different reduction factors, a survey was undertaken separately for residential, commercial, industrial and specialty buildings. The sampling method discussed in Sect. 2.7 was adopted as buildings were chosen randomly from the different districts of the country. The spatial coefficients are computed in the GIS platform.

Roof obstructions

The obstructions on the rooftops of residential units were mainly due to overhead water tanks, solar water heaters, staircase rooms and parapet walls. An average obstruction coefficient value of 0.895 was recorded for the 30 sampled residential units Fig. 5 in Mauritius. For the case of commercial Fig. 6, industrial Fig. 6 and specialty Fig. 7 buildings, the obstacles were mainly due to air extractors, roof signs, roof drains, pyramid roof structures, skylights, AC package units and chimneys. The obstruction coefficient for commercial and industrial buildings was found to be 0.936 on average, whilst that for specialty buildings had an average value of 0.954. The average value of 0.928 is used as a representative unit for the obstruction coefficient of all building rooftop categories on the island.

Table 3 Sample selection of rooftop buildings based on population density of districts

District	Location	Population density (P/km^2)	Ratio	Building type	No of samples
Pamplemousses	North	785	0.096	Residential	3
				Commercial and industrial	3
				Specialty	3
Riviere du Rempart	North	700	0.086	Residential	3
				Commercial and industrial	3
				Specialty	3
Flacq	East	464	0.057	Residential	2
				Commercial and industrial	2
				Specialty	2
Grand Port	South	432	0.053	Residential	2
				Commercial and industrial	2
				Specialty	2
Savanne	South	278	0.034	Residential	1
				Commercial and industrial	1
				Specialty	1
Black River	West	321	0.039	Residential	1
				Commercial and industrial	1
				Specialty	1
Port Louis	West	2946	0.361	Residential	10
				Commercial and industrial	10
				Specialty	10
Plaines Wilhems	Centre	1875	0.230	Residential	7
				Commercial and industrial	7
				Specialty	7
Moka	Centre	357	0.044	Residential	1
				Commercial and industrial	1
				Specialty	1

Shading factor

Besides shadows cast by structures present on the rooftops of buildings, neighbouring trees contribute significantly in decreasing the overall shading coefficient. An average shading coefficient value of 0.942 was noted on the rooftops of residential buildings. Commercial and industrial buildings recorded an average shading value of 0.966 whilst specialty buildings registered an average value of 0.969. Consequently, we use an average value of 0.959 as a representative unit for the shading coefficient of all building rooftop categories on the island.

Rooftop aspect

The effect of orientation from the rooftops of buildings is also taken into consideration. From field survey and sampling, it is noted that the majority of small and large buildings (95%) have flat rooftops ($r_{flat} = 0.95$). Due to being unaffected by orientation, these structures will undergo no

reduction ($f_{flat} = 1$). Pitched-roof buildings account for the remaining percentage of the residential houses ($r_{pitch} = 0.05$). These buildings are observed to have 50% north-facing area on average as shown in Figs. 6 and 7 ($f_{pitch} = 0.5$). Mauritius, being located in the southern hemisphere, implies that north-facing roofs will be exposed to higher sunshine throughout the year. The fraction of roof area which is adequately oriented, C_a, using the approach of [14], is given by:

$$C_a = r_{flat}.f_{flat} + r_{pitch}.f_{pitch} = (0.95 \times 1 + 0.05 \times 0.5) = 0.975. \quad (5)$$

PV panels racking

The available area for PV installations will be further reduced depending on the structural limitations imposed by the mounting frames. Inter-row spacing is an important factor that needs to be taken into consideration to prevent shadows cast by a row of panels onto another [21]. A simulation performed by [19] on PVSOL software shows that the
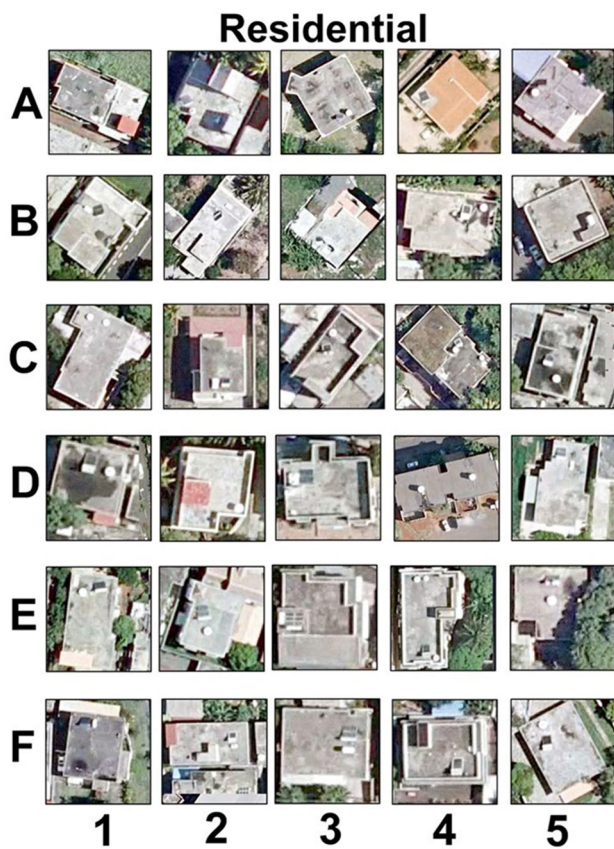
Fig. 5 Sample selection of residential units for analysis

Fig. 6 Sample selection of commercial and industrial units for analysis

PV panels' racking coefficient for an optimum configuration with suitably spaced rows of solar panels turns out to be 0.72. The racking coefficient represents the space between panels on the roofs. We therefore use this conservative value as PV panels' racking coefficient for the case of Mauritius.

Total rooftop area

Digitization of building rooftop areas in Mauritius was performed by the MOHL in 2010. Using the feature extraction tool available in ArcGIS on the digitized layer shapefile, built-up areas corresponding to all nine districts of the country were extracted separately. The next step involved computing the total roof area for the different districts using the area calculator available in ArcGIS. The population census of 2011, carried out nearest to that period of time when digitization of settlement areas was performed, was made available by Statistics Mauritius [22]. Consequently, the population for the above-mentioned districts were acquired. A final low-value point was obtained by digitizing the rooftops of about ten houses in a locality where the population was known beforehand and computing for the total area. A plot of total roof area against population resulted in a linear relationship, with an
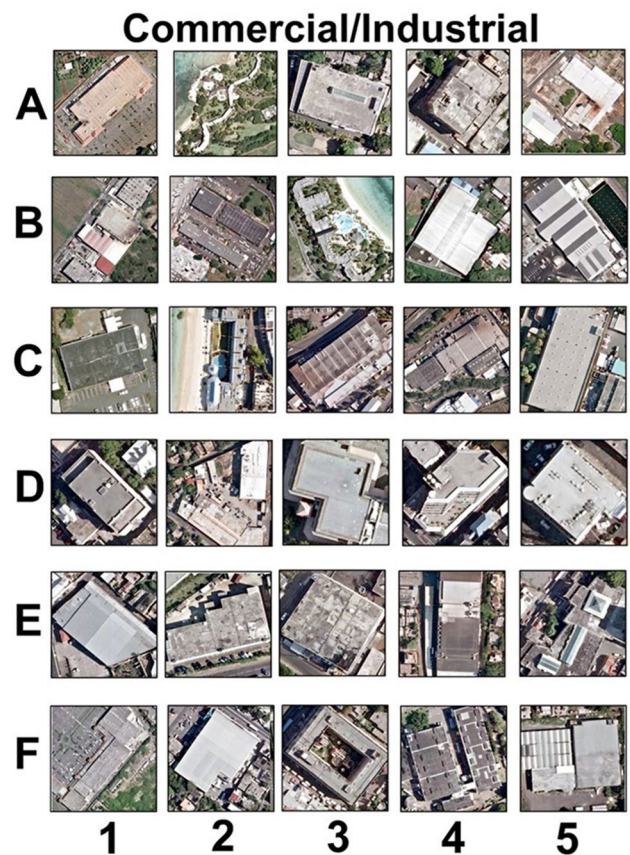
R-squared value of 0.971 as depicted in Fig. 8, indicating excellent correlation across both large and small census subdivisions.

The linear relationship observed in Fig. 8 suggested a total roof area per capita of 94.96 m^2/capita $\pm$ 15% which was later employed in Eqs. (3) and (4) [23]noted values in the range 24.4 m^2/capita to 180.5 m^2/capita for Spain prior to accounting for the effects of reduction from shading and obstructions. Also, [14] reported a value of 70 m^2/capita for the Ontario region of Canada. Consequently, this value of 94.96 m^2/capita was observed to be a fairly reasonable estimate in the Mauritian context when considering the relative density of built-up areas distributed across the island.

A base value of 1567,000 was noted from the y-intercept of the plot in Fig. 8. As suggested by [11], the base value may be explained due to the presence of sparsely developed infrastructure with large vacant spaces and under developed zones with significantly small population. We choose to disregard this value as on the large scale, 1567,000 m^2 lies within the error and is therefore regarded as a negligible corollary of producing a best fit line.
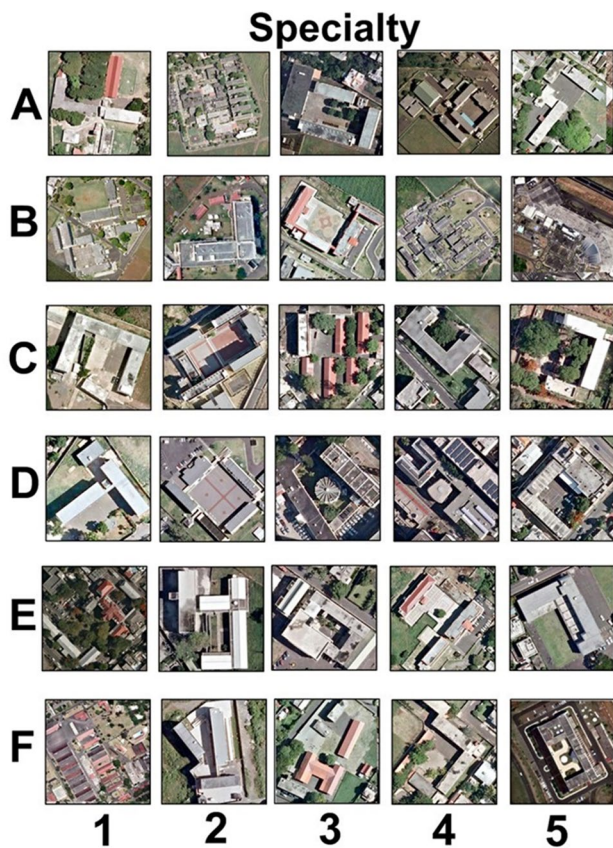
Specialty

Fig. 7 Sample selection of specialty units for analysis

Net energy contribution from PV system

Using Eq. (3), the area available for PV deployment per capita, $A_{PV/capita}$, has been calculated to 59.33 m²/capita $\pm$ 15% ($A_{PV/capita} = 94.96 \times 0.928 \times 0.959 \times 0.975 \times 0.72$). As compared to the available area per capita for Ontario (13.1 m²/capita $\pm$ 6.2%) [14] and Karachi (4.42 m²/capita $\pm$ 5%) [11], the available area for PV deployment in Mauritius is a significantly high value. This is attributed to the relatively high number of flat-roofed buildings with significant amount of unused spaces.

Extrapolation of this result using Eq. (4) to cover the entire region of Mauritius yields a value of 75,070,783 m² $\pm$ 15%. This value is representative of the total available area for rooftop PV deployment which is free of obstructions, shading and other uses whilst being appropriately oriented. It is interesting to note that the available area for PV deployment is about three times higher in Mauritius as compared to south-eastern Ontario [14]. Additionally, it is about 1403 times higher in Mauritius as compared to DHA Karachi Phase 7 [11].

The solar power potential of rooftop PV deployment in Mauritius is estimated at 20.04 GW whilst an annual energy output of 32,512 GWh is expected using crystalline-silicon PV panels. Additional computations reveal that monocrystalline Si based PV systems installed on the rooftops of existing buildings may provide as much as 43.4 times the peak power demand of the country, while poly-crystalline Si can achieve a target of 36.3 times. Thin film and amorphous Si can reach a value of 17.1 times and 16.6 times the peak power demand, respectively. These results highlight the extremely high potential of rooftop PV deployment in Mauritius.

Proposal for a novel Solar City

Having assessed the rooftop PV potential of all existing buildings in Mauritius, the next step involves the proposal of a novel design for an ensemble of buildings at the city scale and having PV panels on their rooftops. This collection of buildings with PV rooftops forming an urban area, will be termed as a Solar City.

Identification of optimum site for Solar City

Identification of a parcel of land for the construction of the Solar City is dependent mainly on five factors: (1) PV resource potential; (2) remoteness from built-up areas; (3) suitability of the topography; (4) proximity to grid transmission network; (5) proximity to main road networks.

Besides the PV resource potential, remoteness from built-up areas is an important factor which had to be taken into consideration since part of the ideology of the current research also aimed at designing a novel city with the large-scale deployment of rooftop PV panels from the ground up. Consequently, one of the criteria was that the identified parcel of land should contain no built-up areas so as to prevent the forced displacement of local residents. Another equally important factor is the fact that the topography of the land surface and surroundings needs to be relatively flat such that unwanted shadows are not cast on the rooftop PV panels by neighbouring hills and mountains. The northern region of the island has been identified as having relatively flat lands (slope < 5%), ideal for construction [10].

Other factors which contribute to the identification of the most suitable region for the construction of a solar city include the proximity to grid lines and road networks. The construction of a Solar City where considerable up-front investments have been made in terms of use of existing infrastructures which include transmission lines and road system, bears significant cost benefits [24]. Using existing infrastructures save on expenditures that would have occurred in amending the current grid and road systems so as to access the selected site. Additionally, the closeness from existing road systems has the benefit of material transportation to the optimum site. Taking these into consideration, the optimum site is identified as presented in Fig. 9.
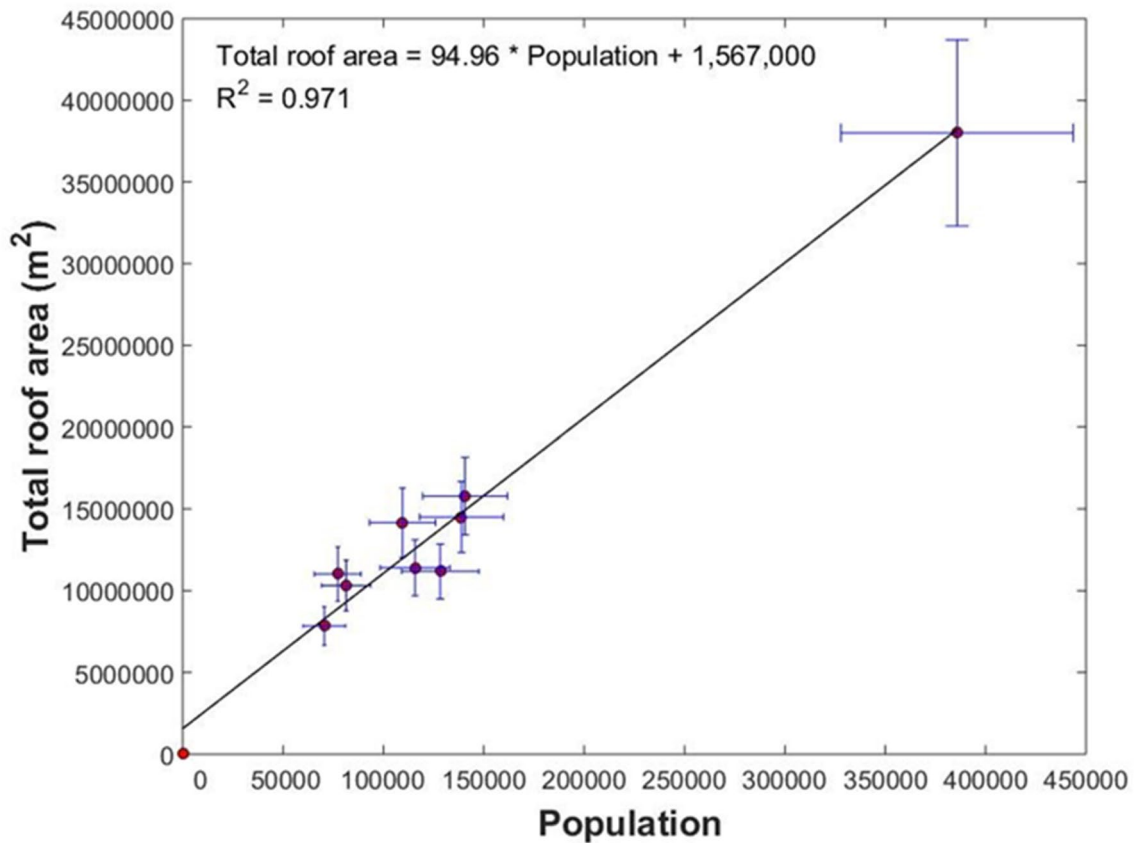
Fig. 8 Total roof area as a function of population for the case of Mauritius. Error bars represent 15% error on each data point

Architectural layout proposal for a Solar City

The concept of Solar City encompasses the deployment of PV energy system in urban environments [25]. This notion stems from the fact that solar PV technology has significantly matured over the last four decades, depicted by reduced costs and rapidly increasing global penetration rates [26]. The Solar City concept has been adopted by numerous countries around the globe. For instance, the Chandigarh city of India, designed by Le Corbusier represents the country's first model Solar City with an aggregate capacity of 11 MW [27]. A 202 kW rooftop PV system on 'Parkview Terrace' multifamily affordable housing has been implemented in California, USA [28]. Germany's city of Freiburg has integrated PV rooftops in the design of the buildings and built to a standard known as 'Passivhaus', which permits energy production to be four times the amount than what is consumed [29].

Cities are economic powerhouses, major energy consumers, and key contributors to environmental degradation. Subsequently, the implementation of such programmes encourages the adoption and dissemination of strategies to improve urban environmental quality and welfare [30]. A proposed design for a Solar City to be situated in the identified optimum site is shown in Fig. 10. The architectural modelling was performed using Google SketchUp (Version: 2008) and the layout was adapted to suit the neighbouring infrastructure.

The electricity generated by the Solar City during daytime will be injected into the island's grid transmission system. Part of the energy harnessed will be dispatched to the city centre and part of it will be fed to residential estates which are attached to the latter. Such a strategy will help promote an eco-friendly city which is self-sustaining in terms of its energy requirements and decrease the country's reliance on imported and polluting fossil fuels. In case where energy generation surpasses consumption, the surplus will be stored in the grid energy storage and dispatched at a later time when production falls below consumption.

As far as thermal comfort is concerned, water features are also integral to the city's scheme in terms of cooling effects. For example, the city's pond and other water features within the several courtyards help to reduce the surrounding temperature thanks to evaporation. In the same way, most of the buildings are slim so as to ease cross-ventilation and allow for proper natural lighting of interior spaces.
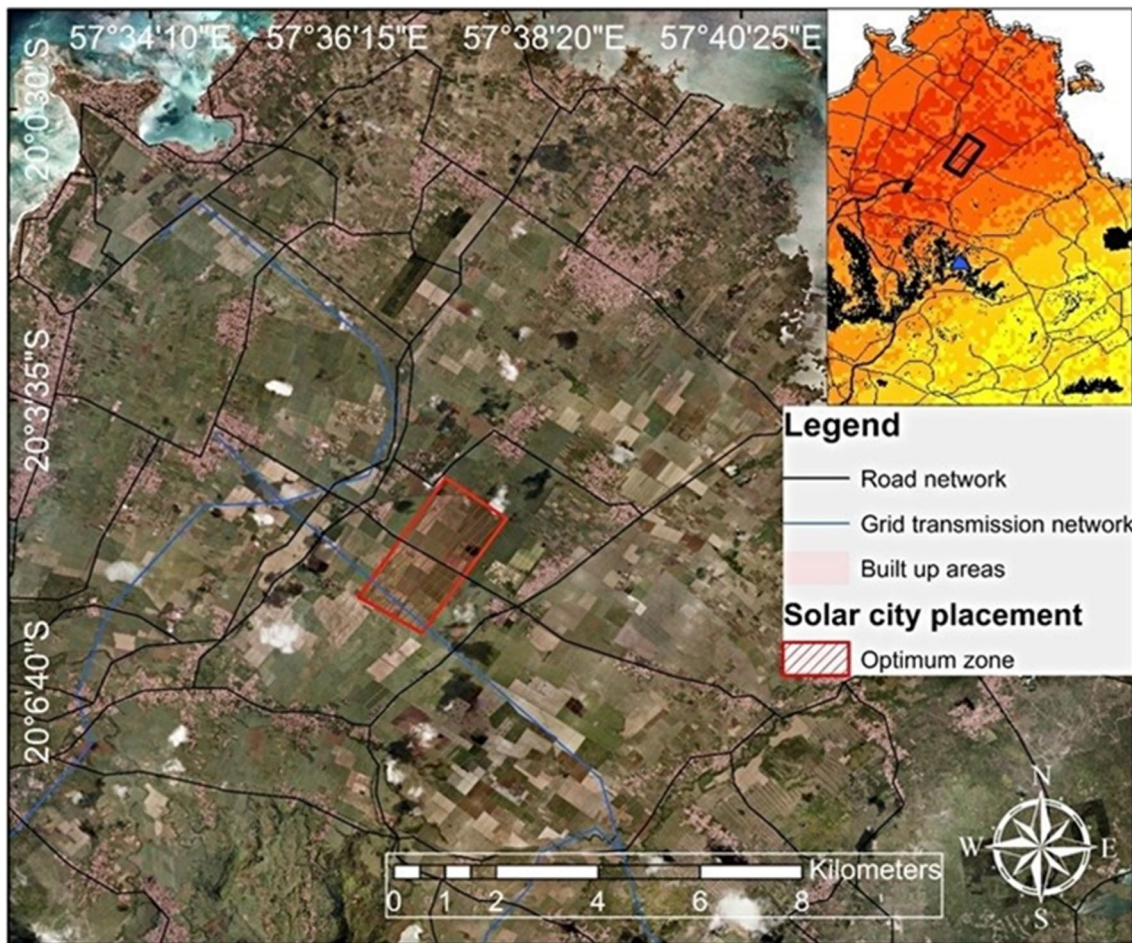
Fig. 9 Location of optimum site for the construction of a Solar City

Component buildings and energy production

The component buildings that make up the Solar City is illustrated in Fig. 11. The relative placement and number of identical buildings within the vicinity of the city is also presented. A solar energy harnessing analysis is performed by applying Eqs. (1) and (2) to the individual building design. The total solar power potential of the Solar City, equipped with mono-crystalline Si PV panels, is estimated at 13.55 MW, whilst the total annual energy output is found to be equivalent to 21.99 GWh.

The main PV solar power plant on the island, Bambous solar farm, has an annual generation capacity of about 24 GWh and is able to avert worth 15,000 tons of CO2 per year [31]. Simple proportion estimates that the construction of the Solar City may help avert worth 13,744 tons of CO_2 per year. Consequently, the construction of the Solar City will act as a solar farm, cater for the environmental needs of a small island developing state, whilst still providing social benefits to inhabitants. The parcel of land identified will be used for the dual purpose of green energy harnessing while still being able to accommodate the social needs of a growing population.

Shading analysis

A shading analysis is performed on the city envelope with the objective to assess the solar energy harnessing capacity of the ensemble of buildings that make up the Solar City. The Solar City proposed consists of mainly low-rise buildings. For example, buildings are mostly 4–5 storeys high, except for the Iconic Tower and the Iconic Office Building that act as a beacon and add strength to the city's main vista. Streets are wide and provide enough space for on-street parking, a bike lane, alleys of trees and pedestrian pathways. It is expected that the leafy trees will cover the streets and stay below the roofline of adjacent buildings to prevent over shadowing. This set up not only makes the city more appealing but it also naturally cools down the street.

The longest shadows are cast at winter solstice when the elevation of the sun is at its lowest point in the sky, while at summer solstice, the shortest shadows are cast [9].
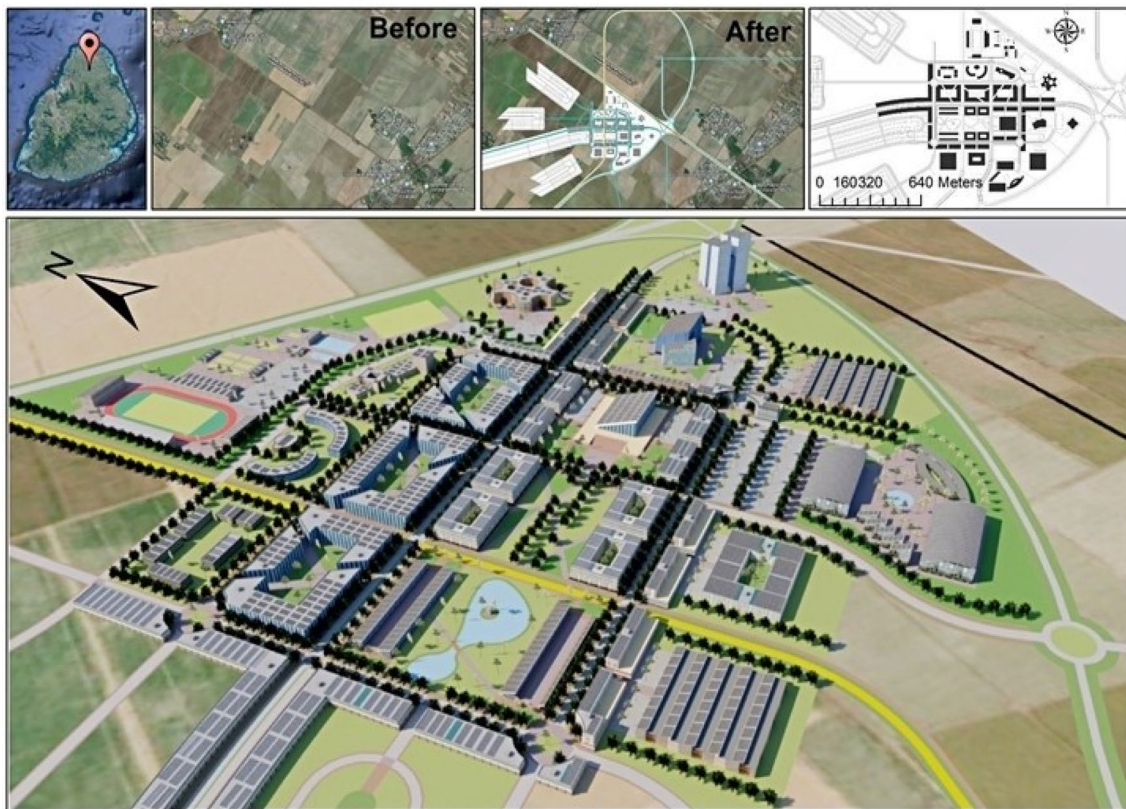
Fig. 10 Proposal of a novel design for a Solar City to be situated in identified optimum site

Consequently, the shading analysis is performed at these two extremes (summer and winter solstices) during normal working hours (9 a.m. and 4 p.m.). At summer solstice, it can be observed that practically no shadow is cast by the buildings at the few exceptions of the Iconic Office Building and the National Arts Centre.

In the morning (9 a.m.) at summer solstice Fig. 12a, shadows cast by the Iconic Office Building, National Arts Centre and Tertiary Institution obstruct about 312.5 m^2, 750.0 m^2 and 250.2 m^2 of neighbouring solar PV panels (Total Shading: 1312.7 m^2), respectively. In the afternoon (4 p.m.), the Iconic Office Building, National Arts Centre and Tertiary Institution cast about 12.5 m^2, 1250.3 m^2 and 375.2 m^2 of shadows (Total Shading: 1638.0 m^2), respectively, on solar PV panels Fig. 12b.

On the other hand, in the morning (9am) at winter solstice Fig. 12c, the Iconic Office Building, National Arts Centre and Tertiary Institution obstruct about 468.8 m^2, 1250.0 m^2 and 75.2 m^2 of neighbouring solar PV panels (Total Shading: 1794.0 m^2), respectively. In the afternoon (4 p.m.) at winter solstice Fig. 12d, the Iconic Office Building, National Arts Centre and Tertiary Institution obstruct about 31.3 m^2, 1339.2 m^2 and 437.5 m^2 of neighbouring solar PV panels (Total Shading: 1808.0 m^2), respectively.

In general, though, it can be observed that the Solar City has been constructed by taking into consideration the effect of shading since the ratio of solar panels obstructed by building structures is practically insignificant.

Practical considerations

Connection to the public network of buildings

Integrating the solar energy derived from the public network of buildings into the national grid constitute a major challenge for local authorities. The main electrical utility of the island has expressed major concerns over the high penetration of variable renewable energy sources in the distribution grid, as it entails grid management and generation planning problems [32]. It is crucial that the energy generated is free from harmonics to avoid occasional imbalances, and electric utilities face the major concern of grid congestion and management during shortages due to the interconnection of several energy sources of variable capacities [33]. Grid management problem might arise owing to the variability in solar energy generation due to the heterogeneity in sky conditions with the presence of passing clouds. These pose a major problem in balancing
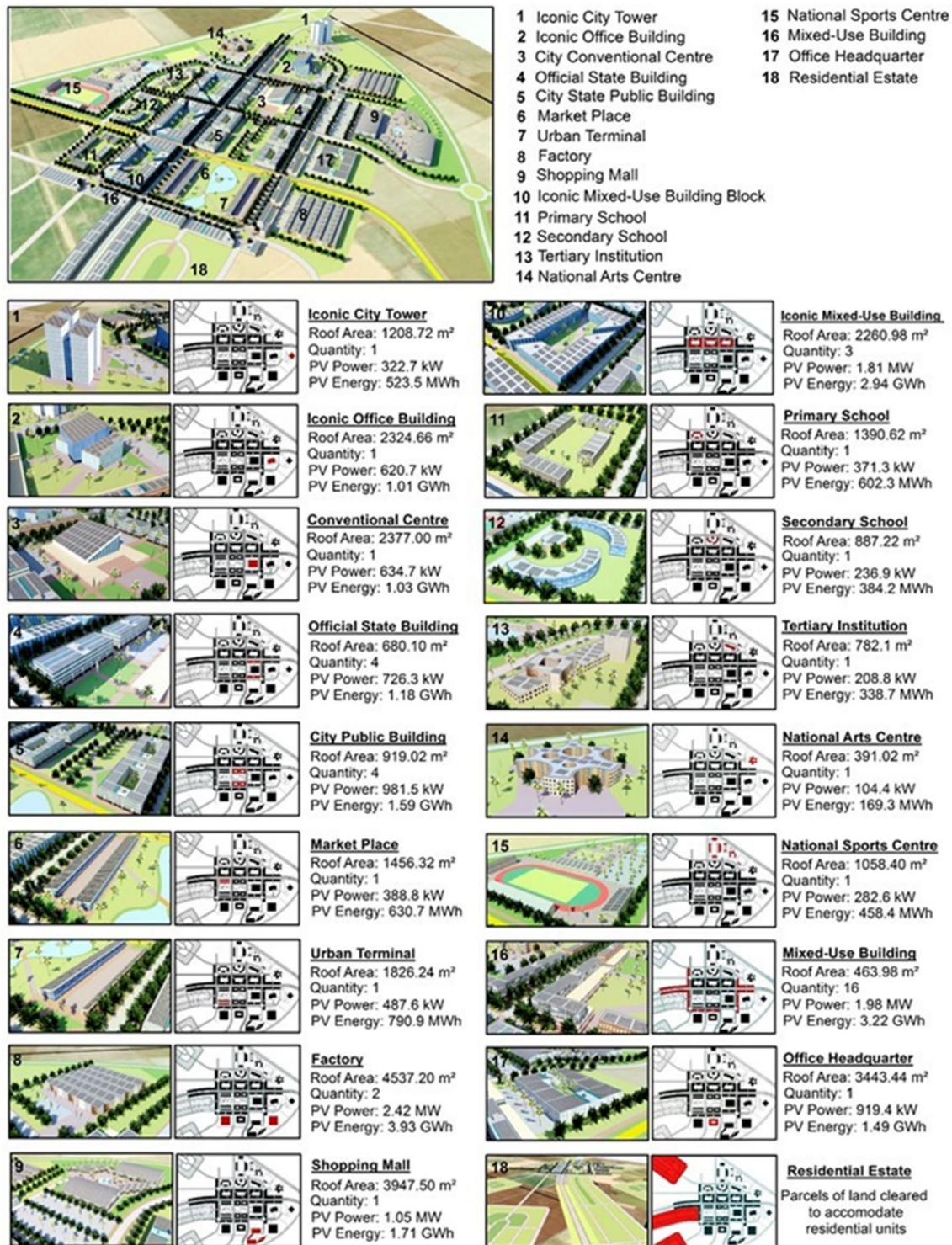
1 Iconic City Tower
2 Iconic Office Building
3 City Conventional Centre
4 Official State Building
5 City State Public Building
6 Market Place
7 Urban Terminal
8 Factory
9 Shopping Mall
10 Iconic Mixed-Use Building Block
11 Primary School
12 Secondary School
13 Tertiary Institution
14 National Arts Centre
15 National Sports Centre
16 Mixed-Use Building
17 Office Headquarter
18 Residential Estate

Iconic City Tower
Roof Area: 1208.72 m²
Quantity: 1
PV Power: 322.7 kW
PV Energy: 523.5 MWh

Iconic Office Building
Roof Area: 2324.66 m²
Quantity: 1
PV Power: 620.7 kW
PV Energy: 1.01 GWh

Conventional Centre
Roof Area: 2377.00 m²
Quantity: 1
PV Power: 634.7 kW
PV Energy: 1.03 GWh

Official State Building
Roof Area: 680.10 m²
Quantity: 4
PV Power: 726.3 kW
PV Energy: 1.18 GWh

City Public Building
Roof Area: 919.02 m²
Quantity: 4
PV Power: 981.5 kW
PV Energy: 1.59 GWh

Market Place
Roof Area: 1456.32 m²
Quantity: 1
PV Power: 388.8 kW
PV Energy: 630.7 MWh

Urban Terminal
Roof Area: 1826.24 m²
Quantity: 1
PV Power: 487.6 kW
PV Energy: 790.9 MWh

Factory
Roof Area: 4537.20 m²
Quantity: 2
PV Power: 2.42 MW
PV Energy: 3.93 GWh

Shopping Mall
Roof Area: 3947.50 m²
Quantity: 1
PV Power: 1.05 MW
PV Energy: 1.71 GWh

Iconic Mixed-Use Building
Roof Area: 2260.98 m²
Quantity: 3
PV Power: 1.81 MW
PV Energy: 2.94 GWh

Primary School
Roof Area: 1390.62 m²
Quantity: 1
PV Power: 371.3 kW
PV Energy: 602.3 MWh

Secondary School
Roof Area: 887.22 m²
Quantity: 1
PV Power: 236.9 kW
PV Energy: 384.2 MWh

Tertiary Institution
Roof Area: 782.1 m²
Quantity: 1
PV Power: 208.8 kW
PV Energy: 338.7 MWh

National Arts Centre
Roof Area: 391.02 m²
Quantity: 1
PV Power: 104.4 kW
PV Energy: 169.3 MWh

National Sports Centre
Roof Area: 1058.40 m²
Quantity: 1
PV Power: 282.6 kW
PV Energy: 458.4 MWh

Mixed-Use Building
Roof Area: 463.98 m²
Quantity: 16
PV Power: 1.98 MW
PV Energy: 3.22 GWh

Office Headquarter
Roof Area: 3443.44 m²
Quantity: 1
PV Power: 919.4 kW
PV Energy: 1.49 GWh

Residential Estate
Parcels of land cleared to accomodate residential units

Fig. 11 Detailed solar energy harnessing analysis of buildings that make up the Solar City alongside with their respective placement

baseload with variable renewable energy sources by maintaining adequate spinning reserve and step load capacity. Consequently, from a practical perspective, the connection of the public network of buildings in the Solar City to the national grid needs to be accompanied with a parallel project aimed at reinforcing the stability of the grid. The following subsection describes how grid stability may be achieved despite the injection of variable solar energy in

Fig. 12 Shadows produced during working hours (9 a.m. and 4 p.m.) for summer and winter solstices

the grid network through the implementation of the Solar City project.

Storage of excess energy

The implementation of pumped storage facilities may be regarded as an important strategy in the Solar City project to achieve grid stability. Pumped storage is particularly useful in cases when there are frequent dips in the generation of an intermittent renewable energy source and when the base-load generators are not responsive enough to these fluctuations. Excess energy from the Solar City may be stored when energy supply exceeds demand, and used at another time of the day when supply falls as demand rises. Despite the propitious conditions for implementing pumped storage facilities in Mauritius to deal with the problem of peak power demand, the capital costs are reported to be particularly high [34]. However, the shift to accommodate a higher share of renewable energy in the mix would need to be accompanied by major investments in storage facilities to support the local grid. Whilst investing in battery may be regarded as a

fairly popular solution to the problem of energy storage, the advantage offered by pumped storage over battery is that the expected life of pumped hydro is longer (~ 100 years) and it requires less maintenance over time [35].

Dealing with complex real-time management problems

In Mauritius, the peak electricity demand has been observed to occur mainly during the week in summer, with a more pronounced effect in the morning [36]. Several demand-side management policies have been adopted in view of stabilizing the peak demand and include the introduction of subsidies on the use of Compact Fluorescent Lamps (CFL), fiscal incentives on the adoption of solar water heaters, and the promotion of efficient energy use through awareness campaigns. However, the rising peak power demand caused by population expansion suggests that supply-side strategies would have to be revisited, besides looking at the demand-side response. While the construction of the Solar City is an effective supply-side strategy to meet the rising power demand, there are several complex real-time management

problems that stem from its implementation. One major problem is the generation of excess electricity that may be an economic burden and require the curtailment of variable renewables [37]. However, the problems arising from the integration of large amounts of intermittent renewable energy in the grid would be mostly solved by investing in adequate storage facilities to reduce curtailment/time-shift by charging when supply exceeds demand and discharging when demand exceeds supply.

Solar City versus distributed rooftop PV deployment on existing buildings

In view of shedding some light on the choice of implementation of centralized versus decentralized electricity generation policies in Mauritius, this subsection attempts to compare phases 1 and 2 of the current study. Despite the fact that there are climate-related benefits stemming from either the implementation of decentralized energy policies targeting the installation of PV panels on the rooftops of existing buildings in the country, or centralized energy policies aiming at the construction of a main city with integrated rooftop PV panels, this subsection attempts to determine the order of importance when it comes to the implementation of policies in a climate-related context.

With an estimated population size of 85,000 inhabitants, the Solar City would have a yearly energy generation capacity of about 0.259 MWh per capita (21,990 MWh/85,000 people). On the other hand, a decentralized rooftop PV system installed on existing buildings of the island would have an annual energy generation capacity of 25.7 MWh per capita (32,512,000 MWh/1265,309 people). Consequently, policy incentivizing the installation of PV panels on the rooftops of existing buildings in Mauritius would generate about 100 times as much energy per capita than the construction of Solar Cities, and should therefore be prioritized. The policy could be in the form of a grant or rebate scheme in addition to installation service facility to encourage the adoption of PV panels on the rooftops of buildings in the country. Nonetheless, innovation in the architectural layout of cities by integrating solar PV rooftops could have tremendous climate-related benefits whilst meeting the energy demand of an increasing population.

Errors and limitations

One of the limitations of the current research is that the digitized roof print areas available were created back in 2010 while the nearest population census data available was that of 2011. Under the assumption that the population in the various districts did not change significantly over that one-year interval from 2010 to 2011, a linear relationship was deduced. From that linear trend, an extrapolation of result

was conducted to determine the total rooftop area of all buildings in Mauritius from the total population census of 2017.

Error has been introduced due to the hand-digitization of rooftops of educational buildings from Google Earth images. The resolution and tilt of the satellite images may have introduced some errors through the overestimation or the underestimation of the actual value. Additionally, the digitized built-up areas made available had overestimated some roof prints. Also, the determination of total roof and shading areas during sampling stages was performed using hand-measurement tools through estimations and led to possible sources of errors.

Since no census data was available regarding the percentage of buildings in Mauritius which were categorised as residential, commercial, industrial, hotel and educational, an arithmetic mean of the reduction coefficients was conducted instead of performing a weighted average. However, this step was justified as the reduction coefficients did not vary much from one building category to another.

The mean absolute error in the footprint areas of the total number of buildings in all nine districts on the island was estimated to 15%. This represents the error on each data value and is represented by the error bars of Fig. 8.

Conclusions

Assessment of rooftop PV potential for islands situated near tropical and subtropical regions is important, in view of reducing their dependence on remote countries to satisfy their energy requirements. Consequently, we present in this study, a methodological framework employed by several countries worldwide, to assess the PV potential of all existing buildings at the country-scale. Buildings were first categorised as residential, commercial, industrial and specialty. An appropriate sampling strategy was thereafter applied based on population density to determine the shading, obstruction and orientation coefficients for the different building types. Extrapolation of the results to the country-scale revealed that the deployment of mono-crystalline Si PV panels on the available roof space of existing buildings in Mauritius can yield about 20.04 GW, with an annual energy capacity of 32,512 GWh.

A second aspect of this study investigates at the possibility of integrating a novel Solar City in an identified optimum site on the island. The city will serve for the dual purpose of solar energy harnessing while catering for the social needs of an increasing population by providing residential and other social facilities. The architectural design of each building is adapted to the Solar City by meeting the main requirement of the buildings' rooftops to be inclined at 20.9° or kept flat to accommodate tilted solar PV panels at 20.9° and oriented

northwards. An energy analysis conducted revealed that the Solar City has a power potential of 13.55 MW, with a total annual energy capacity of 21.99 GWh and would help avert worth 13,744 tons of CO_2 per year. A shading analysis performed, showed that the city has been designed by taking into consideration the effect of shadows cast by building structures and that can attenuate the solar energy harnessed. The shadows cast on PV panels in the Solar City are practically insignificant throughout the year.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. D'Amore, L., Kalifungwa: Meeting the challenges of climate change to tourism: case studies of best practice. . Cambridge Scholars Publishing, Cambridge (2014)
2. Obergassel, W., Arens, C., Hermwille, L., Kreibich, N., Mersmann, F., Ott, H.E. and Wang-Helmreich, H. Phoenix from the ashes: an analysis of the Paris Agreement to the United Nations Framework Convention on Climate Change. 2015
3. Moka.mu. Moka, a sustainable city that focuses on solar energy, Available online at https://www.moka.mu/en/blog/smart-solutions/a-sustainable-city-that-focuses-on-solar-energy/. (2019). **[Accessed on 9 Nov 2020]**
4. GCF. Accelerating the Transformational Shift to a Low Carbon Economy in the Republic of Mauritius, available online at: https://www.greenclimate.fund/documents/20182/574760/Fundingproposal-FP033-UNDP-Mauritius.pdf/f9678474-67eb4083-9479--dcae6db59f0. (2016). **[Accessed on 30 Apr 2018]**
5. EDB. Renewable energy, Available online at https://www.edbmauritius.org/opportunities/renewable-energy/. (2020). **[Accessed on 9 Nov 2020]**
6. Duvat, V.K., Anisimov, A., Magnan, A.K.: Assessment of coastal risk reduction and adaptation-labelled responses in Mauritius Island (Indian Ocean). Reg. Environ. Change **20**(4), 1–15 (2020)
7. SM. Population and Vital Statistics - Year 2017, Available online at: http://statsmauritius.govmu.org/English/Publications/Documents/2018/EI1367/PopVitalYr17.pdf. (2018). **[Accessed on 24 Apr 2018]**
8. SM. Population Growth and Distribution, Available online at http://statsmauritius.govmu.org/English/Pages/2000/volumeIV/popu.htm. (2000). **[Accessed on 24 Apr 2018]**
9. Doorga, J.R.S., Rughooputh, S.D., Boojhawon, R.: High resolution spatio-temporal modelling of solar photovoltaic potential for tropical islands: case of Mauritius. Energy **169**, 972–987 (2019)
10. Doorga, J.R., Rughooputh, S.D., Boojhawon, R.: Multi-criteria GIS-based modelling technique for identifying potential solar farm sites: a case study in Mauritius. Renew. Energy **133**, 1201–1219 (2019)
11. Khan, J., Arsalan, M.H.: Estimation of rooftop solar photovoltaic potential using geo-spatial techniques: a perspective from planned neighborhood of Karachi-Pakistan. Renew. Energy **90**, 188–203 (2016)
12. Assouline, D., Mohajeri, N., Scartezzini, J.L.: Quantifying rooftop photovoltaic solar energy potential: a machine learning approach. Sol. Energy **141**, 278–296 (2017)
13. Dehwah, A.H., Asif, M.: Assessment of net energy contribution to buildings by rooftop photovoltaic systems in hot-humid climates. Renew. Energy **131**, 1288–1299 (2019)
14. Wiginton, L.K., Nguyen, H.T., Pearce, J.M.: Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. Comput. Environ. Urban Syst. **34**(4), 345–357 (2010)
15. Gagnon, P., Margolis, R., Melius, J., Phillips, C., Elmore, R.: Estimating rooftop solar technical potential across the US using a combination of GIS-based methods, lidar data, and statistical modeling. Environ. Res. Lett. **13**(2), 024027 (2018)
16. Green, M.A., Hishikawa, Y., Dunlop, E.D., Levi, D.H., Hohl-Ebinger, J., Ho-Baillie, A.W.: Solar cell efficiency tables (version 52). Prog. Photovoltaics Res. Appl. **26**(7), 427–436 (2018)
17. Doorga, J.R., Rughooputh, S.D., Boojhawon, R.: Modelling the global solar radiation climate of Mauritius using regression techniques. Renew. Energy **131**, 861–878 (2019)
18. MESD. Moving towards renewable energy-Solar water heater grant scheme, Available online at: http://download.govmu.org/files/2016/MOVING%20TOWARDS%20RENEWABLE%20ENERGY%20-SOLAR%20WATER%20HEATER%20GRANT%20SCHEME.pdf. (2017) **[Accessed on 26 Dec 2018]**.
19. Dehwah, A.H., Asif, M., Rahman, M.T.: Prospects of PV application in unregulated building rooftops in developing countries: a perspective from Saudi Arabia. Energy Build. **171**, 76–87 (2018)
20. Wiki. List of building types, Available online at: https://en.wikipedia.org/wiki/Listofbuildingtypes#Specialty. (2018) **[Accessed on 24 Dec 2018]**
21. Noorollahi, E., Fadai, D., AkbarpourShirazi, M., Ghodsipour, S.H.: Land suitability analysis for solar farms exploitation using GIS and fuzzy analytic hierarchy process (FAHP)—a case study of Iran. Energies **9**(8), 643 (2016)
22. SM. Population and vital statistics—year 2011, Available online at http://statsmauritius.govmu.org/English/Documents/demography2012.pdf. (2011) **[Accessed on 24 Dec 2018]**.
23. Izquierdo, S., Rodrigues, M., Fueyo, N.: A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations. Sol. Energy **82**(10), 929–939 (2008)
24. Szabó, S., Moner-Girona, M., Kougias, I., Bailis, R., Bódis, K.: Identification of advantageous electricity generation options in sub-Saharan Africa integrating existing resources. Nat. Energy **1**(10), 1–8 (2016)
25. Scheer, H. Solar city: reconnecting energy generation and use to the technical and social logic of solar energy. In: Urban energy transition. Elsevier, pp. 15–26 (2008)
26. REN21. Renewable energy policy network for the 21st century (REN21), Available online at: http://www.ren21.net/Portals/0/documents/Resources/GSR/2013/GSR2013highres.pdf. (2013). **[Accessed on 3 Mar 2019]**.
27. RenewableWatch. Model Solar City—Chandigarh puts its rooftops to good use, Available online at: https://renewablewatch.in/2017/06/01/modelsolar-city/. (2017) **[Accessed on 6 Mar 2019]**.
28. Renewableenergyworld.com. California Bridges the Green Divide with Nation's Biggest Solar Program for Low-income Renters, Available online at: http://www.renewableenergyworld.com/articles/2016/02/california-bridges-the-green-divide-with-nation-sbigg

estsolar-program-for-low-income-renters.html. (2016). **[Accessed on 8 Mar 2019].**

29. Inquisitr.com. Germany builds a solar city that produces four times the energy it consumes, available online at https://www.inquisitr.com/1982709/germany-builds-a-solar-city-that-produces-fourtimes-the-energy-it-consumes-video/. (2015). **[Accessed on 9 Mar 2019].**

30. Byrne, J., Taminiau, J., Kurdgelashvili, L., Kim, K.N.: A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. Renew. Sustain. Energy Rev. **41**, 830–844 (2015)

31. Sarako.mu. Mauritius now exploiting solar energy, Available online at: http://www.sarako.mu/en/80/mauritius-now-exploiting-solar-energy.html, (2014). **[Accessed on 1 Mar 2019]**.

32. Carnegie Clean Energy. High penetration renewable energy roadmap for the Republic of Mauritius, Available online at http://www.mric.mu/English/Documents/High%20Penetration%20Renewable%20Energy%20Roadmap%20-%20Republic%20of%20Mauritius2018.pdf. (2017). **[Accessed on 14 Nov 2020]**

33. Goel, M.: Solar rooftop in India: Policies, challenges and outlook. Green Energy Environ. **1**(2), 129–137 (2016)

34. Elahee, M.K.: Potential of hydropower in Mauritius: myth or reality? Energy Sources Part A **35**(10), 921–925 (2013)

35. Entura. Battery vs pumped hydro – Are they sustainable?, Available online at https://www.entura.com.au/batteries-vs-pumped-storage-hydropower-are-they-sustainable/. (2017) **[Accessed on 18 Nov 2020]**

36. Elahee, K.: The challenges and potential options to meet the peak electricity demand in Mauritius. J. Energy Southern Afr. **22**(3), 8–15 (2011)

37. Edoo, M.N., King, R.T.A.: New insights into the technical challenges of the Mauritius long term energy strategy. Energy **195**, 116975 (2020)