Journal of Environmental Studies and Sciences (2023) 13:643–657
https://doi.org/10.1007/s13412-023-00840-x

ORIGINAL ARTICLE

Transition process from fossil energy to photovoltaic energy power of ethnic communities belonging to the natural parks in the Colombian Pacific: A diagnostic study

Jennifer Nessim[1] · Sammy J. Martinez-Deusa[2] · Wilson Lopera[3,4] · Katherine Gross[3,4]

Accepted: 15 May 2023 / Published online: 5 July 2023

Abstract
For an energy transformation project with emerging technologies to be viable and sustainable, it requires community participation, the social appropriation of the knowledge of the technology to be implemented, and the assessment of its social and environmental impact. In this context, this research carried out a diagnostic study on the energy consumption of ethnic communities belonging to National Natural Parks in the Colombian Pacific in order to provide indicators of the potential and relevance of portable photovoltaic solar energy for small-scale energy supply in these communities. For this purpose, four strategic sites in the district of Buenaventura were selected to implement questionnaires to collect technical data on demographic characterization (age, occupation, ethnicity, educational level, residence time), solar exposure, architectural infrastructure, energy sources, use of electrical elements, and energy consumption. The study focused on five sectors of interest: (i) housing, (ii) microenterprises, (iii) schools, (iv) health centers, and (v) boats. Fuelwood and diesel were found to be the main sources of energy in the region; this represents continuous pollution of gases and noise. Electricity is supplied mainly through diesel power generators with a cost per kWh higher by 86% than the average value in the interconnected area. It was identified that the most representative economic activities of these communities are fishing, and other activities associated with tourism; therefore, after diagnosing the use of low-power electrical elements in different types of boats, we propose a portable photovoltaic solar system adjusted to local environmental conditions and the needs of artisanal fishing.

Keywords Photovoltaic solutions · Off-Grid · Ethnic communities · Natural parks · Low-income · Pacific region

Introduction

The development of new technologies and the growth of resources for the reduction of CO_2 emissions, and the energy transformation towards renewable energy sources are currently topics of primary interest at the global level. These topics have the participation of private entities, universities, technological research centers, non-governmental organizations, and governmental and intergovernmental institutions that seek the definition of public policies, research, technology transfer, and expansion of markets for their implementation.

According to a forecast published by the International Energy Agency in 2019: "Renewable power capacity is set to expand by 50 percent between 2019 and 2024, led by solar PV. This increase of 1,200 gigawatts is equivalent to the total installed power capacity of the United States today. Solar PV alone accounts for almost 60 percent of the expected growth, with onshore wind representing one-quarter." As part of this

✉ Katherine Gross
katherine.gross@correounivalle.edu.co

Jennifer Nessim
jennifer.nessim@correounivalle.edu.co

Sammy J. Martinez-Deusa
sammy.martinez@correounivalle.edu.co

Wilson Lopera
wilson.lopera@correounivalle.edu.co

1 Vicerrectoría de Investigaciones, Universidad del Valle, 25360 Cali, A.A, Colombia

2 Grupo de Bionanoelectrónica, Universidad del Valle, 25360 Cali, A.A, Colombia

3 Centro de Excelencia en Nuevos Materiales (CENM), Universidad del Valle, A.A, 25360 Cali, Colombia

4 Grupo de Película Delgadas (GPD), Universidad del Valle, A.A, 25360 Cali, Colombia

photovoltaic (PV) expansion, crystalline silicon cells are the most common technology in use today, claiming more than 90% of the global market. Most commercial modules have a conversion efficiency — the fraction of solar energy that is converted into usable electricity — of 15–20% (Photovoltaics report. Fraunhofer Institute for Solar Energy Systems 2022). However, the next generation of solar modules, especially thin film, promises higher conversion efficiency and lower cost, using fewer raw materials for manufacturing. They are flexible and lightweight but can degrade faster than crystalline silicon, reducing their lifespan (Zhang et al. 2018; Conibeer 2007; Emmott et al. 2016; Velilla et al. 2019; Wilson et al. 2020).

The new generation of PV technologies has given way to portable PV power, promoting the development and use of low-power portable devices, which are innovative solutions for off-grid needs (camp, cottage, boat, or off-grid home) YALT 2022. Currently, there are offers on the market, such as an 18-W portable folding solar panel (with current controller) for charging laptops, 12-V batteries, mobile phone, iPhones, tablets, digital cameras, and other digital products out of power, when you are hiking and traveling (NaturePower 2021). The portable PV power market includes lighting, coolers, solar bags, clothing such as jackets and hats, and geolocators.

The International Energy Agency (IEA) invites the world's ministers of energy and mines meeting every two years to define energy security and open to energy efficiency in third world countries. For the 2021 meeting, the Colombian minister announced the growth of new clean energy alternatives to encourage the sustainable reactivation of energy transition, energy security, and mining diversification and formalization (IEA 2021). Brazil is the first Latin American country working on the transition energy process with an impact on low-income regions (Ferreira et al. 2018). The transition process for low-income regions occasionally has shown limited results at the follow-up of the social appropriation process in the communities' technology receptors (Mala et al. 2009).

The transition to a clean energy process brings infrastructure and research linked to technological transition processes as a dynamic social process designed to create synergy models between technology advances and communities' needs. The Innovation systems (IS) dynamics (Hekkert et al. 2007a) are a global trend among citizens under 50 years of age. Continuous exposure to the acquisition and development of knowledge emerges as a basis for building the capacity to generate new knowledge at the micro-level of transitions in practice and everyday life (Köhler et al. 2019). In the western world, the cultures are frequently open to new technologies, and the social changes are inherent (Chaparro 2001). Nevertheless, there are closed communities by geographical or ethnic boundaries that violate those processes, as is the case of some communities in rural areas of third world countries, specifically in Colombia, which are not connected to the electricity network (off-grid) and with limited access to electricity. These areas are called *Non-Interconnected Zones* (*NIZ*) (ZNI for its acronym in Spanish). Non-interconnected zones (NIZ) are those regions that do not receive public electricity service through the Colombian national grid. They represent 52% of the country's territory (equivalent to the size of France) and have an estimated total population of 1,900,000 inhabitants (equivalent to 3.7% of the total population) (IPSE 2022) giving a population density of 3 inhabitants/km^2. This low population can be explained by an extraordinarily complex geography. Impenetrable forests, tropical meadows, the Amazon rainforest, the Andes mountain range, deserts, and extensive coastlines of the Pacific Ocean and the Caribbean Sea form the landscape of these off-grid areas. Because Colombia is one of the most biodiverse countries in the world and given the enormous, widely scattered population, bringing electricity to NIZ has been a major challenge for engineers and politicians. Since grid expansion is very difficult and costly, distributed generation (also known as decentralized generation) has become the most suitable solution for electrification in these areas. Colombia has 62 protected areas that include 43 National Natural Parks, of which more than 80% are in Non-Interconnected Zones (Online. 2022).

Buenaventura, officially *the Special, Industrial, Port, Biodiverse and Ecotourism District of Buenaventura*, is a district, a city, and the main seaport of Colombia and one of the ten most important ports in Latin America, moving more than 53% of the international trade of the country (DIMAR 2018). Due to the particular economy, demography, geography, and biological conditions, this port represents an excellent region for international business.

Buenaventura region has all tropical climates between 0 and 4000 m sea level, it has two National Natural Parks at the pacific region of unsurpassed ecological value: (1) Uramba-Bahía Málaga natural park with enriched biomes like a very humid tropical forest, coastal, cliffs, islands, and the body of water with soft and rocky seabed at sea level. The protected area reports 1396 species distributed in 9 groups of animals and plants. The marine area is home to 254 species of mollusks, 240 species of marine and/or estuarine fish, 237 species of crustaceans, some of them in danger of extinction, 68 species of polychaetes, 28 species of echinoderms, 18 species of sponges, 18 species of cnidarians, and 6 species more of other little marine animals. (2) The Farallones natural park located between 200 and 4200 m above sea level was designated as a national natural reserve since 1968, growing from the western Andes mountain range to the Pacific Ocean coast, it is the setting for 30 rivers, it is home to 540 birds' species, 108 endangered plant species, and some of them 40 m long. In this park are represented:

the humid pluvial forest of a warm floor, a humid forest of a temperate floor, the humid forest of a cold floor, and paramo biomes (Naturales and de Colombia 2022). This area is classified as a tropical wet forest, whit temperatures up to 24 °C and precipitations up to 3.000 mm/year (Perea-Ardila et al. 2019). About the marine life, estuaries (Cantera and Blanco 2001) and mangroves forest are of great importance to preserve as unique ecosystems (Castellanos-Galindo et al. 2006; Laverde-Castillo 2016) (Neira and Cantera Kintz 2005; Lazarus-Agudelo and Cantera-Kintz 2007; Lucero et al. 2012; Álvarez-León 2003).

In the natural park of the Uramba- Bahía Málaga (3°56—4°05 N and 77°19—77°21 W) is located the region of Chucheros with 180 inhabitants. At the Los Farallones National Natural Park, between the San Juan and the Naya rivers which comes from mountains to flow into the Pacific Ocean, is located the region of Yurumanguí (3° 09´ 45″—76° 56´00" and 3° 29¨43" 77° 24´ 53"), beside the Yurumanguí river with 2.182 inhabitants most of them slaves' descendants (Consejo Comunitario de la Cuenca del Río Yurumanguí 2020). Figure-S5 displays a map showing Colombia/Buenaventura and the places where the study has been conducted.

Chucheros and Yurumangui are examples of rural communities belonging to natural parks, characterized by difficult geographical access, low population density, and low economic income, with access to renewable resources for wind, solar and ocean energy resources that are not used (Vides-Prado et al. 2018), Access to these areas is only possible by boats, which depart from the docks *El Piñal* and *Turístico* of Buenaventura only once a day. In these regions, electricity distribution never arises because it represents high infrastructure costs for low-income people without the ability to pay for services (CEPAL 2017) (Planeación and Energética-UPME 2015) (Superservicios 2018) (IPSE 2014). The problems found in the communities pertaining to our study are similar to those of other communities that live in the natural parks of developing countries, as for instance in Africa and Latin America.

To resolve energetic problems in remote areas and consider that natural life conservation reserves at Natural parks are a global priority in these regions, the transition to clean energy has to include PV energy supplies with low Ambiental impact. Within this context, this research aims to diagnose the energy consumption of ethnic communities in *NIZ* belonging to natural parks of the Colombian Pacific (case studies: Chucheros and Yurumanguí) to propose solutions for energy transformation according to the needs and environment of the communities; energy solutions based on new generations of photovoltaic technology for portable low power applications with a positive impact on the economy and well-being of the Pacific Natural Parks population. For this purpose, questionnaires were implemented to collect technical data on demographic characterization (age, occupation, ethnicity, educational level, residence time), solar exposure, architectural infrastructure, energy sources, use of electrical elements, and energy consumption. The study focused on five sectors of interest: housing, microenterprises, schools, health centers, and boats. For the case of boats, a sector of high relevance to the community, we propose a portable photovoltaic solar system adjusted to local environmental conditions and the needs of artisanal fishing. With this research, indicators are proven that account for the relevance of implementing new generation photovoltaic solar technologies in the short term to mitigate the negative environmental impact that the use of fossil fuels, especially the use of diesel generators (Jakhrani 2022) ("ATS 2022), represents in natural park areas, due to the air pollution and noise (Farhan et al. 2021).

Methodology

In designing the methodology, two types of characteristic rural areas were considered in the Pacific region: one with maritime access (Chucheros) and the other with fluvial access (Yurumanguí); Likewise, data on the population, available in the Buenaventura Chamber of Commerce, were taken into account. In particular, account was taken of the fact that in the rural populations of the Pacific the inhabitants are:

1. Older adults requiring medical services
2. Adults with activities focused on: fishing, eco-tourism (hotels and restaurants), maritime transport (passengers and merchandise) and tourist guides
3. Children and young people of primary and secondary education age

These types of population characteristic defined the five sectors of interest in this study: housing, microenterprises, schools, health centers, and boats.

Surveys were conducted in four strategic sites in the district of Buenaventura: the rural regions of Chucheros and Yurumanguí belonging to the *NIZ* and in two docks within the city. To understand and diagnose the energy needs and the process toward new Renewable Energy models in the population of Pacific National Natural Parks, three strategies were designed as described below.

1. ***Community training on clean energy*: ** Black communities have their community government and authority in their territories. Therefore, the first strategy called Community Training on Clean Energy consisted of (i) meetings with Black community councillors to socialize the research objectives and request permission to

access communities in the National Natural Parks in La Uramba—Bahia Málaga (Chucheros) and Los Farallones (Yurumanguí) and (ii) Meetings with the entire community in Chucheros and with professionals from the educational and health system in Yurumanguí using an educational brochure with basic information on the benefits of the use of renewable energy sources and emerging photovoltaic technologies. Each person who participated in the survey received the brochure, which was designed with full-color diagrams and photographs for visual interpretation and simple words for people with low educational levels.

2. ***Data Collection:*** Questionnaires were implemented to collect technical data on demographic characterization (age, occupation, ethnicity, educational level, residence time), solar exposure, architectural infrastructure, energy sources, use of electrical elements, and energy consumption. The study focused on five sectors of interest: housing, microenterprises, schools, health centers, and boats, where:

(i) **Housing:** to diagnose energy sources and the daily use of electrical appliances.
(ii) **Microenterprises:** to diagnose energy sources and the daily use of electrical appliances.
(iii) **Health centers:** to diagnose energy sources and the use of instruments and tools associated with health care.
(iv) **Schools:** to diagnose energy sources and the use of electrical elements and electronic devices of the schoolchildren and teachers.
(v) **Boats**: to diagnose energy sources and the use of basic implements such as geolocators, night light, telecommunications, echo sounders, and refrigeration.

Demographic characterization and surveys in the housing, microenterprise, and school sectors were carried out in the Chucheros region. Since Chucheros has no Health Centers and only one school, these sectors were covered in the Yurumanguí region.

In the case of the boot sector, the surveys were carried out in two docks of Buenaventura D.E: *El Piñal dock*, where the boat service connects the main city with all the coastal towns of the Pacific, which is mainly used by the rural population; the *Turistico dock* with a boat service for the transport of tourists and the rural community living in the maritime regions.

3. ***Diagnosis of energy consumption and needs*:** The third strategy corresponds to the triangulation of the information collected with the costs of current power sources in these regions and a diagnosis of the needs potentially addressed by portable photovoltaic solar power.

Table 1 Sectors of interest surveyed per region

	Chucheros, la Uramba-Bahia Málaga	Yurumanguí, Los Farallones
Housing	72 (72)	0 (563)
Microenterprises	9 (9)	0 (unknown)
Health centers	0 (0)	2 (3)
Schools	1 (1)	4 (12)

This work aims to link technological research with the needs of communities considering the dynamics of innovation systems (IS) (Hekkert et al. 2007b). The transition process for low-income regions has occasionally shown limited results in monitoring the social appropriation process in community recipients (Mala et al. 2009). In our methodology we thus incorporate as an initial activity, direct contact with communities to socialize emerging PV technologies. This aspect is in line with the work of Davila et al., who propose that achieving effective processes of technological transition in communities requires the fulfilment of three dynamic characteristics. The first is that users have technical and cognitive mastery of technology; the second is to determine what has been learned previously and apply it to the needs of the current user; and the third characteristic of its diffusion and permanence is, that the appropriation of these new technological advances is accessible and available to everyone (Dávila Rodriguez 2020).

Photographic record

The research was documented through photographs of houses, schools, and health centers, aimed at showing the types of architectural structures and evaluating the feasibility of implementing new photovoltaic technologies. Each participant accepted, signaling the informed consent. The photographs can be found in the Supplementary Information.

Permissions

This research had the support and permission of the black community counselors and the ethical permission of the Central Research Ethics Committee (CIREH), Universidad del Valle, No. 017–021 for the use and analysis of questionnaires and images and the processing of information confidentially.

Table 2 Boat Distribution by function and dock

	Piñal dock	Touristic dock
Artisanal fishing	80	–
Commercial fishing	–	52
Cabotage	33	–
Tourist transport	–	11
Freight transport	4	–
Total	117	63

Results and analysis

The results presented below consolidate the technical information collected through surveys directed at the following sectors of the community: (i) housing, (ii) microenterprises, (iii) schools, (iv) health centers, and (v) boats. Table 1 show the number of surveys carried out by sector and by region; 72 houses, 9 micro-enterprises (6 hotels, 1 kindergarten, 1 store, and 1 restaurant) in Chucheros; 2 rural Health Centers, and 5 schools accepted to participate and received training on clean energies. The existing population number is reported in parentheses in each box. It should be mentioned that the housing and microenterprises sector was carried out in Chucheros; while in Yurumanguí we focus on the sectors of health centers and schools.

On two docks, boat surveys were directed to 180 captains and owners' boats (Piñal: 117 and Touristic: 63). They accepted to participate and received training on clean energies. The boats were classified into five categories according to their function. Table 2 shows the boat distribution by function and dock.

The following results are presented in two parts: (i) energy consumption and needs in Chucheros and Yurumanguí and (ii) energy consumption and needs of boats.

Energy consumption and needs in Chucheros and Yurumanguí

This section presents the results of the surveys on demographic characterization, architectural structure, energy supply, and consumption of the housing, microenterprise, school, and health sectors.

Demographic characterization

The demographic characterization provided data on age, occupation, ethnicity, and residence time, which were linked to the analysis of PV energy implementation. The results correspond to 180 inhabitants, the total population in Chucheros. Of these, 59% belong to the female gender.

A. ***Age distribution***

Figure 1 shows age distribution: about 7.2% are children under 5 years of age, 37.2% of the population is of schoolchildren age (5 to 20 years), 54.5% are of working age (21–60 years), while 1.1% are adults over 60 years old.

B. ***Occupation distribution***

The occupation and professions in the population are strongly determined by their ancestral roots. Men's work is focused on fishing, tourist travel or transport, while women's work revolves around the home and *piangua* mussel picking. The occupation of the population was subdivided into four categories: schoolchildren, employed, unemployed, and self-employed. As shown in Fig. 2, about 28% of the population are schoolchildren, 6% are employed, 1.6% are unemployed, and the majority of the population (64.4%) has an occupation as self-employed. Within the group of self-employed, the majority (34.4%) are engaged in fishing (fishermen (16.9%) and *piangueras* (17.5%)); in second place they are engaged in general services (14.2%), followed by occupations associated with cooking (cooks (3.3%) cook assistants (3.3%)), and 4.4% are tour guides and below 5% are engaged in other work (see inset). *Piangueras* are women who select the piangua from the mangroves on low tide. Piangua is a mollusk covered with a blackish Shell that keeps inside a yellow and black body similar to oysters, it grows in mangroves only. Piangua harvesting and Fishing are the largest source of employment for women and men, respectively, transmitted from parents to children. Enterprises of the region are directed to tourism (Ospina Niño 2017): food, lodging, guidance, and tourist transportation of special coverage during the whale watching season between June–October (Ávila et al. 2017). All of the above shows the boat sector's great relevance for this type of community.

C. ***Ethnicity***

The predominant ethnic group in the region is Afrodesendant (98%), while only 1% are indigenous and the other 1% are half-caste.

D. ***Residence time***

About 47% of the population are permanent residents, 42% live only during high touristic seasons, while 11% live intermittently between urban and rural regions. The land belongs to communities by ancestral right only; in these regions, many people have been displaced by violence and migrating to the cities, so many homes and crops are currently abandoned.

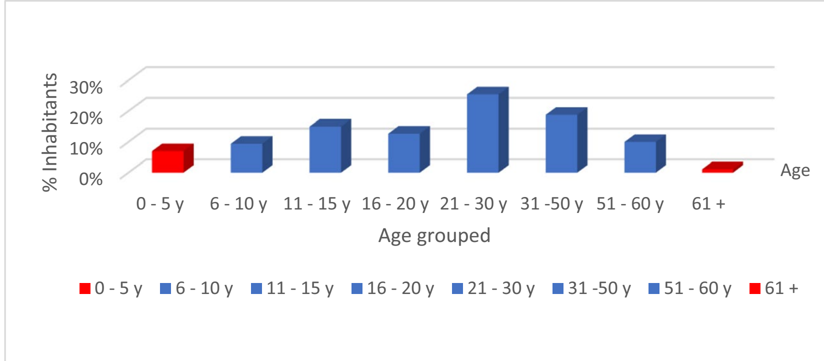

Fig. 1 Population´s age average in Chucheros, La Uramba-Bahia Málaga natural Park, Colombia 2022

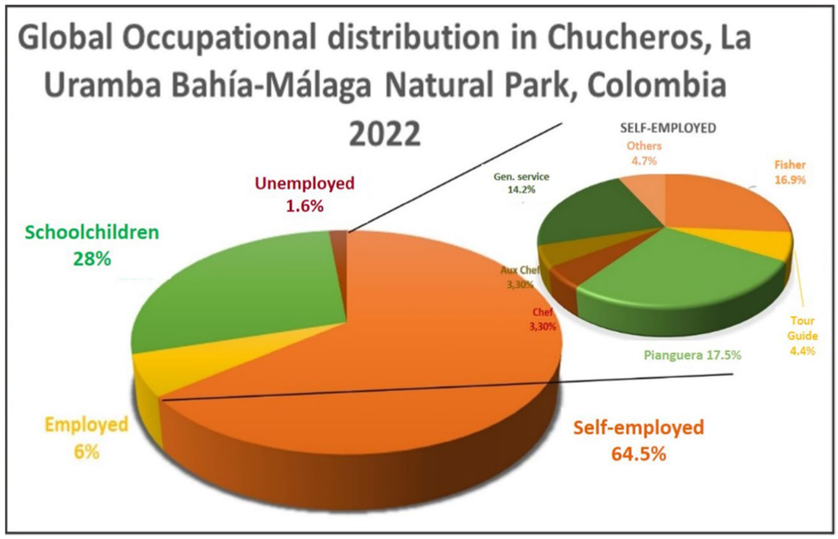

Fig. 2 Occupational distribution in Chucheros La Uramba-Bahia Málaga Natural Park, Colombia 2022

Table 3 Solar exposure of people in Chucheros, La Uramba-Bahía Málaga Natural Park, Colombia

Solar exposure/work	From 6:00 a.m to 4:00 p.m	Population %
Fisher	5 h/day	16.9%
Piangueras	2 h/day	17.5%
Tourist guidance	6 h/day	4.4%
People going to work/schools	2 h/day	61.2%

E. *People solar exposure*

Table 3 shows the distribution of the hours of sun exposure in the community according to their occupation; the time considered was between 6:00 a.m and 4:00 p.m. The Fishers group and tourist guidance have the highest value of solar exposure. The majority of the population (61.2%) is exposed to the sun for an average of 2 h/day while moving between their homes and workplaces or schools.

The results of the demographic characterization show that this rural area, belonging to a natural park, is mainly inhabited (above 70%) by the population aged 11–50 years. This population is characterized by being possible users of electrical and electronic devices, such as cell phones, tablets, and computers for their educational and work performance. At the occupational level, it is evident that the majority are engaged in a self-employed occupation outside the group of schoolchildren. Fishing is the most usual occupation of the population; at the same time, this group of people engaged in fishing, together with tour guides, have a sun exposure between 2 and 6 h a day. On the other hand, most people have sun exposed for an average of 2 h a day while traveling between their homes and their workplaces or schools. The latter represents a good potential for the implementation of portable photovoltaic technologies. In the case of fishing vessels, there is a great potential to use a portable photovoltaic system to meet the needs of devices such as geolocators, echo sounders, communication equipment, LED lights, refrigeration, for example.

Table 4 Architectural structure in houses and hotels in Chucheros, La Uramba-Bahia Málaga Natural Park, Colombia

Walls	Wood 88%	Brick 11%	Drywall 1%
Roof	Zinc sheet 90%	Straw roof and organic 6%	Eternit roofing 4%
Floor	Wood 100%		

Table 5 Energy power resources used in Chucheros, La Uramba-Bahia Málaga Natural Park, Colombia

Sector	Electric power source		For cooking	
	PV panel	Diesel generator	Firewood	Gas cylinders
Housing and microenterprises ($n=81$)	1	11	81	38
Schools ($n=5$)	1	4	4	0
Health centers ($n=2$)	1	0	0	0

Arquitectural structure

The architectural structure of the houses is a fundamental variable in the feasibility study of a photovoltaic installation; in this sense, the questionnaire asked about the type of roof and walls of the dwellings. The results for the type of walls show that 88% of the houses (including 6 hotels) have wooden walls, 11% have brick walls, and 1% have Drywall. All roof structures are made in wood, with 90% Zinc sheet ceiling, 4% Eternit roof, and 6% Straw and organic roof, as described in Table 4. For details on roofs, walls and floors, see Figure S1 in Supplementary Information.

The characteristics of the local architectural structures make it clear that they are not suitable to support standard photovoltaic installations that involve mounting a solar panel above the roofs, which have a weight of approximately 20 kg and require an aluminum infrastructure for the installation of the modules. This situation represents a clear opportunity to introduce emerging solar technologies characterized by their low weight and mechanical flexibility for the electricity supply of these communities.

Energy supply and consumption

The energy supply surveys show that only a minority of the population has access to electricity, which is supplied almost entirely by diesel generators. The Diesel generators used in the study area are single-phase at 220/110 V 60 Hz with nominal powers between 3000 and 4000 W, a fuel storage capacity of 4 gal and autonomy between 10 and 13 h working at 50% of the maximum supported load. These generators have been in use for 6–7 years; however operating and maintenance conditions have been inadequate, so that both their condition and performance fall below expectations. Diesel generators in the housing sector are privately owned. A generator powers 3–5 households belonging to the same family group. The generator is used only for 3 h a day; this usage time is limited by the amount of fuel that families can finance daily. In case of repair, the family must cover the costs. Diesel generators in schools and health centers are owned by the state.

Table 5 shows the number of housing units, micro-enterprises, schools, and health centers electrically supplied by diesel generators or photovoltaic panels. Diesel generators are used by 11 of the 72 houses (including some microenterprises); also, 4 of the 5 schools are supplied with this fuel. Photovoltaic energy is present only in one house, one school, and one health center. Although this health center has a solar panel installed, it is not in operation.

On the other hand, firewood is the main source used for cooking food. One hundred percent (81/81) of the housing and microenterprise sectors use firewood for cooking. In these sectors, 38 of the 81 respondents stated that they also use gas cylinders for cooking.

After identifying the sources of electrical energy used in the different sectors of interest, we went on to identify the electrical elements supplied with these sources, considering their power level: low, medium, and high. The results are presented for each sector of interest.

A. ***Housing and microenterprises***

Figure 3 shows the electrical elements used in the housing and microenterprise sectors supplied by PV solar panel and diesel generators, according to their power level. The power level is represented with three colors: yellow for low-, orange for medium-, and red for high power. In the high power range, we find elements such as a freezer, fridge, washing machine, and light indoors; these are supplied by photovoltaic energy. In the medium power range, the community uses TVs, fans, PCs, and radios, which diesel generators supply. The element mainly used by the community is certainly the cell phone. Adult people use cell phones exclusively and correspond to low technological standards with low power consumption. It is worth mentioning that on average, one diesel generator supplies 4 households. Figure S4 graphically describes the distribution of appliances that the 4 housing units use on average. In Chucheros, such equipment is mainly found in households dedicated to tourism.

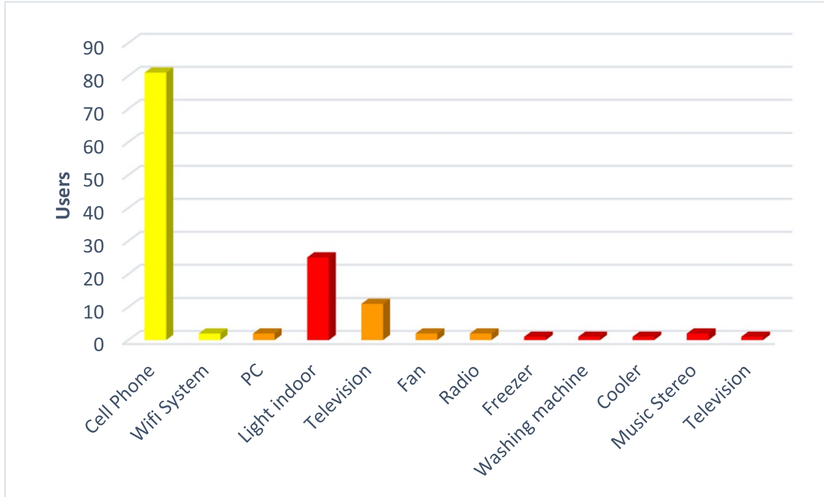

Fig. 3 Electrical elements distributed by power level and source of supply

Table 6 Electrical elements used in schools in Chucheros, La Uramba-Bahía Málaga, and Yurumanguí, Los Farallones Natural Parks, Colombia 2022

School	Energy supply	# school children	Electrical elements
Maria Luisa Elementary school in Chucheros	Solar panel	12	PC, video beam, Wi-Fi system,
Esther Aramburo school in San Antonio—Yurumanguí	Diesel generator	26	PC, router, tv
Esther Aramburo school in San José	Diesel generator	133	Lighting and office users
Esther Aramburo school in Juntas	Diesel generator	30	Lighting and office users
Esther Etelvina Aramburo school in Veneral	Diesel generator	134	PC router, video beam, TV, fan

Table 7 Energy supply for Health Centres in Yurumanguí, Los Farallones Natural Parks, Colombia 2022

Health centers	Energy supply	# Habitants in the zone	Services
Health care Veneral	Diesel generator	189	Closed for infrastructure damage
Health care San Antonio	Solar Panel	339	Insufficient services, only Vaccines service

B. *Schools*

As previously presented, 4 of the 5 schools are supplied electrically by diesel generators and only 1 by a photovoltaic system. The solar panel at Maria Luisa Elementary School in Chucheros is used to power a PC, a video beam, and a Wi-Fi system. Table 6 shows the electrical elements used in each school powered by diesel generators. The school in San Antonio de Yurumangui uses diesel generator for 4 h a day for PC, TV, and power router. Esther Aramburo school in San José and Esther Aramburo school in Juntas use the diesel generator for 4 h for indoor light and office users only. Esther Etelvina Aramburo school in Veneral uses a diesel generator 4 h a day for indoor light, PC, router, video beam, TV, and fan.

C. *Health centers*

Within this sector, it was only possible to access two health centers, both located in the region of Yurumanguí (in Veneral villages (189 inhabitants) and San Antonio (339 inhabitants). Table 7 shows the electrical elements used in these health centers. Although the Veneral Health Center has a diesel generator, it is closed due to fairly deteriorated infrastructure. Figure S2 shows photographs of this case. In the case of the health center of San Antonio, although it has a solar panel on its roof, it does not offer sufficient services; it only offers the service of vaccines, which are stored in polystyrene boxes there, and during the transport by boat that lasts at least 4 h. In the Chucheros region, despite having 180 inhabitants, no health centers are providing primary care services.

Table 8 Average use (hours per day) of electrical elements

	Diesel generators		Solar panel	
	Electrical device	(Hours/day)	Electrical device	(Hours/day)
Low power	Cell phones	2	Cell phones	2
Middle power	Router	2	Router	8
	TV	3	TV	5
	Fan	3	Fan	8
	Radio	2	Radio	8
	PC	2	PC	8
			Video Beam	2
High power	Washing machine	1	Washing machine	1
	Light indoor	3	Freezer	8
			Light indoor	5

Table 9 Average monthly consumption (kWh) per household

Element	Hour/day	Power (W)	# of elements	Energy (Wh)	Energy (kWh)
Cell phones	3	7	5	105	0.105
Laptop	3	200	1	600	0.6
Fan	3	80	1	240	0.24
Radio	3	300	1	900	0.9
TV	3	200	1	600	0.6
Incandescent indoor light	3	100	4	1200	1.2
One-day consumption					3.645
Consumption in 1 month					109.35

Estimation of energy consumption (kWh) and cost per kWh

To estimate the average consumption and cost per kWh, the information on the time of use (hours per day) of these elements were collected. Table 8 shows the average use time of the electrical elements supplied by diesel generators and solar panels, according to their power level. From here, it is identified that equipment supplied with solar energy presents a long time of use than equipment supplied with diesel fuel. For economic and environmental reasons (gas and noise pollution), a diesel generator is kept in operation for only 3– 4 h a day, usually between 7 and 11 p.m.

We estimate the average monthly consumption of a house supplied with a diesel generator considering the equipment used in homes, which according to the results of the surveys, can be obtained with the parameters summarized in Table 9:

Each house has an energy consumption of 109.35 kWh per month, with service availability of only 3 h at night, corresponding to the time in which a Diesel generator is in operation. It is important to mention that the power (W) per element is relatively high because the appliances used in the community are obsolete, and their energy efficiency is very low. According to the community report, a household must provide 1/4 gallon of fuel daily to the Diesel generator. Table 10 presents the estimated cost of operation of diesel generator per month: a gallon of diesel costs approximately $USD 3.78, which implies a total cost per month of $USD 28.35 for 109.35 kWh, representing a cost of $USD 0.26 per kWh; This value is a fairly high cost for low-incoming communities, considering that in the urban area of Buenaventura the cost per KWh is about $USD 0.14 and the availability of service is 24 h without limit for the use of electrical or electronic devices (UPME 2015).

Table 10 The estimated cost of operation of diesel generator per month

Input	Qty (gal.)	Cost per gal	Cost per day	Cost per month
Fuel	1/4	$ USD 3.78	$ USD 0.945	$ USD 28.35
Total monthly cost per community				$ USD 28.35

The results of this research show that the consumption of fossil fuels and the emission of CO_2 in homes, schools, and hotels is a regrettable reality in this rural region belonging to natural parks in the Colombian Pacific region. In addition to the environmental cost, the inhabitants are forced to pay a high cost per kWh and additional costs associated with the boat transportation of supplies: gas cylinders and diesel gallons. This is aggravated by the consumption of firewood for cooking food in homes and its possible impact on natural reserves. It should be noted that these fuels transported in

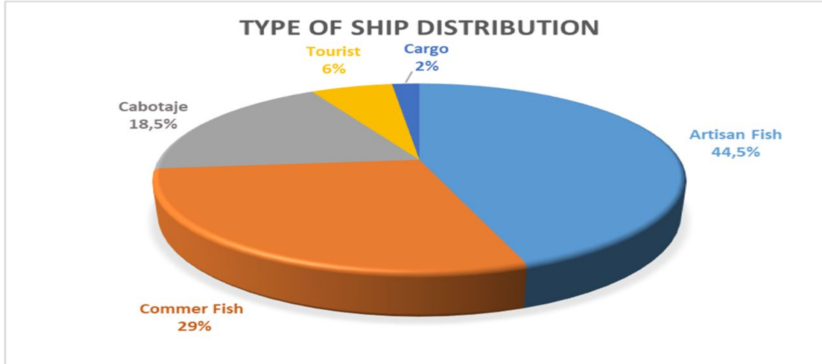

Fig. 4 Types of boats according to the service or activity carried out

small-capacity vessels are at risk of spilling, causing pollution to marine life with a direct impact on the region's ecosystems.

From the housing/hotel point of view, it is observed that only the brick constructions with the roof of Eternit (a school, a house, and a health center) use conventional solar panels of Si (some of them donated by international entities like USAID). Traditional constructions in the region based on wood and zinc sheets are not suitable for silicon panel installations. The latter has two implications: (i) that the transition to clean energy models also involves a transformation in the architectural structure with more robust housing models; or (ii) that such a transition can take place through the implementation of emerging photovoltaic technologies, characterized by its flexibility and lightness, which are more in line with current housing conditions.

The low level of implementation of solar energy can have several causes: (i) the community does not have the economic capacity to access a conventional photovoltaic system; (ii) the community is not interested in such technologies because it requires technical skills; (iii) difficult geographical conditions involve major efforts for the introduction of Si solar panels on a large scale; (iv) The environmental impact of such structures on natural reserves at the end of their useful life is unknown. For all these reasons, we believe that there is a great opportunity to provide energy solutions to these communities through emerging PV technologies, such as flexible and lightweight solar panels (Laalioui et al. 2020). These types of cells can power low-power devices such as cell phones, tablets, laptops, and lighting with LED bulbs, which would significantly reduce diesel fuel consumption. In addition, this type of technology could have a positive impact on the health centers sector through the use of solar refrigerators (low-power DC refrigerators), which are of vital importance for the storage of vaccines and biological elements sensitive to the high temperatures characteristic of the region.

Study of energy consumption and needs of boats

The boats are an imminent necessity for the inhabitants of the rural areas of the district of Buenaventura; in that sense, in this section we focus on diagnose the consumption and energy needs of the boat sector, a survey was carried out on two representative docks: *El turístico* and *El Pinal*, finally, 180 boats were surveyed. The surveys were designed to identify (i) the different types of boats, (ii) type of motors (electric, diesel, or gasoline), and (iii) the level of provision of electrical elements of basic needs, such as cell phones, LED lighting, echo-sounder, geolocator, communication equipment, night light, and cooling. Figure 4 shows the different types of boats according to the service or activity carried out, namely 44.5% are artisanal fishing boats, 29% are commercial fishing boats, 18.5% are cabotage boats (transport of people), 6% are boats for tourist transport, and only 2% are cargo boats. The latter evidence that the activity mainly developed by boats is directed to fishing (73.5%). Figure S3 shows the photographs of boats representative of each sector.

Provision of a basic electrical element

Every boat owner was asked about the provisioning of basic electrical elements. Figure 5 shows the percentage of boats provided by the basic elements such as communication equipment, cell phone, LED light, geolocator, night light, echo-sounder, and refrigeration. As the figure shows, communication equipment is present in 100% of boats, cell phones are used by 77%, LED lighting is implemented by 65%, and 49% have a geolocation system. Only 33% of the boats have refrigeration capacity; within this percentage, the majority correspond to commercial fishing boats. Regarding the geolocation system, it is important to mention that while 100% of commercial fishing boats have one, only 7% of artisanal fishing boats have this system. At this point, it becomes interesting to show the provisioning level of electrical elements depending on the type of boat. For this, Fig. 6 presents a list of the basic electrical elements and the provisioning level for each type of boat. At the same time, the green scale indicates a good level, and the red scale indicates a low provisioning level of the electrical elements.

The first thing that stands out is that commercial fishing boats have, with an advantage, the best provisioning level of electrical elements (all boxes are green), which means that more than 80% of commercial fishing boats have all

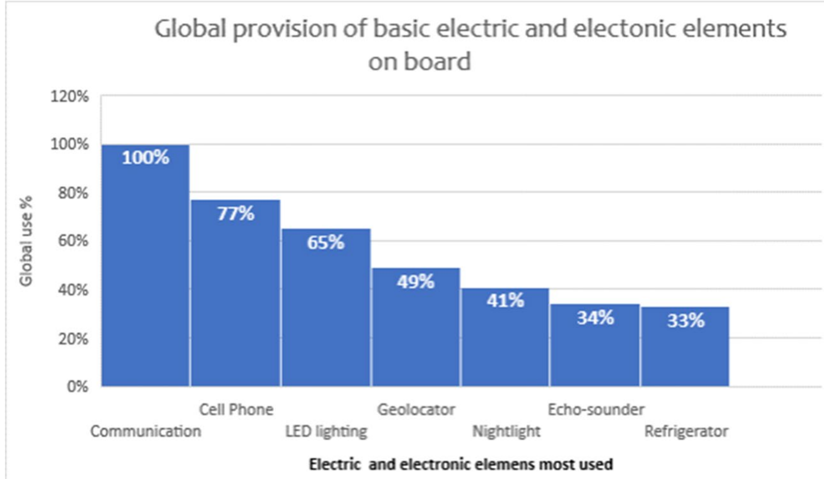

Fig. 5 Global provision of basic electrical elements on board

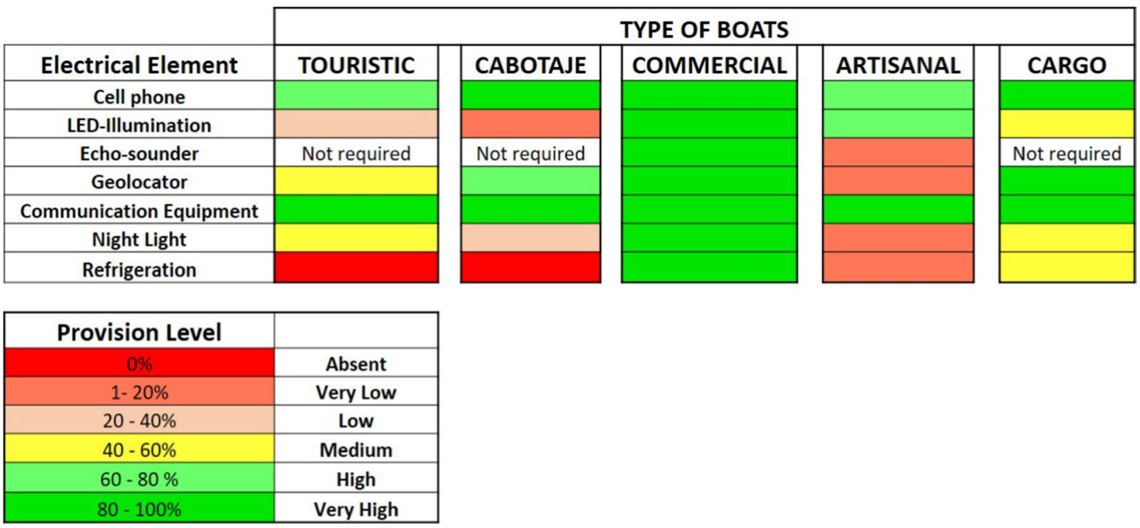

Fig. 6 Provision level of basic electrical elements depending on the type of boat

the basic elements. In contrast, artisanal fishing boats present a low provisioning level in echo sounder, geolocator, night light, and refrigeration (red boxes); only 1–20% are provisioned with these elements. Another aspect that draws attention is the case of tourist boats; only a small number are provisioned with LED lighting, and only about half of these have geolocation equipment.

The surveys showed that 12-V batteries power all these electrical elements. All batteries used to power the boats are charged from the city's power grid rather than photovoltaic cells. None of the surveyed boats have a photovoltaic energy installation. Given this, we want to propose a model of a portable photovoltaic system to supply low power consumption in boats according to actual needs. For this model, we consider the need for an artisanal fishing boat to support a work that usually starts at 4:00 a.m and ends at 7:00 a.m.

Portable photovoltaic solution

The model of portable photovoltaic solution for small-scale fishing boats considers four main aspects: (i) energy consumption required by the boats, (ii) meteorological conditions and the performance of emerging technologies in the tropical zone of the Pacific region, (iii) battery bank considering the energy autonomy of the boats, and (iv) portable electronic equipment control and conversion of electricity (solar controller and inverter). Table 11 presents the technical data for this model.

The energy consumption of the artisanal boats is relatively low (0.56 kWh) since it uses low-consumption electronic equipment (see Table 11), giving viability to a portable photovoltaic solution with thin-film PV technologies. The Thin-Film PV technologies considered for the portable

Journal of Environmental Studies and Sciences (2023) 13:643–657

Table 11 Artisanal boat: Average consumption per day

Element	Hour/day	Power (W)	# of elements	Energy (Wh)	Energy (kWh)
Cell phone	1	15	1	15	0.015
LED Illumination	2	10	2	40	0.04
Echo-sounder	1	200	1	200	0.2
Geolocator	3	5	1	15	0.015
VHF—Communication	3	5	1	15	0.015
Night light	2	10	1	20	0.02
Refrigeration	3	85	1	255	0.255
One-day consumption					0.56

Table 12 Daily average PCE obtained for the PV technologies

PV Technologies	PCE obtained [%]	PCE in STC [%]	Average Tc [°C]
CIGS	10.28	11.77	49.20
CdTe	8.26	11.10	48.17
OPV	3.60	4.18	48.39
A-Si	2.59	3.68	46.19

solution and the average power conversion efficiency (PCE) in the tropical zone of the Pacific region are shown in Table 12. This study was carried out over two months using a monitoring and characterization station in outdoor environments, which considers different meteorological parameters (irradiance, temperature, humidity and wind speed) and allowed to identify that the photovoltaic CIGS technology has a higher performance and is the most suitable for the portable photovoltaic solution compared to other thin film technologies (OPV, A-Si and CdTe) (Muftia et al. 2020). The average relative humidity level in the testing period was 80.9%, with a maximum of 96.1% and a minimum of 56.9%. The average ambient temperature level was 28.82 °C, with a maximum of 34.72 °C and a minimum of 22.38 °C. Measurement data is only recorded during daytime hours (6:00–19:00) due to the operation time of the solar panels that depends on the irradiance.

STC standard test conditions, *PCE* power conversion efficiency, *Tc* cell surface temperature.

The power required in photovoltaic panels by artisanal boats depends on the average daily energy that we receive from the sun (Irradiation). The analysis and design of a PV system is usually based on Peak Solar Hours (PSH). This magnitude is equal to the length of an equivalent day with a constant irradiance equal to the 1-sun intensity (1 kW/m^2), resulting in the same value of the daily radiation. This parameter has units of time, and when given in hours, it has the same numerical value as the total daily radiation in kWh/m^2-day (Page 2012). According to the data obtained by the monitoring platform, the daily radiation in the Pacific region is equal to 4,120 Wh/m2, then, PHS is calculated by Eq. 1.

$$PSH = \frac{Irradiation}{Irr_{STC}} = \frac{4,120[Wh/m^2]}{1,000[W/m^2]} = 4.12[h] \tag{1}$$

where Irr_{STC} is the Irradiance under Standard Test Conditions which is defined at 1,000 W/m^2 for photovoltaic technologies and the irradiation is the integral of the irradiance over a given time, that is, the energy emitted by the sun.

$$PV\ power\ required = \frac{Energy\ Consumption}{PSH} = \frac{560[Wh]}{4.12[h]} = 135.92[W] \tag{2}$$

From Eq. 2, we find that power to be installed of 135.92 [W] in solar panels is required to cover the energy consumption of 560 [Wh/day], which corresponds to the total electrical charge estimated for the artisanal boats.

Figure 7 shows the layout of our portable PV model. Our portable PV proposal is divided into 3 stages: (i) a PV generation system composed of an array of two 70W solar panels with thin-film CIGS technology and a generation capacity of 576.8 [Wh/day] considered 4.12 h of peak sun, (ii) an energy storage system made up of a 100Ah 12 V solar battery with an energy storage capacity of 540 [Wh] considering a 50% depth of discharge to extend its useful life, and (iii) an electronic system integrated with a solar controller that admits a current of 10[A] and a battery voltage of 12[V], and an inverter of 800[W] that covers the instantaneous power of the equipment of the artisanal fishing boat.

Additionally, the portable solution for artisanal boats includes a DC solar refrigerator (see Fig. 7), designed to meet very high energy efficiency requirements and has a DC compressor with lower energy losses in conversion (DC-AC), and tolerates work on the move and inclined positions. These features make this solar cooler suitable for artisanal boats and can be powered by emerging low-power PV technologies with a small battery bank.

Our portable PV solution would increase the productivity and competitiveness of fishers by the following points: (i) energy autonomy in artisanal boats allows fishing activities of longer duration, (ii) increased conservation of fish for later commercialization, (iii) reduction of operating costs of artisanal boats, having solar PV technology as a source of

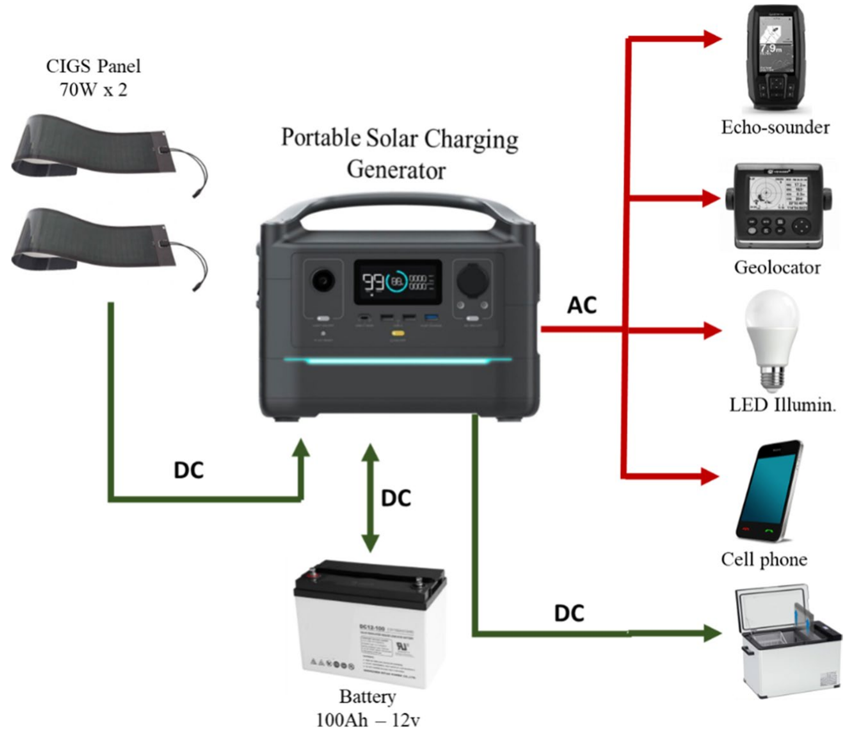

Fig. 7 Portable photovoltaic solution for Artisanal fishing boat

electricity generation, and (iv) positive environmental impact by reducing CO_2 using clean sources of electricity generation.

Conclusions

This research focused on ethnic communities with high levels of poverty, inhabiting remote rural areas belonging to natural parks, in order to project energy solutions by implementing portable photovoltaic systems based on emerging technologies. In this context, this research provided indicators on the potential of implementing emerging photovoltaics to the real needs of vulnerable communities; considering the community from the beginning with the purpose that the transition to clean energies can be a friendly and fair process with all stakeholders.

The population characterized in this study, representative of the population in ZNI belonging to Pacific Natural Park, sustains its economy in self-employed activities, which are primarily associated with fishing and tourism. These, in turn, imply a high level of exposure to solar radiation. Likewise, this population, together with the schoolchildren population, represents great potential for implementing portable solar energy. The population of NIZ inhabitants of the Chucheros region, belonging to the La Uramba natural park, mainly uses fossil fuels for electricity supply and for cooking food, such as diesel fuel and firewood, respectively. Photovoltaic solar energy is practically absent in this sector; likewise, the conventional architectural structures in the communities of Chucheros and Yurumanguí are not suitable to support installations of conventional silicon solar panels on their roofs. It is worth noting that the results obtained from these two regions are representative of the rural communities that inhabit the national parks located on the Pacific and Caribbean coasts of the country, in which fishing and tourism are the main economic activities.

The cost per kWh of electricity provided by Diesel generators is 86% higher than the average cost paid by the residents of Buenaventura interconnected to the network. This is due to higher fuel, maintenance, and transport costs. The energy consumption of a house supplied with a diesel generator is 109.35 kWh per month, with service availability of only 3 h a day. This corresponds to 69.6% of the monthly electricity consumption of an average household in Colombia with service availability of 24 h a day. This high-power consumption is due to the use of obsolete home appliances and incandescent bulbs; however, the low income of the population and low levels of education do not make possible the technological updating of the appliances and the use of LED bulbs, which would lower operating costs: on replacing the four lighting points with LED technology there would be a saving of 29.62% in energy consumption (kWh/month), which corresponds to a monthly saving of $USD 8.42; the latter indicates that the return on investment (acquisition of 4 LED bulbs) would be recovered in just one month. Likewise, the ecological savings implied by no longer using the diesel generator, which demands 7.5 gallons per house per month, is reflected in the reduction of approximately 916.2 kg of CO per year per house.

It was found that the provisioning of basic electrical elements for the performance of the boats is highly varied according to the typology of this; while the commercial fishing boats are quite well equipped with these elements, an average artisanal fishing boat is not. The study of the energy needs in the boat sector showed the high difference in the level of supply of basic electrical elements depending on the type of boat; in particular, when comparing the activity of commercial fishing and artisanal fishing, the latter shows a deficit in this regard. Faced with this reality, we proposed a portable photovoltaic solution (composed of two solar panels with thin-film CIGS technology, a system for load control and storage) adjusted to the real needs of artisanal fishing; including a cooling component for fishery products. Our results on artisanal boats are representative of fishing communities in third world countries that live in high levels of poverty and social vulnerability and are part of a research commitment that believes that the energy transition to new photovoltaic technologies for this sector represents an opportunity to improve the food supply and the local economy of this type of population.

Although the photovoltaic system was proposed for the particular case of small-scale fishing boats, we must bear in mind that the same portable system can be used in other contexts: (i) In the household and microenterprise sectors, the portable PV system would immediately replace the use of diesel generator for cell phone power and LED lighting; (ii) In the case of health centers, the portable PV system could cover the need to refrigerate key medicines and biological material; (iii) schools could benefit from LED lighting and a tablet charging; these are the benefits inherent in portable photovoltaic technologies. This panorama about the benefits and versatility of portable photovoltaic systems, adapted to the real needs of this type of communities, was socialized to the community councillors. They received these results in a very positive way and are hoping to implement a pilot test in their community in the short term.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13412-023-00840-x.

Acknowledgements The authors would like to thank the Black Community Counselors from Yurumanguí and Chucheros for your acceptance to participate and to Universidad del Valle Pacífico for support on research phase.

Author contribution Conceptualization, J.N and K.G. Methodology, J.N and K.G.; validation, J.N, J.J.M, W.L and K.G.; formal analysis, J.N, J.J.M and K.G; investigation, J.N, J.J.M, W.L and K.G.; resources, J.N. and K.G.; writing—original draft preparation, J.N and K.G.; writing—review and editing, J.J.M and W.L; visualization, J.N, J.J.M and K.G.; supervision, K.G.; project administration, W.L and K.G.; All authors have read and agreed to the published version of the manuscript.

Funding Open Access funding provided by Colombia Consortium The authors received financial support of Fondo CTeI—Sistema General de Regalías, through project BPIN 2018000100092.

Declarations

Informed consent Informed consent was obtained from all subjects involved in the study.

Conflict of interest The authors declare no competing interests.

References

Álvarez-León R (2003) Los manglares de Colombia y la recuperación de sus áreas degradadas: revisión bibliográfica y nuevas experiencias. Madera y Bosques 9(1):3–25

"ATS Journals," 06 12 2022. [Online]. Available: https://doi.org/10.1164/ajrccm.183.10.1437.

Ávila I, Correa L, Van Waerebeek K (2017) Where humpback whales and vessel traffic coincide, a Colombian pacific case study. Boletín Del Museo Nacional De Historia Natural, Chile 66(1):85–99

Bati ASR, Zhong YL, Burn PL et al (2023) Next-generation applications for integrated perovskite solar cells. Commun Mater 4:2. https://doi.org/10.1038/s43246-022-00325-4

Cantera JR, Blanco JF (2001) The estuary ecosystem of Buenaventura Bay, Colombia. In: Seeliger U, Kjerfve B (eds) Coastal marine ecosystems of Latin America. Ecological Studies, vol 144. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-04482-7_19

Castellanos-Galindo G, Caicedo-Pantoja J, Mejia-ladino L, Rubio Rincón E (2006) Peces marinos y estuarinos de Bahía Málaga, Valle del Cauca Pacífico Colombiano. Biota Colombiana 7(12):263–282

Comisión Económica para América Latina y el Caribe (CEPAL) (2017) "Avances en materia de energías sostenibles en América Latina y el Caribe: Resultados del Marco de Seguimiento Mundial. informe de 2017," Publicación de las Naciones Unidas, Santiago, 2017.

Chaparro F (2001) Conocimiento, aprendizaje y capital social como motor de desarrollo. Ci Inf Brasilia 30(1):19–31

Conibeer G (2007) Third-generation photovoltaics. Materialstoday 10(11):42–50

Consejo Comunitario de la Cuenca del Río Yurumanguí (2020) Documento caracterización del daño colectivo para pueblos y comunidades étnicas. Buenaventura D.E, Unidad para la atención y reparación integral a las víctimas

Dávila Rodriguez L (2020) Divulgación para la apropiación del conocimiento cientifico y tecnologico. Caracterización y propuesta de estudio. Revista iberoamericana de Ciencia, Tecnología y Sociedad 15(45):11–35

de Planeación U, Energética-UPME M (2015) Integración de las energias renovables no convencionales en Colombia. Bogotá D.E, La Imprenta editores

DIMAR (2018) Boletín Técnico y Estadistico 2018. Bogotá DC, no 2, p 53. [Online]. Available: https://www.dimar.mil.co/

Emmott C, Moia D, Sandwell P, Ekins-Daukes N, Hösel M, Lukoschek L, Amarasinghe C, Krebs F, Nelson J (2016) In-situ, long-term operational stability of organic photovoltaics for off-grid applications in Africa. Sol Energy Mater Sol Cells 149(5):284–293

Farhan A, Salman R, Farhan S (2021) Studying the effect of diesel power generator noise on the publicity in Ramadi City. J Phys: Conf Ser 2114:012078

Ferreira A, Kunh S, Fagnani K, De Souza T, Tonezer C, Rodrigues Dos santos G, Coimbra-Araujo C (2018) Economic overview of the use and production of photovoltaic solar energy in Brazil. Renew Sustain Energy Rev 81:181–191

Hekkert M, Suurs R, Negro S, Kuhlmann S, Smits R (2007a) Functions of innovation systems: A new approach for analysing technological change. Technol Forecast Soc Chang 74(5):413–432

Hekkert M, Suurs R, Negro S, Kuhlmann S, Smits R (2007b) Functions of innovation systems: A new approach for analyzing technological change. Technological Forecasting and Social Change. Technol Forecast Soc Chang 74(4):413–432

IEA, "https://www.iea.org," 2021. [Online].

"IPSE," 06 12 2022. [Online]. Available: https://ipse.gov.co/.

Jakhrani AQ, Othman A-K, Rigit ARH, Samo SR (2012) Estimation of carbon footprints from diesel generator emissions. In: 2012 international conference on green and ubiquitous technology, pp 78–81. https://doi.org/10.1109/GUT.2012.6344193

Köhler J, Geels F, Kern F, Markard J, Onsongo E, Wieczorek A, Alkemade F et al (2019) An agenda for sustainability transitions research: State of the art and future directions. Environ Innov Societal Trans 31(6):1–32

Laalioui S, Alaoui K, Dads H, Assali K, Ikken B, Outzourhit A (2020) Progress in perovskite based solar cells: scientific and engineering state of the art. Rev Adv Mater Sci 59(3):10–25

Laverde-Castillo J (2016) Notas sobre algunos serfulidos (Annelida, Polychaeta) de Bahía Málaga, Pacífico Colombiano. Boletín De Investigaciones Marinas y Costeras 18(1):83–93

Lazarus-Agudelo J, Cantera-Kintz J (2007) Crustáceos (Crustacea: Sessilia, Stomatopoda, Isopoda, Amphipoda, Decapoda) de Bahía Málaga, Valle del Cauca (Pacífico Colombiano). Biota Colombiana 8(12):221–239

Lucero C, Cantera J, Neira R (2012) Pesqueria y crecimiento de la piangua (Arcoida: Arcidae) Anadara tuberculosa en la Bahía de Málaga del Pacífico Colombiano, 2005–2007. Rev Biol Trop 60(11):203–217

Mala K, Schläpfer A, Pryor T (2009) Case studies of remote atoll communities in Kiribati. Renew Energy 34(2):358–361

Muftia N, Amrillahb T, Taufiqa A, Ariprihartac S, Diantoroa M, Nure H (2020) Review of CIGS-based solar cells manufacturing by structural engineering. Solar Energy 207(9):1146–1157

NaturePower (2021) 18-Wat folding solar panel with 8 amp charge controller datasheet. Vietnam, pp 1–8. [Online]. Available: https://naturepowerproducts.com/

Neira R, CanteraKintz J (2005) Composición taxonómica y distribución de las asociaciones de equinodermos en los ecosistemas litorales del Pacífico Colombiano. Rev de Biol. Trop. 53(12):195–206

"Parque Nacionales," 06 12 2022. [Online]. Available: https://www.parquesnacionales.gov.co/portal/es/parques-nacionales-naturales/.

Ospina Niño J (2017) Paisaje y territorio en la playa Juan de Dios, Bahía Málaga, Pacífico Colombiano (2005–2016): una aproximación desde la nueva geografia del turismo. Cuadernos de Geografía: Revista colombiana de geografía 26(7):31–52

Page J (2012) “The Role of Solar-Radiation Climatology in the Design of Photovoltaic Systems,” in *Practical Handbook of Photovoltaics*. Academic Press. Augustin McEvoy, Tom Markvart and Luis Castañer, pp 573–643

Parques Nacionales Naturales de Colombia, "https://www.parquesnacionales.gov.co," 05 2022. [Online].

Perea-Ardila M, Oviedo-Barrero F, Leal-Villamil J (2019) Mangrove forest mapping through remote sensing imagery: study case for Buenaventura, Colombia. Rev De Teledetección 53(6):73–86

Photovoltaics report. Fraunhofer Institute for Solar Energy Systems, "www.ise.fraunhofer.de," 06 Dic 2022. [Online].

Superservicios (2018) Zonas No Interconectadas – ZNI: Diagnóstico de la Prestación del Servicio de Energía Eléctrica. Superintendencia de Servicios Públicos Domiciliarios. Bogotá DC, p 68. [Online]. Available: https://www.superservicios.gov.co/sites/default/archivos/Publicaciones/Publicaciones/2019/Nov/diagnostico_de_la_prestacion_del_servicio_zni_-_07-11-2019-lo_1.pdf

UPME (2015) Plan Energetico Nacional Colombia: Ideario Energético 2050. Unidad de Planeación Minero Energética, Republica de Colombia. Bogotá, p 184. [Online]. Available: http://www.upme.gov.co/Docs/PEN/PEN_IdearioEnergetico2050.pdf

Velilla E, Ramirez D, Uribe J, Montoya J, Jaramillo F (2019) Outdoor performance of perovskite solar technology: Silicon comparison and competitive advantages at different Irradiances. Sol Energy Mater Sol Cells 191(3):15–20

Vides-Prado A, Ojeda Camargo E, Vides-Prado C, Herrera Orozco I, Chenlo F, Candelo J, Barrios Sarmiento A (2018) Techno - economic feasibility analysis of photovoltaic systems in remote areas for indigenous communities in the Colombian Guajira. Renew Sustain Energy Rev 82(2):4245–4255

Wilson G, Al-Jassim M, Metzger W, Glunz S, Verlinden P, Xiong G, Mansfield L et al (2020) The 2020 photovoltaic technologies roadmap. J Phys D Appl Phys 53(9):493001

Zhang Y, Samuel I, Wang T, Lidzey D (2018) Current Status of Outdoor Lifetime Testing of Organic Photovoltaics. Adv Sci 5(8):1800434