AIMS Energy

AIMS Energy, 6(3): 436–452.
DOI: 10.3934/energy.2018.3.436
Received: 29 March 2018
Accepted: 20 May 2018
Published: 25 May 2018

http://www.aimspress.com/journal/energy

Research article

Assess the local electricity consumption: the case of Reunion island through a GIS based method

Fiona Bénard-Sora[1,]*, Jean-Philippe Praene[1] and Yatina Calixte[2]

[1] University of La Reunion, PIMENT Laboratory, 117 rue du Général Ailleret 97430 Le Tampon, France
[2] University of La Reunion, Department of Building Sciences and Environment, France

* **Correspondence:** Email: fiona.sora@univ-reunion.fr; Tel: +0262579141.

Abstract: Succeeding energy transition is the current challenging objective of many remote islands such as Reunion Island to reduce their dependency to fossil resources. To define an efficient energy framework strategy for the territory, it is important to be able to assess the electricity consumption intensity per typology of consumers. A particular attention must be paid on building electricity consumption in energy planning scenarios. This paper proposes to investigate the electricity consumption ratio per square meter per building type which appears as a relevant indicator. The proposed methodology aims at filling the lack of data (ratio kWh/m^2/ type of consumers) when this information doesn't exist for a territory. This type of ratio can be useful in two ways: on the one hand to characterize the building energy demand, and, on the other hand, to understand the consumption mode of the inhabitants. We can therefore provide future energy policy framework in favor of demand-side management what is a key step, a lock to solve for the deployment of sustainable cities. This work calculates electricity consumption ratios per area by using a GIS (Geographic Information System) method, distinguishing the type of building. The case of Reunion Island is studied and four building categories are identified corresponding to the functional characteristics such as industry, administration, companies and residential. The results highlight that residential sector has one of the lowest electricity ratios with a value of 29.84 kWh/m^2, but also the highest part of electricity consumption, 45.2%. The different ratio value has been cross validated by estimating municipalities electricity consumption based on the distribution of consumers and the associated ratio.

Keywords: electricity consumption ratio; building typology; GIS

1. Introduction

Energy efficiency and greenhouse gases reduction of new buildings are key objectives of international, national and local policies that aim to decrease electricity use in buildings. In France, the first regulations in this direction followed the oil shocks of the 1970s and the French government's desire to secure its energy situation. To secure its situation, it sought to reduce demand on the one hand and launched its nuclear program on the other. The first thermal regulation of buildings (RT1974) in France sets a target of reducing the energy consumption of buildings by 25% compared to the standards in force since the end of the 1950s [1]. This first objective was subsequently updated by a fairly rich French legislative package: LAURE, the French Law on Air quality and the Rational Use of Energy [2], POPE, the Energy Program Act [3], ENE, the Grenelle II law [4], TEPCV, the law on energy transition for green growth [5]. This thermal regulation was followed by numerous updates. The RT2012, currently in force, will be soon replaced: a RT2020 is planned. These objectives of energy saving in buildings are well present in the French energy policy and in order to help implement this policy it is important to characterize the consumption of buildings by distinguishing in particular their function: tertiary, industrial and residential. This type of characterization is generally done by energy agencies such as the IEA (International Energy Agency) or ADEME in France.

Buildings are the main consumers of energy in our modern societies and acting on them is unavoidable [6]. In France, the residential-tertiary sector is the main consumer of final energy (45%) [7]. This shows the importance of studying buildings and the interest of differentiating buildings, according to their function [8]. Studying the characteristics of buildings for the analysis of their energy consumption and their carbon emissions is common in the literature [9] and especially in the study of housing [10].

Our work focus on the final energy consumption in buildings, but more particularly on electricity consumption on Reunion Island. This type of data is actually produced at the national level, but most of it does not exist in the ultra-marine territories, which nevertheless benefit from their own thermal regulations with regard to their specific climatic characteristics. The energy question is assessed at different scales. At the regulatory level, coherence must exist between the different levels: international, national and local. For territories such as island territories, the local part is of particular importance, especially when the territory is attached to a distant metropolis. Energy issues are certainly international, at the local level the stakes can be very diversified. Nevertheless, local planners are regularly confronted with a lack of data on these energy issues [11]. By combining electricity consumption data by type of consumer and GIS data produced by a local energy agency (SPL Energies Reunion) [12] and the IGN (National Institute of Geography) respectively, we propose new methodology to define consumption ratios by highlighting the different building functions. The interest of the work is twofold: initially, it is a matter of creating a data still non-existent on the island. On the second stage, this work should be seen as the answer to a broader problem: urban planning in a context of ecological transition where the issue of energy is central. The urban planning represents an effective tool to improve the sustainable development and produce/favor the emergence of energy-efficient cities [13]. A first work to characterize the consumption of electricity has already been carried out on Reunion Island: the work was done at the municipal level and highlighted the determinants of electricity consumption [14]. The objective is now to refine the scale and highlight consumption ratios by type of surface. Instead of considering communal consumption, we consider the consumption by type of consumer, which allows, by crossing with the building databases of the IGN, to produce the ratios. The first work allowed a classification of the municipalities, the present work should make it possible to produce a new visualization of the spatialized consumptions of electricity.

2. Methodology

2.1. Context: Reunion island, a small island facing the challenge of energy transition

The work concerns the island of La Reunion which is characterized by a particular economic situation. The island is a French overseas department widely sustained by the French government. It is the tertiary sector that dominates the economy of Reunion, with 83.6% of GDP in 2014. The agricultural and industrial sectors are thus down with respectively 1.4 and 7.7% of GDP.

Another main characteristic of the island of Reunion is its steep relief: this forces the population and the activities to gather on the littoral and especially on the west coast (see Figure 1).

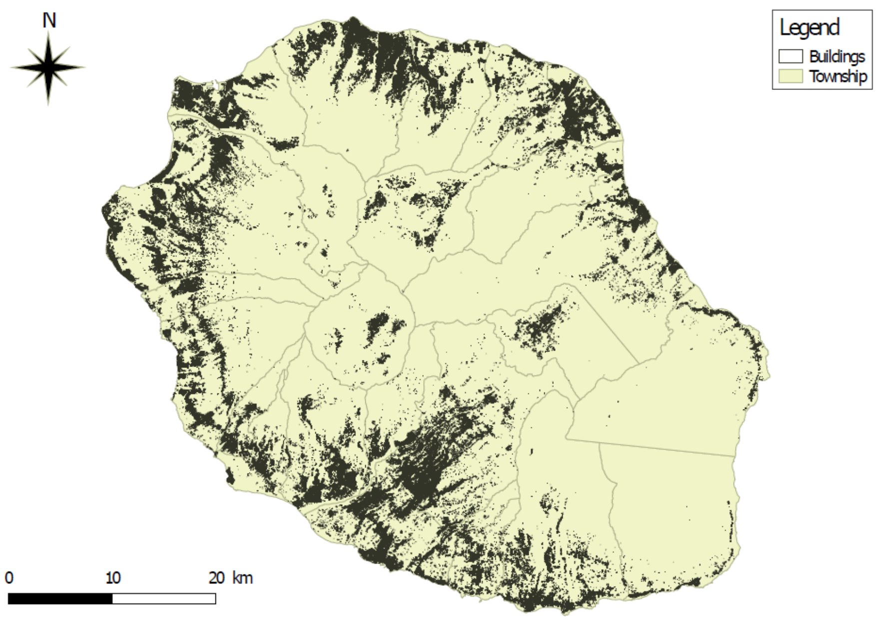

Figure 1. Spatial distribution of buildings.

Reunion Island imports most of its energy resources, including 65% of petroleum products used in transportation, power generation, agriculture and industry. In 2015, the supply of fossil fuels is 1,238.8 ktoe. The local electricity production from renewable resources is 196.4 ktoe, with bagasse and hydraulics as major resources (54% and 22% of local resources respectively). As regards consumption, in 2015, the island shows a primary energy consumption of 1,411.2 ktoe [12].

Like many islands, Reunion Island faces a major problem: the electrification of its rural areas. This type of area is difficult to access, and low density does not provide a cost-effective electricity service for the providers from the global network. Decentralized management of these areas in terms of electricity is often more profitable [15], but the level of poverty of the type of households residing in these areas does not always allow autonomous management [16,17].

2.2. The purpose of a GIS approach

The GIS approach is a useful approach for both quantifying and qualifying a phenomenon. The integration into a single system of analysis of models directly connected to real data facilitates the appropriation of the problem by different stakeholders and consequently permit the development of policy [18]. The GIS approach can build territorial development strategies, develop evolution scenarios and thus improve the process of policy-making.

GIS represents an important analytical potential for the study of energy at the scale of a territory, whether for application to renewable energies or for the modeling of energy consumption [19]. In the scientific literature, it is easy to distinguish several categories of GIS-based models that highlight their potential for urban and energy analysis and policy-making. Indeed, much work has focused on the study of renewable energy potential, whether it is about the solar resource [20–23], the wind resource [23–26] or coupling different resources [27,28]. A number of others studies have focused on urban building energy consumption and microclimate [29–32].

Finally, other work has focused on the spatial study of energy consumption and carbon emissions [33,34].

GIS-based analysis can also be coupled with BIM analysis, as can be demonstrated by recent work on the smart city and urban energy [35] or the connections between a building and its direct urban environment [36].

Since the end of the 1990s, Reunion Island has embarked on an intensive policy to achieve energy autonomy. Promotion of renewable energies, generalization of solar water heaters, coupling of renewable energies with the productive activities of the territory, notably agricultural, energy renovation of buildings, actions to promote energy autonomy are diversified. These efforts have made it possible to achieve a suitable level of green electricity production: in 2015, renewable energy accounted for 36% of electricity production in Reunion, for a total delivered value 2891.3 GWh. Projects for the energy renovation of housing units and the installation of solar water heaters throughout the island to reduce electricity consumption are two axes of a clean policy at the local level: integrating the inhabitants into the energy transition. Indeed, the political authorities raise the importance of integrating the population to make this transition a success. Understanding the consumption of the population is an essential element to better guide them towards change while continuing to meet their needs. An advantage also lies in the ability to locate this consumption. In Reunion, this type of data is not available to the public and must therefore be reconstituted. The method of reconstruction by GIS makes it possible to consider the existing and thus offers a faithful description of the reality.

2.3. Data collection and main assumptions

The objective of this work is to calculate electricity consumption ratios per square meter of built-up area (distinguishing the type of building) by year. In Reunion, there are consumption ratios per inhabitant, but there is no ratio by type of building. However, this type of ratio could make it possible to better simulate urban sprawl or densification by combining electricity needs. The ultimate goal is therefore to forecast the electricity needs of the territory down to the finest possible scale: the building. Two information is needed to calculate this ratio: information on electricity consumption (GWh), and information on the type of building (m^2). For the consumption of electricity, the examination of the BER data was used. For the building surface data (and the typology), it is the INSEE, IGN and Agorah data coupled with the author's knowledge of the territory (see Figure 2).

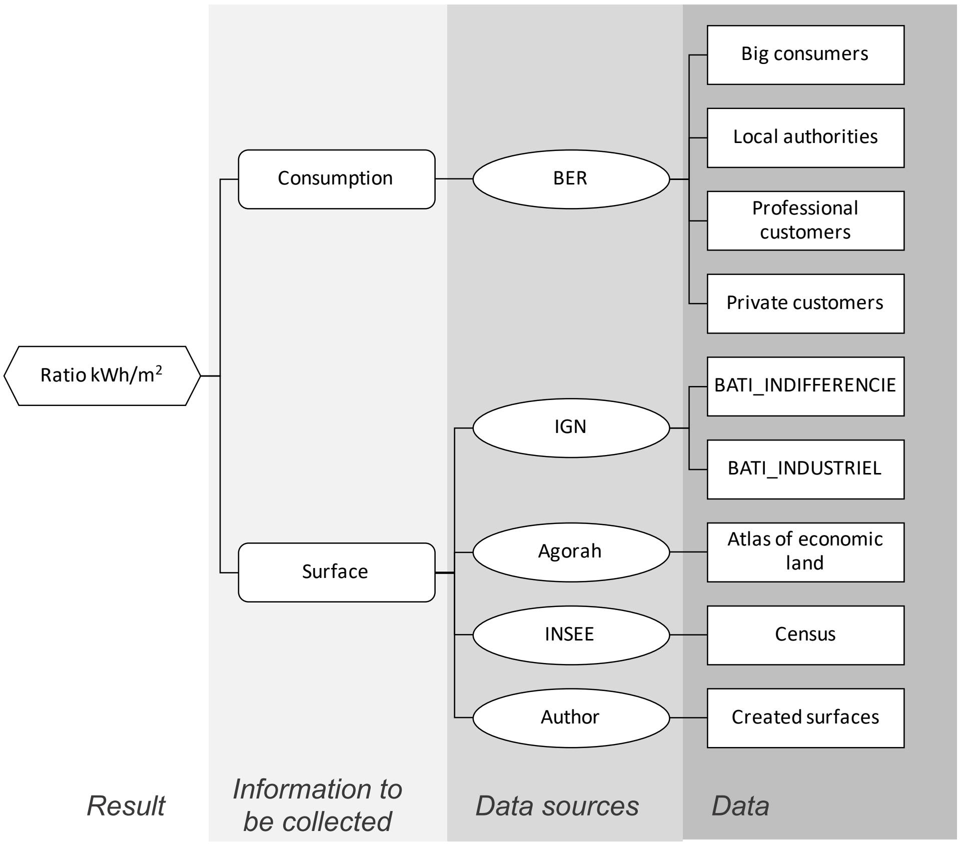

Figure 2. Methodology.

The work is based on a GIS based method and propose a ratio of energy consumption per unit area ($kWh/m^2/yr$). The ratio will also allow distinguishing the type of building. The buildings of the whole territory of Reunion Island are considered. These buildings—which are assimilated to EDF (Electricité de France: Historical electricity supplier in France) "customers"—are segmented into four categories in the Reunion Energy Review (BER) of the Energy Observatory Reunion led by SPL Energie Reunion (see Figure 3):

(1) big consumers, who represent manufacturers, hospitals and airports;
(2) local authorities which means all the premises of the devolved and the decentralized administrations of the French government (Town halls and their annexes, intercommunal bodies, prefectures and sub-prefectures, regional council…), and schools (nursery schools, elementary schools, secondary schools);
(3) professional customers: companies;
(4) private customers: residential customers.

Private customers represent the majority of customers with 329,087 customers out of a total of 370,397, accounting for 45.2% of total consumption (the largest consumer item). The smallest consumer item is local authorities with 16.7% of consumption. It should be noted that the big consumers (hospitals and industry) represent only 1440 customers but 34.6% of consumption. This suggests that the big consumer category should have the highest consumption ratio per unit area, while individual customers should have a much lower ratio.

Thus, the electricity consumption data are taken from the BER and the data on the surfaces must be produced.

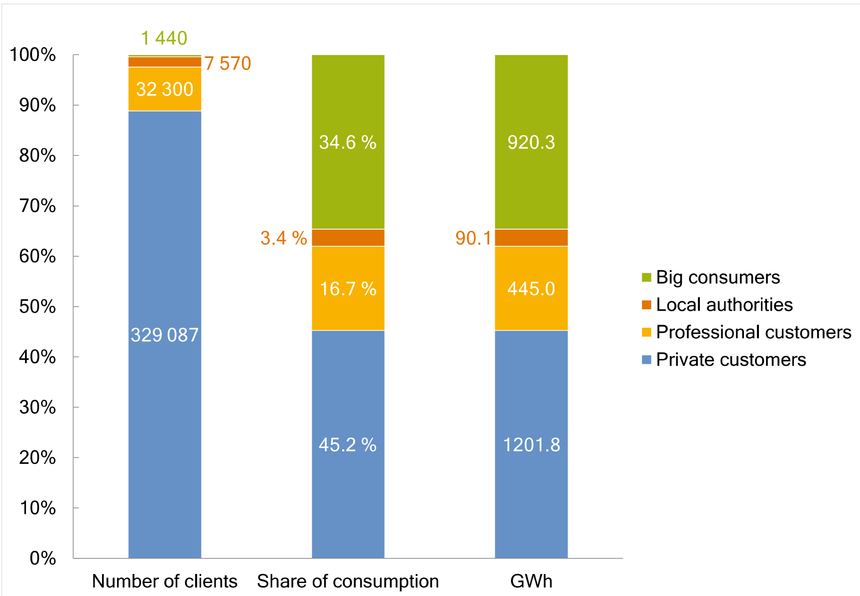

Figure 3. Customers segmentation and share of consumption (2015) Source: EDF-OER.

The methodology proposed is the use of GIS, and more particularly of free and open source software, Quantum GIS (QGIS). It consists of inventorying existing buildings using the IGN's topographic databases: "BATI_INDIFFERENCIE" and "BATI_INDUSTRIEL". To complete the analysis, we use the databases of the census led by the INSEE (National Institute for Statistics and Economic Studies) (RGP on 2013) which supplies data on the number of housing by IRIS zones (statistical division of the French territory).

One of the difficulties of the work rests on the identification in the layers of the IGN of the categories of building by segmenting into four categories (corresponding to the types of customers identified by EDF).

The buildings of the four categories of consumers considered belong to different vector layers:

(1) for the big consumer category: manufacturers correspond to the "BATI_INDUSTRIEL" layer; the hospitals are identified in the "BATI_INDIFFERENCIE" layer and the airports are identified in these two layers. The identification work has been easy here, due to the small number of buildings to be treated and the knowledge of the territory.

(2) for local authorities: the majority of local authorities is in the "BATI_INDIFFERENCIE" layer. The comparison between the total number of local authority customers provided by the BER and the number of customers (buildings) obtained by mapping was necessary for the treatment of this category. The analysis was complemented by the census of the premises on the official websites of the institutions.

(3) professional and private customers correspond to all remaining buildings.

It is therefore on these two latter categories that the work has been more complicated, because belonging to the same layer which is by definition undifferentiated.

For each of the categories of consumers, the buildings missing from the initial layers had to be created.

All the filters and layer mergers that the job required were performed on QGIS. The creation of four vector files corresponding to the four categories of consumers is the basic element for the calculation of the occupied surfaces. For the calculation of the surfaces, it is done by the addition of a new calculation field in the attribute table.

2.4. Special cases

The categories of professional customers and private customers were the most complex to deal with because the vector files of the IGN do not bring any distinction between those two categories. Two possible methods have been identified to separate these two categories. The first is based on the use of information from INSEE and DEAL on the number of dwellings (individual and collective, social and private) to determine the area of residences and then deduct the area of businesses. The second method is based on the use of GIS by considering the total area of firms based on hypotheses based on the work of the Agorah (Regional planning Agency) and the IGN's data and then deduct the area of dwellings. The second method has brought the most satisfaction in terms of precision.

2.4.1. Professional customers

The treatment of this category consists of determining the surface area of buildings of professional clients. To achieve this, the method was to cross two databases:

(1) the basis of the Atlas of economic land produced by the Agorah, which necessitated the creation of 115 zones of activities on QGIS with the help of the IGN Parcel Database.

(2) the base "surfaces_activites" of the IGN Carto database.

The crossing between these two bases and the database including the building made it possible to collect the buildings hosting companies.

The selected buildings then required treatment. Indeed, the hypothesis advanced is that an entity (a building on the vector file) represents a company or a customer. However, the BER informs about the number of professional clients on the island. In addition, NFX35-102 recommends precisely the dimensions of office work spaces and a minimum space of 10 m^2 (Service-public-pro.fr, 2016). All entities whose surface area exceeds 10 m^2 will then be retained. Thus, the area of firms obtained by mapping is thus the sum of the surfaces of the buildings greater than or equal to 10 m^2. The average area per entity was then calculated. The BER data and the number of entities obtained from GIS differ. In order to complete the analysis and obtain a total surface area, this difference was multiplied by the average area per entity. The addition of this latter calculation thus makes it possible to obtain a total area occupied by the businesses.

2.4.2. Private customers

The processing of this category comes last. It results from the subtraction between the total building and the building corresponding to the categories big consumer, local authorities and professional customers. The problem at this stage is related to the GIS analysis. In fact, only surfaces on the ground are obtained. However, for the housing category it is necessary to consider several levels of floors.

No database is able to obtain this type of information. Therefore, a coupling between the INSEE housing data and the surface data is required. In order to consider a number of floors to be allocated to IRIS, it is necessary to consider the diversity of IRIS and thus to produce classes of IRIS.

To do this, we proceed by learning data: a classification by Natural Ruptures (Jenks), a discretization method which consists of minimizing intra-class variances and maximizing inter-class variances, was carried out under QGIS and 11 classes are highlighted. For the learning, the IRIS-Habitat of Saint-Denis are used. The Habitat type is chosen because the treatment takes place in the category of dwellings, the commune of Saint-Denis is selected because the first 9 IRIS the densest in terms of housing belong to this commune.

Thanks to the classes identified by QGIS, we then allocate a number of floors thanks to a field analysis. This number of floors remains an average and IRIS zoning leads to a bias in the analysis (a density on the island would have been more judicious, but the data does not exist).

The following map summarizes the result of the processing of this category (Figure 4). The classification thus carried out reveals two zones of high density in the North and West of the island and some areas of medium density in the South.

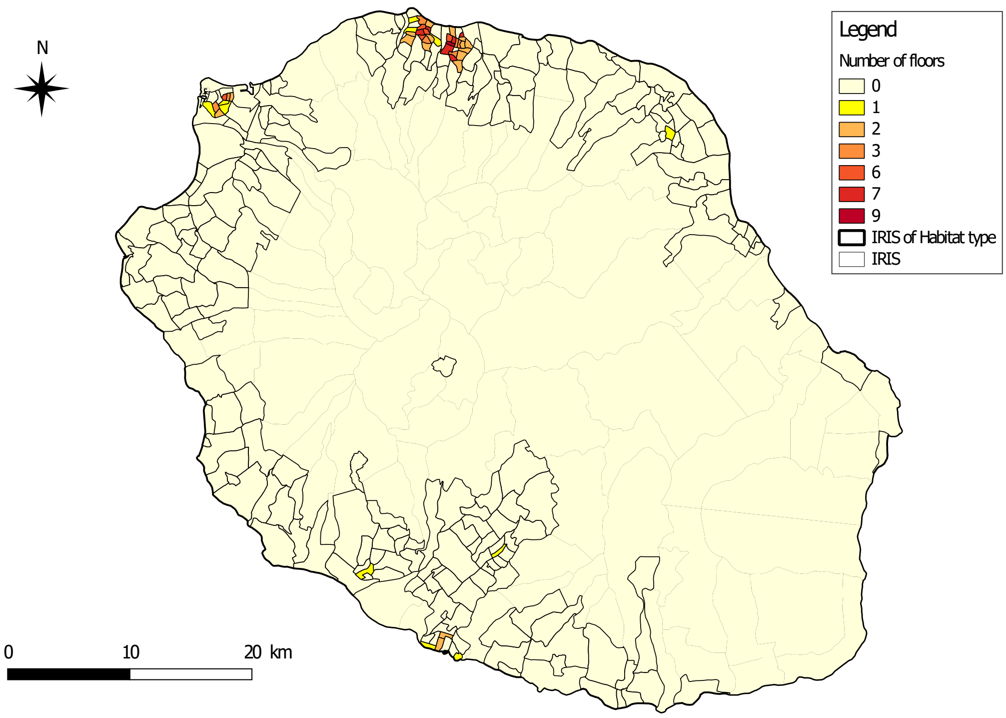

Figure 4. Classification of IRIS by density of residence.

3. Results

An analysis of the entire island structure was carried out and showed a total construction area of 5,515 hectares for a total consumption of 2,657.2 GWh for 2015. This represents an overall consumption of 76.94 kWh/m^2/yr for all sectors combined. This represents 370,397 customers throughout the territory. The results for the four customer categories are presented in the following table (Table 1).

Table 1. Consumption (2015), area and ratio by customers type.

Customers category	Customers type	Electricity consumption (GWh, 2015)[1]	Area (m²)	Ratio (kWh/m²/yr)
Big consumers	industries, hospitals, airports	920.3	5,038,588.000	182.65
Local authorities	Administrations, annexes, schools	90.1	3,260,351.336	27.64
Professional customers	businesses	445	6,578,735.574	67.64
Private customers	residences	1,201.8	40,276,767.000	29.84
Total		2,657.2	55,154,441.910	48.18

[1] source: (Observatoire Energie Réunion, 2016)

Big consumers logically display a higher unit consumption with 182.65 kWh/m^2. The municipalities with the highest consumption are also the most endowed by the area occupied by big consumers (Figure 5).

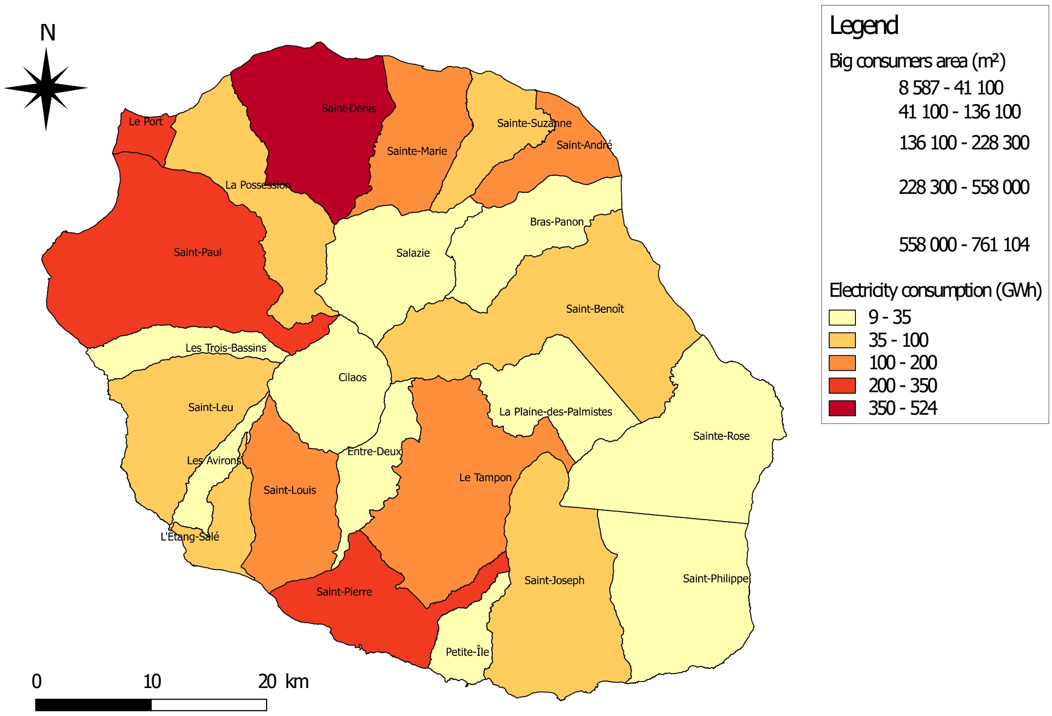

Figure 5. Electricity consumption and big consumers.

Local authorities have the lowest ratio. This is easily explained by the way in which the administrations and schools run: the premises are open only a few hours a day (about 10 hours a day) or even a month (especially for annexes and even schools that are closed weekends and several weeks a year).

Professional customers have a high ratio of 67.64 kWh/m^2. The mode of operation is necessary energy-intensive for this type of consumer, especially because of the use of specific equipment.

Finally, private customers have a ratio of 29.84 kWh/m^2. This ratio is close to the ratio of the BER (with an error of less than 5%), which makes it possible to validate our methodology.

4. Discussion

The "BBC" standard (low energy consumption building standard) imposed by the 2012 thermal regulation in France means a set of measures to be taken on new buildings designed to reduce the consumption of these buildings by 80% compared to a standard building. It then imposes a maximum consumption of 50 kWh/m² per year: this includes ventilation, heating, refreshment, lighting and hot water. In France, in 2011, ADEME stressed that electricity consumption in the residential sector was estimated at 30 kWh/m^2 for buildings located in mainland France, which represents 16.13% of energy consumption [37]. The residential ratio produced for Reunion is consistent with the ratio announced by ADEME for metropolitan France, with an electricity consumption ratio of 29.84 kWh/m^2 produced by our study. In 2015, the BER also produced a residential ratio of 31.37 kWh/m^2 [12], validating the product ratio in our study with a margin of error of less than 5%.

In order to complete our analysis and validate our work, we compared the real municipal consumption (BER) and calculated municipal consumption.

The calculated consumption is the product of the consumption ratios and calculated areas of each consumer category. Figure 6 presents the comparison between the real consumption and the calculated one for all the municipalities of Reunion Island. In the bottom of the plot, a histogram shows the residual for each municipality. The obtained R^2 is 0.97, and the RMSE is 22.8094 for a real value that varies between 9 and 524 GWh. The result is satisfactory with a maximum absolute error of 53.90 GWh for Saint-Paul and a minimum absolute error of 0.11 GWh for Saint-Leu and an average of 16.72 GWh (Figure 6). This corresponds to an error of 560,320 m^2 of residential area or 1.69% of the total residential area.

We can see three types of municipalities: some, for which the estimate is correct (Sainte-Rose, Saint-Philippe, Cilaos for example); others where consumption is underestimated (Saint-Denis, Saint-Pierre, Saint-Paul for example) and others where consumption is overestimated (Le Port, Tampon, Saint-Joseph).

Municipalities whose consumption are underestimated correspond to the major poles of the Island: Saint-Denis, Saint-Pierre and Saint-Paul are the most important urban centers on the island (Figure 7). The extent and complexity of information concerning these poles are therefore probably at stake: these communes deserve a more detailed work with segmentation in city block for a more detailed analysis of the building frame.

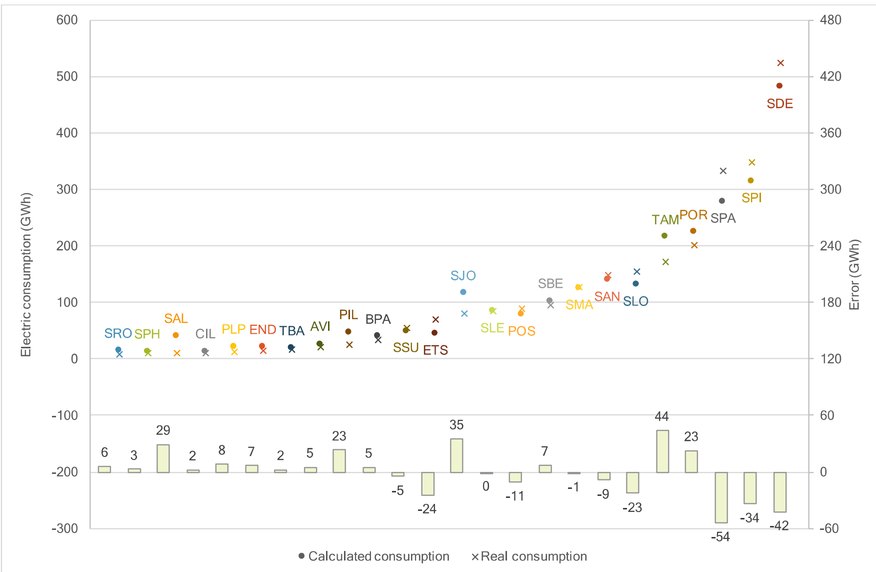

Figure 6. Calculated and real consumption by municipalities.

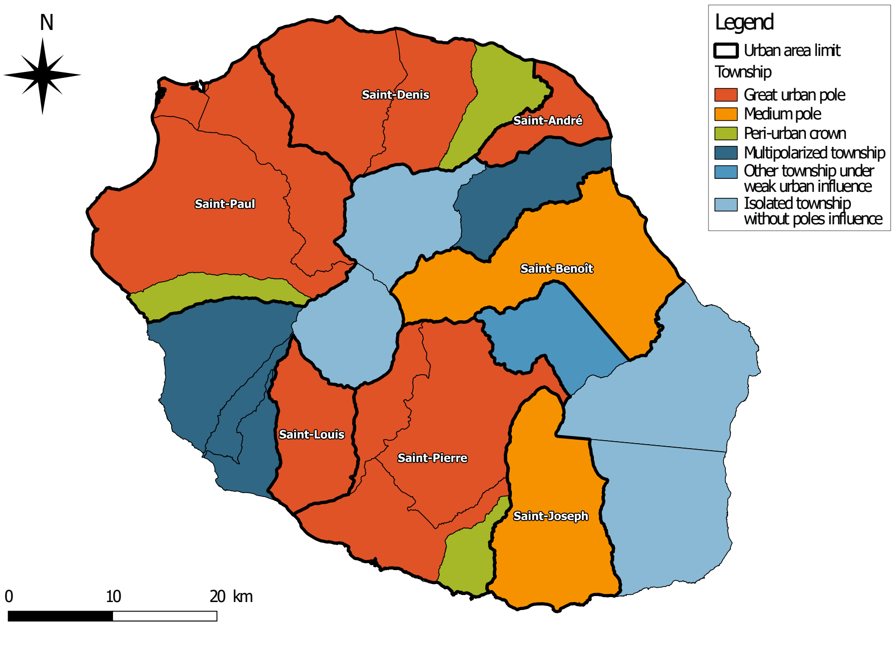

Figure 7. Representation of urban areas.

While the population is the largest share of electricity consumption (45.2 %), it has one of the lowest unit consumption ratios (Figure 8). This confirms that the population is one of the main determinants of the island's electricity consumption [14]. Indeed, the economic organization of the island, with essentially tertiary and a strong economic dependence on France, suggests the weakness of energy-consuming sectors such as industries.

Figure 8. Segmentation of customers: surface, share of consumption and ratio.

The following map shows the spatial distribution of different categories of consumers. The abundance of residential areas is evident in comparison with other types of consumers (Figure 9). The zones corresponding with the large consumers are distributed very unevenly in the territory with a concentration in the cities of Le Port, Saint-Denis and Saint-Pierre. The same applies to the areas occupied by enterprises: the same three zones have been identified in the north, south and west of the island.

Not surprisingly, we can see very clearly that private customers dominate the territory. Our first work to characterize electricity consumption at the municipal level showed that the estimate of electricity needs could indeed focus on the population [14]. This second work is in addition to confirming the importance of the population in the consumption of electricity because of their number, to locate more precisely on the island the electricity needs. Thus, the points of the most consumer and least consumer territories are highlighted. The map shown in Figure 9 could be a great tool for energy planning.

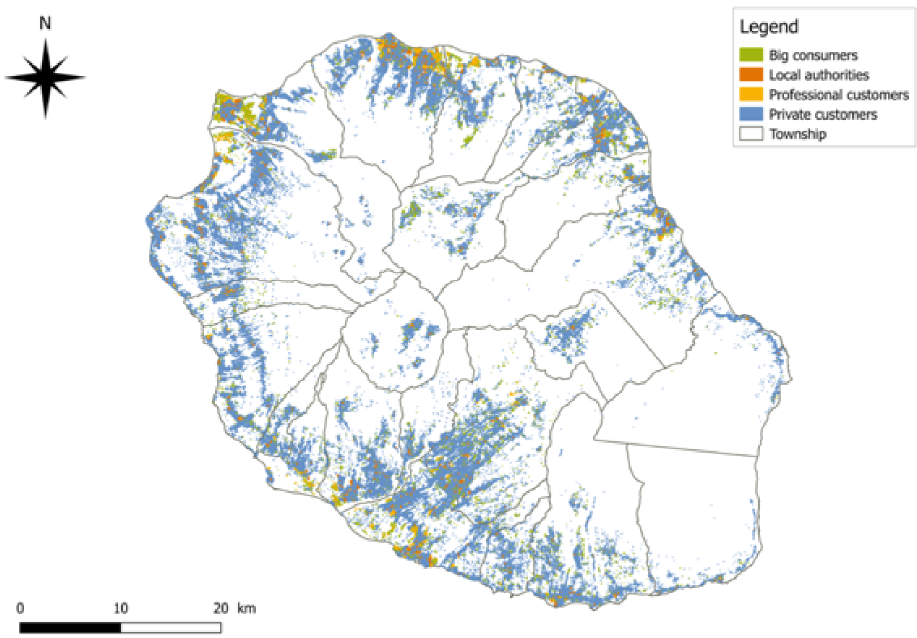

Figure 9. Spatial distribution of the customers.

5. Conclusion

The scope of this work was to produce electricity consumption ratios per square meter of building based on a new GIS approach by segmenting buildings, according to their function: housing, industry, administrations and businesses. These categories correspond to the categories of consumers defined by the electricity supplier: EDF. Their unequal distribution on the territory and their different consumption patterns make it easy to distinguish several consumption ratios. These ratios are based on their distribution on the ground, obtained by mapping, and augmented by hypotheses on the number of floors. The ratios obtained correspond to expectations: the ratio of large consumers is six times higher than that of private customers, the ratio of enterprises is double and the ratio of local authorities is the lowest.

This work is a first attempt to calculate the ratio of electricity consumption per square meter of building. It develops a method using GIS as the basis of calculation. The method allows compensating the lack of information on energy consumption on a territory. It is particularly useful for energy planning scenarios to decrease electricity demand. Most of studies are focused electricity demand per capita, and energy scenarios are mainly based population growth on territory. This article has shown that population is indeed the determinant of electricity consumption. However, it is necessary to consider all economical sector to build a real scenario that takes into account different activities development such in industry or tertiary sector. Our method is very useful for territory that doesn't have any data ratio of electricity consumption by sector and allows in the same to building more accurate scenario.

For further work, it would be useful to define control buildings by consumer categories in order to analyze the actual consumption of these buildings. A second track of deepening would be the analysis of the age of the buildings. Indeed, with the evolution of construction standards, with reference to the various thermal regulations, buildings built today consume less energy than those built ten years ago for example. As we are interested in the way to challenge energy transition, this methodology will be repeated over years, if in the case of a residential or tertiary sector a decrease is actually noticed. The ratio could be used by energy planners as an indicator of success of electricity consumption reduction.

Finally, the most significant point of the ratio is the fact that the information is brought for a typology of the building. This choice was not harmless, because urban development strategy is basically based on urban sprawl or densification, which means most of the time: building area. It seems to us more convenient to define this ratio per sector of activity for better energy planning scenarios modeling.

Electricity consumption represents 37% of the energy consumed in residential and commercial buildings in France in 2012 [37] and 23.1% of total energy consumption in Reunion Island in 2015 [12]. The increasing trend in energy consumption of buildings will continue over the next few years due to the expansion of the built area and associated energy needs, as long as resources and land allow. The private initiative, in conjunction with government intervention through the promotion of energy efficiency, the limitation of energy consumption and social awareness of the rational use of energy, will be essential for a future sustainable energy supply. Thus, the effort to conserve energy in residential, commercial and industrial buildings, while maintaining an optimal indoor environment, is an ongoing struggle to minimize dependence on fossil fuel sources. It also makes it possible to secure the energy balance and reduce the environmental impact of fossil fuels by reducing greenhouse gas emissions.

Acknowledgements

This project is part of the TRANSEETER research project funded by the University of La Reunion through its incentive program on energy transition.

Conflict of interest

The authors declare no conflict of interest in this paper.

References

1. EDF (2013) Il était une fois les réglementations thermiques. Available from: https://travaux.edf.fr/construction-et-renovation/la-reglementation-thermique-2012/il-etait-une-fois-les-reglementations-thermiques.
2. JORF (1996) LOI n° 96-1236 du 30 décembre 1996 sur l'air et l'utilisation rationnelle de l'énergie (1). Available from: https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000381337&categorieLien=id.
3. JORF (2005) Loi n° 2005-781 du 13 juillet 2005 de programme fixant les orientations de la politique énergétique. Available from: https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000813253&categorieLien=id.
4. JORF (2010) LOI n° 2010-788 du 12 juillet 2010 portant engagement national pour l'environnement (1). Available from: https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434&categorieLien=id.
5. JORF (2015) LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte (1). Available from: https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000031044385&categorieLien=id.
6. Cheng MY, Chiu KC, Lien LC, et al. (2016) Economic and energy consumption analysis of smart building–MEGA house. *Build Environ* 100: 215–226.
7. ADEME. Climat, Air et Energie, Chiffres clés; 2013.
8. Durable CGaD. Repères-Ciffres clés de l'environnement; 2015; Paris.
9. Ma JJ, Du G, Zhang ZK, et al. (2017) Life cycle analysis of energy consumption and CO_2 emissions from a typical large office building in Tianjin, China. *Build Environ* 117: 36–48.
10. Blom I, Itard L, Meijer A (2011) Environmental impact of building-related and user-related energy consumption in dwellings. *Build Environ* 46: 1657–1669.
11. Parshall L, Gurney K, Hammer SA, et al. (2010) Modeling energy consumption and CO_2 emissions at the urban scale: Methodological challenges and insights from the United States. *Energ Policy* 38: 4765–4782.
12. Réunion OE. Bilan énergétique Ile de La Réunion 2015; 2016.
13. Amado M, Poggi F, Amado AR (2016) Energy efficient city: A model for urban planning. *Sustain Cities Soc* 26: 476–485.
14. Bénard-Sora F, Praene JP (2016) Territorial analysis of energy consumption of a small remote island: Proposal for classification and highlighting consumption profiles. *Renew Sust Energ Rev* 59: 636–648.
15. Mungwe J, Mandelli S, Colombo E (2016) Community pico and micro hydropower for rural electrification: experiences from the mountain regions of Cameroon. *AIMS Energy* 4: 190–205.
16. Dornan M (2015) Reforms for the expansion of electricity access and rural electrification in small island developing states. *AIMS Energy* 3: 463–479.

17. Wolf F, Surroop D, Singh A, et al. (2016) Energy access and security strategies in small island developing states. *Energ Policy* 98: 663–673.
18. Alhamwi A, Medjroubi W, Vogt T, et al. (2017) GIS-based urban energy systems models and tools: Introducing a model for the optimisation of flexibilisation technologies in urban areas. *Appl Energ* 191: 1–9.
19. Li C (2017) GIS for Urban Energy Analysis. Reference Module in Earth Systems and Environmental Sciences.
20. Man SW, Zhu R, Liu Z, et al. (2016) Estimation of Hong Kong's solar energy potential using GIS and remote sensing technologies. *Renew Energ* 99: 325–335.
21. Nematollahi O, Kim KC (2017) A feasibility study of solar energy in South Korea. *Renew Sust Energ Rev* 77: 566–579.
22. Yushchenko A, Bono AD, Chatenoux B, et al. (2017) GIS-based assessment of photovoltaic (PV) and concentrated solar power (CSP) generation potential in West Africa. *Renew Sust Energ Rev* 81: 2088–2103.
23. Mentis D, Hermann S, Howells M, et al. (2015) Assessing the technical wind energy potential in Africa a GIS-based approach. *Renew Energ* 83: 110–125.
24. Cristea C, Jocea AF (2016) GIS Application for wind energy. *Energ Procedia* 85: 132–140.
25. Cavazzi S, Dutton AG (2016) An offshore wind energy geographic information system (OWE-GIS) for assessment of the UK's offshore wind energy potential. *Renew Energ* 87: 212–228.
26. Jangid J, Bera AK, Joseph M, et al. (2016) Potential zones identification for harvesting wind energy resources in desert region of India? A multi criteria evaluation approach using remote sensing and GIS. *Renew Sust Energ Rev* 65: 1–10.
27. Anwarzai MA, Nagasaka K (2017) Utility-scale implementable potential of wind and solar energies for Afghanistan using GIS multi-criteria decision analysis. *Renew Sust Energ Rev* 71: 150–160.
28. Vasileiou M, Loukogeorgaki E, Vagiona DG (2017) GIS-based multi-criteria decision analysis for site selection of hybrid offshore wind and wave energy systems in Greece. *Renew Sust Energ Rev* 73: 745–757.
29. Quan SJ, Li Q, Augenbroe G, et al. (2015) A GIS-based energy balance modeling system for urban solar buildings. *Energ Procedia* 75: 2946–2952.
30. Mutani G, Delmastro C, Gargiulo M, et al. (2016) Characterization of building thermal energy consumption at the urban scale. *Energ Procedia* 101: 384–391.
31. Tornay N, Schoetter R, Bonhomme M, et al. (2017) GENIUS: A methodology to define a detailed description of buildings for urban climate and building energy consumption simulations. *Urban Climate* 20: 75–93.
32. Palme M, Inostroza L, Villacreses G, et al. (2017) From urban climate to energy consumption. Enhancing building performance simulation by including the urban heat island effect. *Energ Buildings* 145: 107–120.
33. Jiang Y, Gu P, Chen Y, et al. (2017) Modelling household travel energy consumption and CO_2 emissions based on the spatial form of neighborhoods and streets: A case study of Jinan, China. *Computers, Environment and Urban Systems*.

34. Lu H, Liu G (2014) Spatial effects of carbon dioxide emissions from residential energy consumption: A county-level study using enhanced nocturnal lighting. *Appl Energ* 131: 297–306.
35. Yamamura S, Fan L, Suzuki Y (2017) Assessment of urban energy performance through integration of BIM and GIS for smart city planning. *Procedia Eng* 180: 1462–1472.
36. Niu S, Pan W, Zhao Y (2015) A BIM-GIS integrated web-based visualization system for low energy building design. *Procedia Eng* 121: 2184–2192.
37. ADEME. Bâtiment, Edition 2013, Chiffres Clés; 2013.