PV potential of the public building stock of the Basque Country

Mikel Garro-Aguilar[a*], Ana Picallo-Perez[a], Pablo Hernandez-Cruz[a], Juan Mª Hidalgo-Betanzos[b], JM Sala-Lizarraga[a] and Imanol Ruiz de Vergara-Ruiz de Azua[b]

[a] Research group ENEDI, Department of Energy Engineering, University of the Basque Country (UPV/EHU); Alameda Urquijo, S/N, 48013 Bilbao, Vizcaya, Spain; e-mail: mikel.garro@ehu.eus
[b] Thermal Area of the Laboratory of Quality Control of Buildings of the Basque Government; Aguirrelanda 10, Vitoria-Gasteiz, Spain

Abstract:
The energy consumption of buildings is constantly increasing and not only impacts on resources, but also emits polluting gases into the atmosphere. For this reason, there is a great commitment to integrate renewable energies, as well as to renovate and hybridize the energy facilities of existing buildings. Spain has a large potential to exploit solar energy and this is reflected in the PV integration in buildings, as PV self-consumption has risen to 1,203MW installed. However, buildings still have a high potential for improving photovoltaic applications and can help to increase the exploitation of renewable resources. Following European recommendations and Spanish directives, the Basque Government is analysing how to conduct the renovation of the existing public housing stock to achieve more sustainable housing and take into account the quality of life of the users. To this end, the project Plan ZERO-Plana, led by ALOKABIDE "Public institution of the Basque Government", was developed to, among others, increase renewable energy implementation for self-consumption. This work takes a step forward and analyses the photovoltaic potential of the public building stock of the Basque Country based on a GIS application. The objective is to, on the one hand, account for the PV potential in each of the public housing units themselves and, on the other hand, to analyse the possibility of implementing energy communities in the Basque Country to supply the energy use of these buildings, as well as to compare the viability of both options.

Keywords:
ALOKABIDE; PV potential; energy community; Vitoria-Gasteiz; QGIS; renewable energy; rooftops.

1. Introduction

Spain, due to its climate and geographical location, has a significant number of sun-hours during the year, which allows the exploitation of clean energy with significant potential to meet energy needs. Given that a large part of the world's population is concentrated in cities, it is necessary to establish urban plans to ensure the sustainable development of urban environments, using available human resources and technology. In addition, Buildings are responsible for approximately 40% of the energy consumption of the European Union (EU) [1]. Residential buildings in particular accounted for the 27% of the final energy consumption of the EU in 2020 [2], so one of the options is to produce energy through solar technology, such as placing photovoltaic panels on building rooftops. Therefore, this work assesses the solar potential of the city of Vitoria-Gasteiz, as a geographical area with suitable characteristics for the installation of solar panels and the possibility to create different energy communities in this area.

1.1. State of the art

Accordingly, some studies have identified areas of high population density, such as urban centres, as places with high potential for solar production, such as Ávila and Zamora [3], Miraflores de la Sierra (Madrid, Spain), Gassar and Cha [4] in Geneva (Switzerland), Guevara [5] (Perú) and Haegermark and Dalenbäck [6] (Sweden).

In terms of feasibility analysis, analysis is frequently restricted to figuring out solar radiation, although the environment is still crucial. In addition, the study can be further detailed, as it is done in the case of housing in Valencia (Spain), Aparisi [7], where the orientation of the roof and the adjacent buildings are taken into account, as well as the tilt of the roof. On the other hand, the polytechnic school of engineering in Gijón studied photovoltaic feasibility in Asturias (Spain), Guerrero [8].

https://doi.org/10.52202/069564-0154

The PV potential can be estimated by using different models or methods. In this study, the method used is based on a Geographic Information System (GIS). This method or tool has been employed in numerous studies for various purposes, including the estimation of PV potential in rooftops. Examples include Quiros-Tortos et al.'s [9] consideration of various factors when integrating GIS data sources in a PV analysis and Khan and Arsalan's [10] use of the GIS tool to determine the best rooftops for solar PV applications in Karachi. Baiocchi et al. [11] also uses this tool to study the effect of defining different PV criteria, and Davybida et al. [12] uses GIS to design a PV system for a built-up roof in Poland, which generates an electrical power of around 100 MWh/year.

Moreover, this tool can be used to determine the influence of different elements on PV solar energy generation, and Silveire Júnior et al. [13] uses GIS to determine the influence of aerosol in the state of Goiás (Brazil).

Apart from GIS there are different models that can be used to analyse the PV potential of an area. For instance, of Mohajeri et al. [14], used Machine Learning to classify urban characteristics for solar applications, including the impacts of different roof shapes on annual solar PV electricity production.

The electricity obtained from the PV installation can be used in different ways. Current policies are promoting the combination of technologies such as heat pumps or solar thermal collectors, and these possibilities have been studied in articles such as Wang et al. [15]. This last work analyses three different configurations to supply the heating and DHW demands of a dwelling (ST, PV/T and PV with ASHP). Herrando et al. [16] analyses the possibilities of using solar thermal collectors to meet the heating and DHW demands of a dwelling (ST, PV/T and PV with ASHP), and Ayadi and Al-Dahidi [17] compares how to implement heating and cooling in a building with solar thermal and solar electric power.

In addition, some countries are also promoting energy communities, which is a relatively new concept. Frieden et al. [18], Jeriha [19] and Gjorgievski et al. [20] reviewed the current regulatory framework and analyse the social arrangements, technical designs and impacts of an energy community. As it is known, with energy communities the heating, cooling and electrical demand can be assessed, so this could be a great opportunity for the public house stock of Vitoria-Gasteiz to introduce this kind of initiative into work, due to its geographical and distributional situation.

1.2. Regulatory framework

This section briefly explains the European, Spanish and regional regulatory framework.

1.2.1. European framework

In Europe, the recent directives are seeking to promote new roles for citizens who produce and use energy by promoting local energy markets and introducing the concept of energy communities.

One of the most remarkable directives, is the Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 [21], on the promotion of the use of energy from renewable sources. This directive defines Renewable Energy Communities (REC) as "*A legal entity; which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;. The shareholders or members of which are natural persons, SMEs, or local authorities, including municipalities; the primary purpose of which is to provide environmental, economic, or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits*.".

This directive establishes that the Renewable Energy Communities (RECs) have the right to produce, consume, store, or sell renewable energy, or to share what is generated by producing units owned by that community and to access all energy markets. It also mandates member states to provide a framework to encourage and facilitate the development of RECs, as well as to guarantee the right of consumers to participate in a REC.

Another remarkable directive is the Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 [22], which defines the common rules for internal market for electricity in Citizen Energy Communities (CEC) as follows. "*A legal entity that: is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises; has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders*."

This directive establishes the obligation for member states to provide a favourable legal framework for CECs that ensures that: (1) participation in CECs is open and voluntary; (2) the distribution system operator cooperates, in return for fair compensation, to facilitate the transfer of electricity between different CECs; (3) CECs are subject to procedures and charges that ensure that they contribute adequately and in a balanced way to the overall sharing of system costs.

https://doi.org/10.52202/069564-0154

These two directives are included in the “Clean Energy Package” [23], which proposes an adaptation of the European energy policy framework to facilitate the transition away from fossil fuels toward cleaner energy.

1.2.2. Country framework

In Spain, the most recent regulations related to electricity self-consumption are “*Real Decreto-ley 15/2018*” [24], which establishes urgent measures for energy transition and consumer protection, and “*Real Decreto-ley 244/2019*” [25], which regulates the administrative, technical and economic conditions for electricity self-consumption, promoting the consumption of km0 energy.

In addition to these regulations, the Spanish state proposes the "*Plan Nacional Integrado de Energía y Clima 2021-2030*" [26], which describes several measures for the penetration of renewable energies and energy efficiency, as well as introduces local energy communities and the importance of citizen participation in the energy field. For the latter, lines of action are set out to develop the appropriate regulatory framework to define these legal entities and encourage their development.

In addition to this national plan, the Spanish government in 2020 proposed the document "*Estrategia de Descarbonización a Largo Plazo 2050*" [27] with the aim of becoming a climate neutral country by 2050 by transforming the energy and economic system in a stable and joint manner with the help of citizens.

1.2.2. Regional framework

In the Basque Country, there are different regulations and strategies that establish guidelines to favour the use of renewable energies and sustainable development.

This is the case of Ley 4/2019, of 21 February [28], on energy sustainability in the Basque Autonomous Community and its development decree, “*Decreto 254/2020”*, of 10 November [29], whose objective is to promote energy saving and efficiency measures, and the promotion and implementation of renewable energies. The spatial planning guidelines, approved by “*Decreto 128/2019”* of 30 July [30], state that renewable energies must be increasingly incorporated into the construction of our territory.

The Basque Energy Strategy 2030 [31] identifies, after a full analysis of the surrounding, elements that will be key to the transition towards a sustainable energy system in the Basque Country. This analysis includes: energy saving and efficiency; renewable energies; infrastructures and networks; distributed energy, self-consumption and energy cooperatives; non-conventional gas; energy and environmental taxation; policy integration; governance; adaptation to climate change in the energy system; and the importance of health co-benefits.

2. Case study

This work examines 157 sections of 31 public housing buildings, managed by ALOKABIDE, in the city of Vitoria-Gasteiz (Basque Country, Spain), with an average age of 16-year-old. In addition, 84% of the 31 buildings have a D and E labels in primary energy consumption or CO2 emissions [32], which means they have relatively low values.

This analysis focuses on electrical consumption and considers the available data obtained from previous works. Therefore, after averaging the number of households and consumption in Vitoria-Gasteiz, we obtain the average monthly consumption profile of a household, see Figure 1. It is also taken into account that 21 out of 31 buildings already have renewable energy solar thermal systems installed, but there is still space to expand the facility and increase the renewable production.

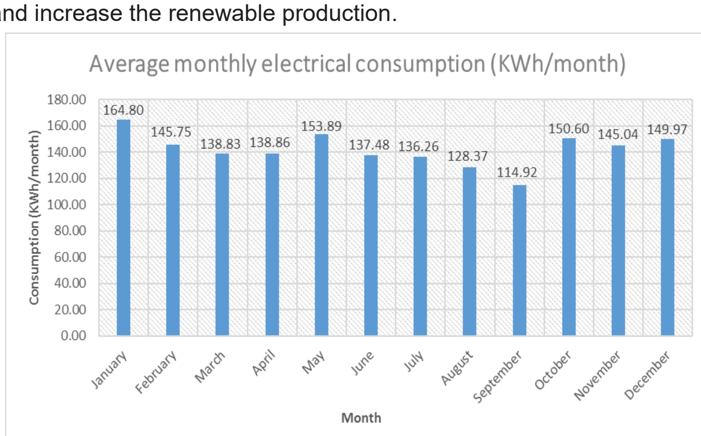


Figure. 2. Average monthly electrical consumption of the buildings studied in Vitoria-Gasteiz.

https://doi.org/10.52202/069564-0154

Due to technical limitations, only a specific number of buildings will be analysed in this work, which are collected and depicted in Figure 2. The analysis of the rest of the public building stock can be done in an analogous way.

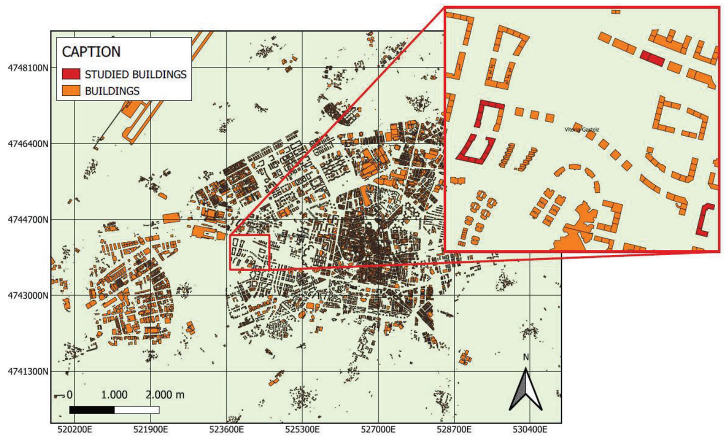


Figure. 2. Buildings studied in Vitoria-Gasteiz.

3. Methodology

QGIS Georeferencing Software (Open Access Geographic Information System) has been used for studying solar radiation from the rooftops of public buildings in Vitoria-Gasteiz. This tool organizes large volumes of data from a particular place in the world, allowing data to be stored, manipulated, analysed and modelled.

3.1. Data

Topographic data have been obtained from GeoEuskadi [33], which collects data from the entire Autonomous Community of the Basque Country. These are LIDAR (L*aser Imaging, Detection, And Ranging*) type and are obtained by optical remote sensing through a laser light. That is, with accurate x-y measurements, they define a compact sample of the Earth's surface as in cartographic applications of aerial laser images. These data contain cadastral information on all the localities of the Basque Country, such as buildings, urban centres, rural areas, railway lines, roads, etc., as well as data on the boundaries of each municipality. It also contains other data on the DSM sheets (Digital Surface Model) representing all the elements of the soil surface, such as vegetation, buildings, infrastructure, and soil itself.

3.2. Methods and indicators

Once the topographic data have been obtained and downloaded into the software, they are assigned a reference system of type ETRS89/UTM zone 30N, and are also assigned to the other layers of QGIS.

Between these layers, radiation accumulates by means of a device called Potential Incoming Solar Radiation. This device simulates accumulated radiation over a time-period, taking into account the type of radiation selected. In the case of this study, a period of one year, 2018, has been set by months, with a 7-day and 1-hour jump, and takes into account total or global radiation, i.e., the sum of direct, diffuse, incident, reflected and absorbed radiation. Therefore, monthly layers are obtained, for example, the total radiation of August and December is gathered in Figure 3 and Figure 4.

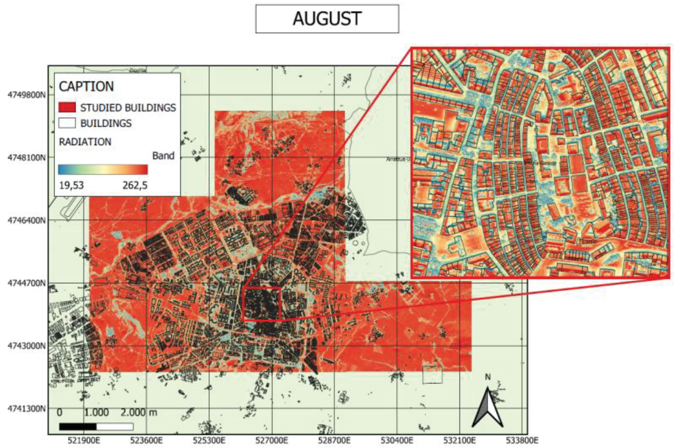


Figure. 3. Accumulated radiation during August.

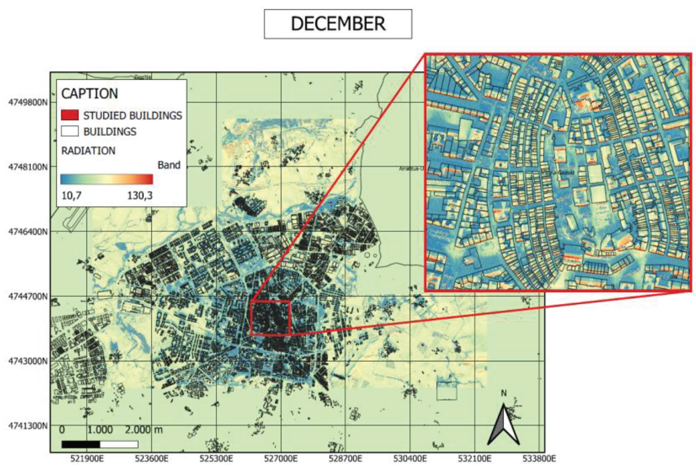


Figure. 4. Radiation accumulated on December.

As it can be seen, there is a huge difference between the maximum and minimum total radiation reaching the layers in both months of August and December.

The layer of the same size as the DSM simulation sheet is then cut to collect only radiation data consistent with buildings (public houses); see figure 5.

https://doi.org/10.52202/069564-0154

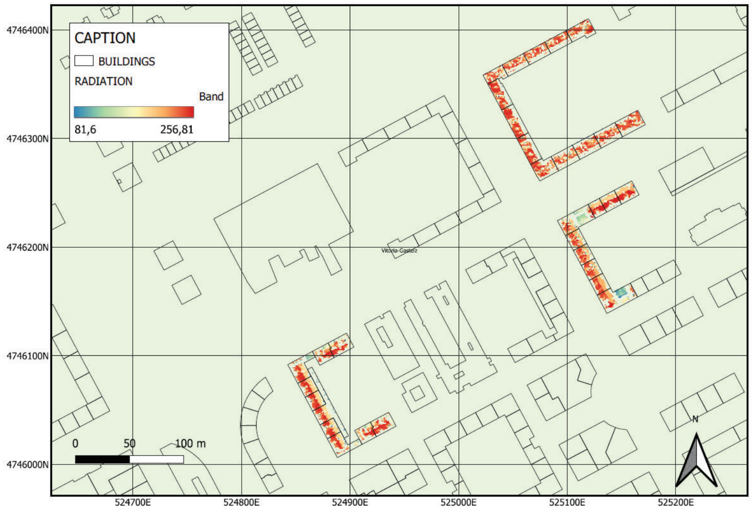


Figure. 5. Radiation accumulated on building rooftops.

Thus, once the radiation potential of residential rooftops has been achieved, three criteria are proposed to identify the suitable rooftops, as Delphine Khana mentions [34]:

- C.1) The rooftops must contain at least 65 kWh/m^2 of accumulated solar radiation in one month.
- C.2) The slope of suitable roofs must be less than or equal to 45 degrees, as steep slopes tend to receive less sunlight. The 45 degree limit is defined according to the latitude of Vitoria-Gasteiz, which is 42.85 °, since the optimal inclination is ± 10 ° compared to the local latitude.
- C.3) The rooftops, which are oriented north and receive less sunlight, are rejected.

Once the appropriate rooftops are identified and their radiation potential is obtained, the next step deals with analysing the possibilities of establishing energy communities, taking into account the location of the buildings of the public houding stock, since the consumption points must be at a maximum distance of 500 metres from the production point. Following these instructions, seven energy communities are proposed in Figure 6.

Figure. 5. Energy communities proposed in Vitoria-Gasteiz.

From now on, considering the seven energy communities, only 134 buildings out of the original 157 will be analysed (since the rest are outside of the circles), and for this analysis, several indicators have been determined to better understand the analysis:

- <u>Optimal surface of section rooftops</u> [m^2]

Indicates the appropriate surface of the PV panel installation rooftop according to the predefined criteria.

- Percentage of optimal surface [%]

It is the ratio between the optimal surface of the building and the total.

$$Percen.opt.surf.(\%) = \frac{Opt.surf.\ (m^2)}{Total\ surf.\ (m^2)} \quad (1)$$

- Photovoltaic efficiency [%]

It relates the photovoltaic capacity of each section to the electrical consumption. This indicator allows a detailed analysis of the context of each building.

$$PV\ eff.(\%) = \frac{PV\ capacity\ (KWh)}{Elec.consumption\ (KWh)} \quad (2)$$

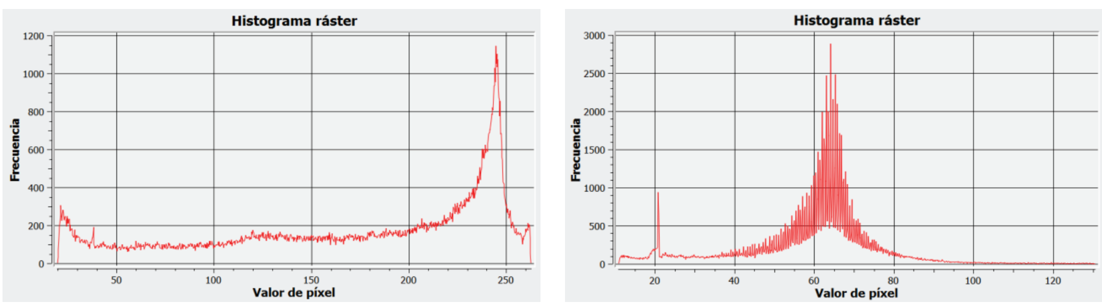
4. Results

The most significant results are related to the following:

- Histograms of radiation based on the first calculation.
- Optimal surface of the buildings, after applying the three criteria to the rooftops.
- Radiation percentage of each cover for the introduction of a PV facility.
- Photovoltaic efficiency of the proposed energy community.

4.1. Histograms

Accordingly, Figure 6 shows the histograms of August and December associated with the buildings of Figure 5, where the most repeated value of the accumulated radiation in August is around 240 kWh/m^2 and in December around 65 kWh/m^2.



(a) (b)

Figure. 6. Histogram of the accumulated radiation: a) August, b) December.

4.2. Optimal Surface

As it has been said, each building is examined according to three criteria (C.1, C.2 and C.3) to identify suitable rooftops. A building-by-building analysis has been carried out and the global results are gathered in Table 1.

Table 1. Summary based on three criteria

Optimal surface (m^2)	Total surface (m^2)	Percentage (%)
25,076.20	52,804.88	47.49

Consequently, only 47.49% of the total roof capacity is considered adequate for installing PV panels.

But what is more, some parts of this area are not suitable for installing a photovoltaic panel, since there are also areas with obstacles, such as chimneys, antennas, etc. Because of that, the results are afterwards filtered and analysed more precisely in order to identify the specific areas of the rooftop detecting the obstacles, according to the following three criteria:

- C.4) Buildings with an adequate area of less than 25% are excluded.
- C.5) Buildings with an optimal surface area of less than 30% and an optimal surface area of less than 100 m^2 are eliminated.
- C.6) Suitable areas of less than 10 m^2 are excluded.

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Based on these extra criteria (considering C.1-C.6), the number of the optimal percentage falls from 47.49% to 47.10%, as shown in Table 2.

Table 2. Summary based on all six criteria

Optimal surface (m2)	Total surface (m2)	Percentage (%)
24,871.76	52,804.88	47.1

4.3. Including PV facility

In addition, on the one hand, only 25% of the optimal surface can be covered with photovoltaic panels (in order to avoid panel loss of shadow, inclination, structure, space for maintenance, etc.). On the other hand, photovoltaic panels are estimated to have 15% performance and 86% PR (Performance Ratio). Thus, the monthly electricity contribution on public residence decks has been calculated with this equation:

$$Elec.production\ (KWh) = Surf_{opt} \cdot 0.25 \cdot Rad_{mean} \cdot 0.15 \cdot 0.86 \quad (3)$$

Accordingly, the results of electricity PV production of the selected public buildings of Vitoria-Gasteiz are shown in Table 3.

Table 3. Monthly electricity production

Month	Electricity produced (kWh)
January	43,940.12
February	66,805.28
March	139,575.64
April	191,039.39
May	226,364.23
June	242,116.29
July	235,092.65
August	206,475.89
September	161,275.77
October	110,118.26
November	59,850.77
December	27,482.56

Once the PV electricity production of each of the roofs has been calculated, the electricity consumption of each dwelling and the number of dwellings in each of the buildings need to be considered in order to obtain the percentages of electricity that could be self-consumed.

4.4. Energy Communities

Apart from that and going further, seven energy communities are proposed, which take into account the proximity of the buildings and the criterion of 500 metres (mentioned in section "*3.2 Methods and indicators"*).

As the same conclusions are obtained for all energy communities, and because of technical limitations, only the most representative one will be analysed in this paper, the one shown in Figure 7.

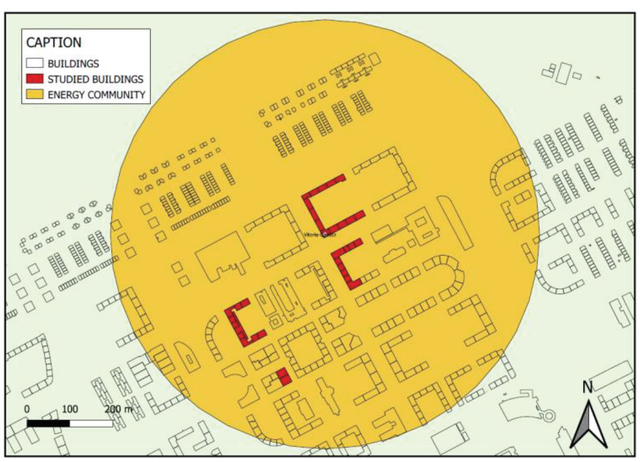

Figure. 7. Selected energy community.

The chosen energy community has the characteristics shown in Table 4:

Table 4. Energy community characteristics

Description (name of the building)	Number of households
Lakua 30	30
Lakua 110	110
Lakua 90	90
Ibaiondo 228	228

Moreover, the monthly electricity produced in the corresponding rooftops (obtained from the previous analysis) and the consumptions of the households (calculated with the corresponding consumption data of 2018) of this energy community are shown in Table 5 and is graphically represented in Figure 8:

Table 5. Production vs Consumption

Month	Total production (KWh)	Total consumption (KWh)	Photovoltaic efficiency (%)
January	7,924.77	75,478.25	10.5
February	15,676.17	66,751.97	23.48
March	28,054.36	63,586.10	44.12
April	38,414.26	63,597.44	60.4
May	45,512.82	70,480.53	64.58
June	48,704.16	62,964.97	77.35
July	47,276.88	62,408.82	75.75
August	41,509.91	58,794.55	70.6
September	32,450.38	52,632.10	61.66
October	21,996.25	68,973.49	31.89
November	11,048.48	66,429.19	16.63
December	5,462.89	68,684.48	7,95

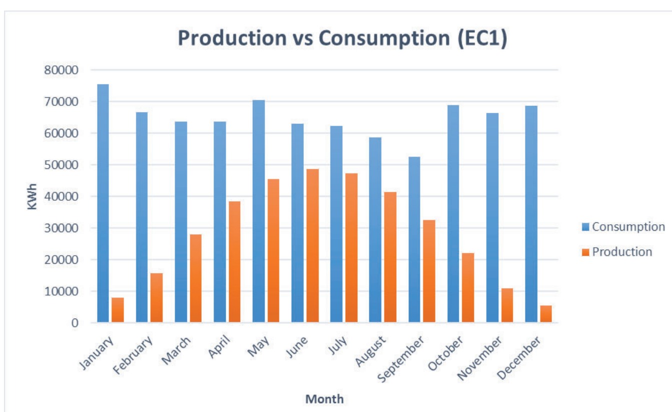

Figure. 8. Production vs Consumption in the selected energy community.

As it can be seen, the selected energy community, composed only by the public residential buildings, is not capable of supplying the total electricity demand in any of the months of the year, although it does supply part of the demand.

Without making an economic analysis of the study, it is too early to conclude whether it is economically viable or not, but at least it can be seen that in the central months of the year the installation of PV panels and the concept of the energy community is an option to be taken into account.

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5. Conclusions and next steps

In summary, the study determines that 47.1% of the total roof surface area of the social housing buildings in Vitoria-Gasteiz is suitable for a photovoltaic installation. Furthermore, by adding the criterion that only 25% of the optimum surface area can be used for photovoltaic installations, it is still possible that all these potential PV installations together could produce more than 1,700 MWh per year, see Table 6.

Table 6. Summary table

Percentage of optimal surface (%)	Electricity production (MWh)
47.1	1,710.14

Furthermore, if an energy community is proposed, the electricity consumption cannot be completely compensated or supplied by the PV electricity production. However, PV production could be increased by adding more buildings' roofs to these communities, following the 500 metres criterion, such as other public tertiary-use buildings.

Therefore, the main conclusions of this study are, on the one hand, that introducing photovoltaic panels in social housing buildings is a viable option, and on the other hand, that implementing energy communities in Vitoria-Gasteiz could be an interesting option but requires further analysis, being the beginning of a community or municipality with a vision towards the future of sustainability.

Considering all this, the next steps would be, at first, to make an economical study of the energy community proposed, and then, to evaluate the possibility of making a hybridization between PV panels and heat pumps, to benefit from their potential as energy storage.

6. Acknowledgments

The authors would like to thank the Basque Government's Laboratory for the Quality Control of Buildings and ALOKABIDE SA for the provided information and help for this study.

7. References

[1] European Commission, "Making our homes and buildings fit for a greener future," 2021. doi: 10.2775/03938.

[2] Eurostat, "Energy consumption in households," 2022. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households#Energy_products_used_in_the_residential_sector%0Ahttps://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households#Energy.

[3] Ávila, A. M. M., & Zamora, A. B. (2015). Estudio del potencial fotovoltaico sobre los tejados del núcleo urbano de Miraflores de la Sierra. Ciemat.

[4] Gassar, A. A. A., & Cha, S. H. (2021). Review of geographic information systems-based rooftop solar photovoltaic potential estimation approaches at urban scales. Applied Energy, 291, 116817. https://doi.org/10.1016/j.apenergy.2021.116817

[5] Guevara Sempertegui, C. I. (2018). Viabilidad de un sistema fotovoltaico para suministrar energía eléctrica a la estación base celular de la empresa Claro ubicado en el Caserío Santa Rosa-Sallique-Jaén Cajamarca.

[6] Haegermark, M., Kovacs, P., & Dalenbäck, J. O. (2017). Economic feasibility of solar photovoltaic rooftop systems in a complex setting: A Swedish case study. Energy, 127, 18-29.

[7] Aparisi Cerdá, I. (2019). Estudio de viabilidad económica de instalaciones fotovoltaicas en entorno urbano. Aplicación a 4 casos de estudio en la provincia de Valencia (Doktorego tesia, Universitat Politècnica de València).

[8] Guerrero Gallego, A. J. (2021). Viabilidad de uso de paneles fotovoltaicos como mecanismo de ahorro energético/CO2 en Asturias.

[9] Quiros-Tortos, J., Valverde, G., Arguello, A., & Ochoa, L. N. (2017). Geo-Information Is Power: Using Geographical Information Systems to Assess Rooftop Photovoltaics in Costa Rica. IEEE Power and Energy Magazine, 15(2), 48-56. https://doi.org/10.1109/MPE.2016.2637158

[10] Khan, J., & Arsalan, M. H. (s. f.). Use of Open Source GIS Tools to Identify Bright Rooftops for Solar PV Applications in Karachi.

[11] Baiocchi, V., Lelo, K., Marzaioli, V., & Vatore, F. (2022). SIMULATION OF THE EFFECTS OF POSSIBLE REGULATIONS FOR THE LOCATION OF WIND AND PHOTOVOLTAIC POWER PLANTS IN THE LAZIO REGIONAL ADMINISTRATION (ITALY). The International Archives of the Photogrammetry,

Remote Sensing and Spatial Information Sciences, XLVIII-4/W1-2022, 43-49. https://doi.org/10.5194/isprs-archives-XLVIII-4-W1-2022-43-2022

[12] Davybida, L., Wyczałek, I., & Plichta, A. (2022). Using GIS and SDSS Tools in the Design of a Photovoltaic System for a Built-up Roof. Geomatics and Environmental Engineering, Vol. 16(4). https://doi.org/10.7494/geom.2022.16.4.31

[13] Silveira Júnior, C. R., Luiz, G. C., Barbosa, G. A. S., & Sousa, L. G. C. (2020). Aerosol Influence on Photovoltaic Solar Energy Generation for the State of Goiás (BRAZIL). 2020 IEEE Latin American GRSS & ISPRS Remote Sensing Conference (LAGIRS), 345-350. https://doi.org/10.1109/LAGIRS48042.2020.9165629

[14] Mohajeri, N., Assouline, D., Guiboud, B., Bill, A., Gudmundsson, A., & Scartezzini, J.-L. (2018). A city-scale roof shape classification using machine learning for solar energy applications. Renewable Energy, 121, 81-93. https://doi.org/10.1016/j.renene.2017.12.096

[15] Wang, X., Xia, L., Bales, C., Zhang, X., Copertaro, B., Pan, S., & Wu, J. (2020). A systematic review of recent air source heat pump (ASHP) systems assisted by solar thermal, photovoltaic and photovoltaic/thermal sources. Renewable Energy, 146, 2472-2487. https://doi.org/10.1016/j.renene.2019.08.096

[16] Herrando, M., Pantaleo, A. M., Wang, K., & Markides, C. N. (2019). Solar combined cooling, heating and power systems based on hybrid PVT, PV or solar-thermal collectors for building applications. Renewable Energy, 143, 637-647.

[17] Ayadi, O., & Al-Dahidi, S. (2019). Comparison of solar thermal and solar electric space heating and cooling systems for buildings in different climatic regions. Solar Energy, 188, 545-560. https://doi.org/10.1016/j.solener.2019.06.033

[18] Frieden, D., Tuerk, A., Roberts, J., D'Herbemont, S., Gubina, A. F., & Komel, B. (2019). Overview of emerging regulatory frameworks on collective self-consumption and energy communities in Europe. 2019 16th International Conference on the European Energy Market (EEM), 1-6. https://doi.org/10.1109/EEM.2019.8916222

[19] Jeriha, J. (2019). Collective self-consumption and energy communities. Compile, 23.

[20] Gjorgievski, V. Z., Cundeva, S., & Georghiou, G. E. (2021). Social arrangements, technical designs and impacts of energy communities: A review. Renewable Energy, 169, 1138-1156. https://doi.org/10.1016/j.renene.2021.01.078

[21] DIRECTIVE (EU) 2018/ 2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 11 December 2018—On the promotion of the use of energy from renewable sources. (n. d.).

[22] DIRECTIVE (EU) 2019/ 944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 5 June 2019—On common rules for the internal market for electricity and amending Directive 2012/ 27/ EU. (n. d.).

[23] Directorate-General for Energy (European Commission). (2019). Clean energy for all Europeans. Publications Office of the European Union. https://data.europa.eu/doi/10.2833/9937

[24] Royal Decree-Law 15/2018 of 5 October on urgent measures for energy transition and consumer protection, Pub. L. No. Royal Decree-Law 15/2018, in Spanish, Real Decreto-ley 15/2018, de 5 de octubre, de medidas urgentes para la transición energética y la protección de los consumidores, Pub. L. No. Real Decreto-ley 15/2018, BOE-A-2018-13593 97430 (2018). https://www.boe.es/eli/es/rdl/2018/10/05/15

[25] Royal Decree 244/2019, of 5 April, regulating the administrative, technical and economic conditions for the self-consumption of electricity, Pub. L. No. Royal Decree 244/2019,, in Spanish, Real Decreto 244/2019, de 5 de abril, por el que se regulan las condiciones administrativas, técnicas y económicas del autoconsumo de energía eléctrica, Pub. L. No. Real Decreto 244/2019, BOE-A-2019-5089 35674 (2019). https://www.boe.es/eli/es/rd/2019/04/05/244

[26] National Integrated Energy and Climate Plan (PNIEC) 2021-2030, in Spanish, Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030. (n. d.). Retrievered March 6, 2023, from https://www.miteco.gob.es/es/prensa/pniec.aspx

[27] Long Term Decarbonisation Strategy 2050, in Spanish, Estrategia de Descarbonización a Largo Plazo 2050. (n. d.). Retrievered March 6, 2023, from https://www.miteco.gob.es/es/prensa/documentoelp_tcm30-516109.pdf

[28] Law 4/2019, of 21 February, on energy sustainability of the Basque Autonomous Community, Pub. L. No. Law 4/2019, BOE-A-2019-3705 25577, in Spanish, Ley 4/2019, de 21 de febrero, de sostenibilidad energética de la Comunidad Autónoma Vasca, Pub. L. No. Ley 4/2019, BOE-A-2019-3705 25577 (2019). https://www.boe.es/eli/es-pv/l/2019/02/21/4

[29] DECREE 254/2020, of 10 November, on Energy Sustainability in the Basque Autonomous Community. - Law Day: Regulations of the Basque Country-Basque Government-Euskadi.eus , in Spanish, DECRETO 254/2020, de 10 de noviembre, sobre Sostenibilidad Energética de la Comunidad Autónoma Vasca. - Legegunea: Normativa del Pais Vasco—Gobierno Vasco—Euskadi.eus. (n. d.). Retrieved March 6, 2023, from https://www.legegunea.euskadi.eus/eli/es-pv/d/2020/11/10/254/dof/spa/html/webleg00-contfich/es/

[30] DECREE 128/2019, of 30 July, by which the Spatial Planning Guidelines of the Autonomous Community of the Basque Country are definitively approved (September 25, 2019). - Legegunea: Normativa del Pais Vasco-Gobierno Vasco-Euskadi.eus in Spanish, DECRETO 128/2019, de 30 de julio, por el que se aprueban definitivamente las Directrices de Ordenación Territorial de la Comunidad Autónoma del País Vasco. (2019, septiembre 25). - Legegunea: Normativa del Pais Vasco—Gobierno Vasco—Euskadi.eus. (n. d.). Retrieved March 6, 2023, from https://www.legegunea.euskadi.eus/eli/espv/d/2019/07/30/128/dof/spa/html/webleg00-contfich/es/

[31] Energy Policy 2030—EVE. (n. d.). Retrieved March 6, 2023, from https://www.eve.eus/Conoce-la-Energia/La-energia-en-Euskadi/Energy-Policy-2030?lang=en-gb

[32] Plan de Ciencia, Tecnología e Innovación—PLAN ZERO PLANA. . (September 1, 2022). https://www.alokabide.euskadi.eus/plan-de-ciencia-tecnologia-e-innovacion-plan-zero-plana/

[33] GeoEuskadi. Datu Espazialen Egitura—Euskadiko DEA. (n. d.). Retrieved March 6, 2023, from https://www.geo.euskadi.eus/webgeo00-inicio/eu

[34] Estimar el potencial de energía solar | Learn ArcGIS. (d. d.). Retrieved March 6, 2023, from https://learn.arcgis.com/es/projects/estimate-solar-power-potential/