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Photovoltaic technology employment in Peru. A literature review

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A B S T R A C T

Peru is a country with plenty of renewable energy sources. However, its power demand depends on more than 50% of fossil fuels. Specifically, the power coming from the sun only represents 1% of the Peruvian energy matrix even though the territory has high radiation indexes. Therefore, the current analysis aims to search for the research situation of photovoltaic energy. Hence, this research looked for literature from RENATI and EBSCO, which provided 398 pieces of academic investigation. After applying the Prisma methodology to select the most relevant thesis and papers, we analyzed 48 elements. We found that the on-grid technology was the most viable in economic terms for projects related to business and electrification. At the same time, off-grid systems have been preferred for sanitation applications. Nonetheless, all the reviewed literature showed that photovoltaic technology positively impacted the environment and was as effective as conventional sources.

1. Introduction

The arising concerns about the sustainability of energy are a world issue. International treaties like the Green Deal in Europe, the Kyoto declaration, and the Paris agreement prove that the world is in the direction of clean energies (Arroyo & Miguel, 2020). Countries that once relied entirely on fossil fuels, like China, are building enormous clean energy plants like the "The Great Wall of the Sun," which catches solar energy through photovoltaic panels (Pui et al., 2014). Also, some countries started building eolic, thermal, hydro, or biomass plants to generate clean electricity (Adra, 2015). However, we will only consider solar energy produced by photovoltaic systems for study purposes.

Although the clean energy generation wave has increased, countries still did not implement aggressive politics to generate clean energy (Larsson, 2009). For instance, Peru is a country that has a high dependency on fossil fuels (Ministerio de Economía y Finanzas, 2012). In fact, about 48% of the Peruvian electricity production relies on the burning of diesel and gas (Organismo Supervisor de la Inversión en Energía y Minería, 2016). Although the gas-burning is the least contaminant of all fossil fuels, it still impacts the air quality (Lattanzio, 2020). Moreover, it is concerning that only 0.5% of the electricity in Peru is generated by solar energy (Organismo Supervisor de la Inversión en Energía y Minería, 2016). Peru has regions with high radiation indexes, especially in areas with high altitudes. Radiation can reach levels up to 18, considered extreme (Hidrología, 2003). Therefore, there is a natural potential to harness the solar energy of those places. Although more than 95% of Peruvian homes have electricity by power lines, which come from the conventional Peruvian electricity sources, some people live in high radiation zones and do not possess electricity power. (Organismo Supervisor de la Inversión en Energía y Minería, 2016). Even though there are plenty of natural resources, the infrastructure cost is prohibitive (Hossain et al., 2019). Of course, that cost suffered a reduction from previous years, but it is still more costly than other energy sources (Fraas, 2014).

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The costs rely on how photovoltaic energy is generated as it can be on-grid, off-grid, and hybrid (Franklin, 2018). The first is a system connected to a net by interconnected inverters and solar panels, producing energy employing solar panels and transporting it to the electric net (Kumar et al., 2018). It has the advantage of supplying power at any time. Also, this system is more efficient and economical than systems that employ storage batteries (Franklin, 2018). The off-grid system employs storage batteries that work with no net system (Ørbaek et al., 2011). Here the solar panel generates energy autonomously, which is stored in batteries. Finally, hybrid systems mix many sources to produce energy like the sun, air, fuel, or water (Franklin, 2018). It can reduce the employment of panels to supply the energy requirement, and it economizes the use of storage batteries (Alktranee & Bencs, 2020). Therefore, it can be more costly than the other systems, but it complements previous ones. Every photovoltaic system is a compound of integrated equipment that transforms energy efficiently from solar power to electricity (Ørbaek et al., 2011). Hence, the conversion is a difference between photovoltaic and thermal energy. Thermal energy converts heat into energy, while photovoltaic only transforms solar power into electrical power (Musunuri et al., 2007). It is necessary to add that a photovoltaic system should gather energy and deliver it appropriately (Dincer & Ratlamwala, 2013). Consequently, the photovoltaic system is a compound of a photovoltaic generator, charge regulator, inverter, battery, protection materials, and the necessary support structure (Franklin, 2018). The photovoltaic generator is a set of integrated panels that supply energy at any moment. Each panel is a group of photovoltaic cells protected by a rectangular plaque that produces the power necessary for the function of the other elements (Franklin, 2018).

The second component, the charge regulator, is necessary to protect the battery in an energy oversupply (Wasfi, 2021). Third, the batteries store the energy produced by the panels, ready to provide it when it is necessary (Ørbaek et al., 2011). Finally, the charge inverter transforms the direct current produced by the solar panel into alternating current, which is the current employed by the electronic devices (Franklin, 2018). Solar energy is cleaner than other sources of electricity (Abolhosseini et al., 2021). Moreover, it is an alternative source of electricity to those generated by heat and water, which depend on costly power lines in challenging geography (Larsson, 2009). Therefore, how is the advance in implementing photovoltaic energy in Peru? The current analysis will answer this question by searching the literature on photovoltaic use in Peru. Consequently, the research will analyze the thesis and papers which explored ways to implement this clean energy in Peruvian locations.

2. Method

We carried out a systematic literature review to answer the question of the introduction. The literature analysis followed the methodological proposal of (Tranfield et al., 2013). Also, the classification of literature followed the Prism methodology proposed by (Moher et al., 2009). Hence, it was necessary to look for academic studies whose scope was implementing photovoltaic energy in different places in Peru. Therefore, the researchers analyzed the thesis and paper with that theme.

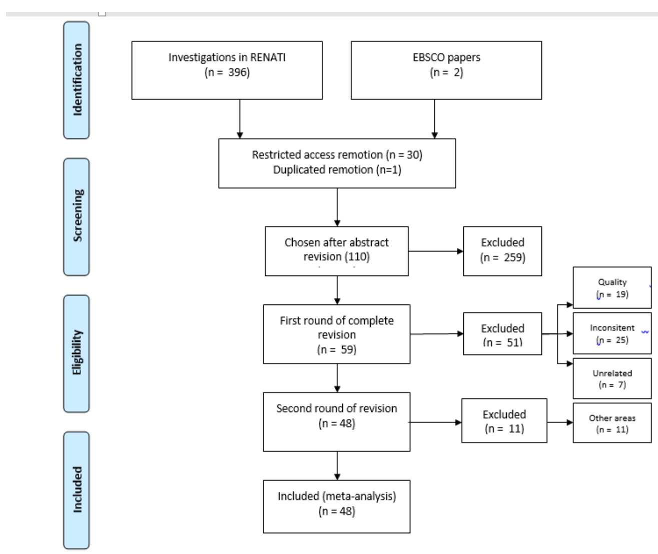

Fig. 1. Flow diagram of research selection

First, the thesis set was searched in a database following the Prism methodology. The database selected was the "Registro Nacional de Trabajos de Investigación" or RENATI which stores the total of the thesis elaborated in Peru. For papers, we dug into the EBSCO database. In the identification step, we found 396 thesis and two papers. After that, we removed duplicated thesis with restricted access in the screening step. Then, we selected only the investigations that applied the photovoltaic technology in Peru. In the abstract revision, we choose studies that showed a complete panorama of the analysis. After that, the first round of unlimited revisions decided on the investigations that had consistency among their components. Also, it was important that the research had an excellent investigation quality and was not related to other energy sources. The second round of revision excluded investigations unrelated to the mechanics of photovoltaic engineering. Finally, only 48 studies were left for further analysis. Fig. 1 portrays the methodology followed.

The 48 investigations, following Ferreira Barale & Rodrigues dos Santos (2017), were classified as follows: electrification, plant, dwelling, business, and photovoltaic sanitation applications.

3. Results

Fig. 2 portrays the number of investigations per year. It is noticeable that most of the selected literature belonged to 2021. Moreover, Fig. 3 shows that most of the analyzed research is from UNAP, followed by UDEP and PUCP. Although the PUCP is considered the most important Peruvian university in the QS ranking, UNAP has an advantage in the issue since photovoltaic energy is widespread in its area of influence. A similar situation is for UDEP since Piura is a region applying solar energy for its climate boundaries. Fig. 4 shows that many photovoltaic energy applications were on electrification. Business and sanitation applications were equal in remarkable numbers.

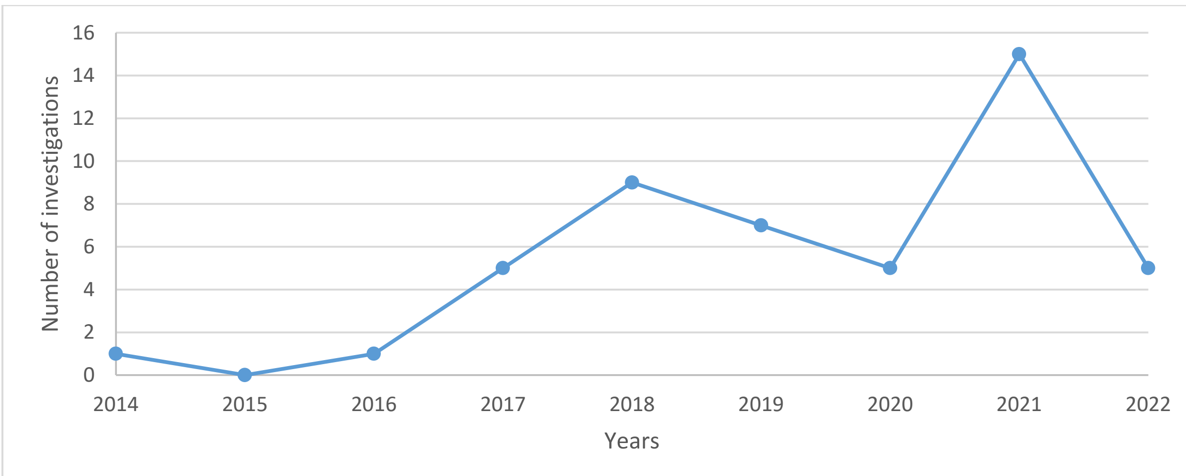

Fig. 2. Number of investigations per year

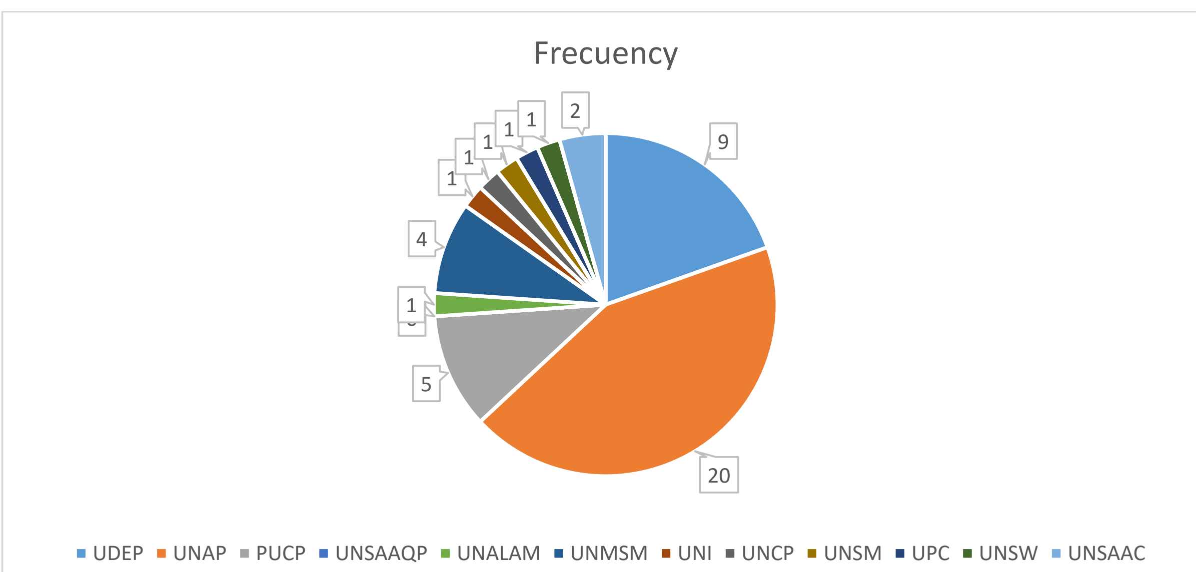

Fig. 3. Investigations per university

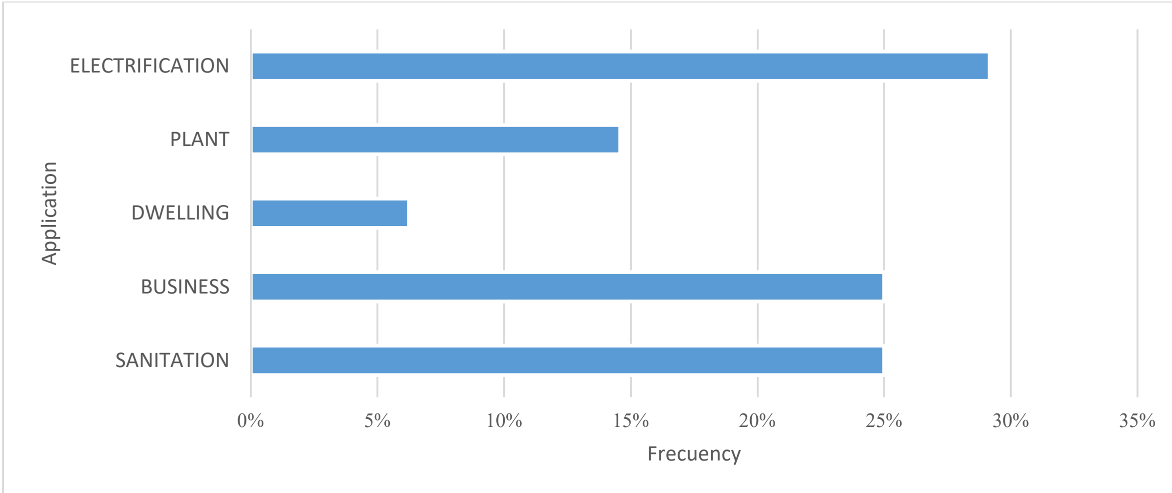

Fig. 4. Photovoltaic applications

Table 1
Summary of analyzed literature

Application	Photovoltaic system	%	Reference							
Electrification	On grid	43%	(Chunga, 2020)	(Ccama, 2017)	(Poclin, 2021)	(V. Quispe & Poccori, 2021)	(Pareja & Pareja, 2019)	(A. Muñoz, 2019)		
	Off grid	43%	(K. Valdiviezo, 2021)	(F. Muñoz, 2021)	(Cáceres, 2018)	(Pérez, 2019)	(Castañeda, 2016)	(P. Valdiviezo, 2014)		
	Hybrid	14%	(Mejía, 2020)	(Chagua & Valdivia, 2017)						
Business	On grid	25%	(Chero, 2021)	(Camasca, 2022)	(Cruz, 2021)					
	Off grid	58%	(J. Mamani, 2018)	(Guerra, 2021)	(Cueva, 2019)	(Ramos, 2017)	(Loja, 2019)	(Prada et al., 2019)	(Camayo et al., 2021)	
	Both	17%	(Espinoza, 2021)	(Uriol, 2020)						
Sanitation	On-grid	8%	(Vilca, 2021)							
	Off grid	67%	(H. Mamani, 2022)	(D. Choque & Ramos, 2018)	(Sosa, 2017)	(Hancco, 2017)	(Benites, 2019)	(Escobar & Choqque, 2020)	(Tinta, 2017)	(Ahumada, 2017)
	Both	8%	(Medina, 2019)							
	Hybrid	17%	(Andrade & Quispe, 2016)	(D. Choque, 2018)						
Plant	On grid	71%	(Torres, 2021)	(A. Quispe, 2017)	(M. Choque, 2017)	(Rodriguez, 2020)	(Huamonte, 2019)			
	Off-grid	14%	(Vázquez & Miranda, 2019)							
	Hybrid	14%	(Flores, 2019)							
Dweeling	Off grid	67%	(Parraga et al., 2020)	(García, 2018)						
	Hybrid	33%	(Yancachajlla, 2021)							

Table 1 shows a brief classification of the literature reviewed by application and system employed. Most of the literature engaged both on and off-grid systems in the electrification application. Furthermore, the business application investigations often apply off-grid systems like sanitation and dwelling applications. However, plant application literature preferred employing grid systems. Hybrid systems had the highest employment in-dwelling application on percentage, while it was not used at all in business.

3.1 Electrification application

The main application of photovoltaic energy is to provide energy to places where conventional power lines cannot arrive. Of course, such energy must meet the devices' demand. Then, Valdiviezo (2021) designed an autonomous photovoltaic system to provide energy in some spaces at Piura University, specifically in the parking lots. The illumination project employed LED illumination to optimize the lighting power. Due to the off-grid system nature, the project was costly. However, the environmental impact was significant.

Similarly, Muñoz (2021) employed LED illumination to illuminate the IME building at the Piura University. The reason to do so was the same as K. Valdiviezo (2021), i.e., the power of LED illumination. Taking advantage of the radiation of Piura, the researcher installed the solar panels. However, the off-grid system was too costly to be a profitable solution. Moreover, the building energy demand was higher than the supply capacity. Another project carried in the same university tried to implement a photovoltaic solution for the energy supply of a radar. Chunga (2020)intended to employ the Piura radiation to generate electricity by solar panels in an off and an on-grid system. The researchers concluded that this energy supply was sustainable for being environmentally friendly; nonetheless, it was necessary to employ an on-grid system to meet the radar energy demand. Mejía (2020) proposed a hybrid solution to supply energy to a building. The researcher proposed a system based on solar and air energy, both autonomous of a conventional power line.

Although the solution was ecological, it was not economically viable. Cáceres (2018) searched for a way to optimize the electric consumption in the lighting of the Nacional de Altiplano Informatics department. Here, it is necessary to add that Puno is a cold place in contrast to Piura. However, its radiation index is one of the highest because of its altitude. Then, the employment of solar energy is widely known in that region. Hence, a LED system powered by an off-grid photovoltaic system was proposed. Although it was an off-grid system, the research found it profitable after four years because it was only for consumption reduction and not for a total replacement of conventional power lines.

Also, in Puno, but in an urban environment, Ccama (2017) studied the viability of an on-grid photovoltaic system. The proposal contained a set of eight photovoltaic systems connected to the power lines. The research found that the project was technically viable, but no further analysis was made on the economic profitability study. Chagua & Valdivia (2017) studied the efficiency of a hybrid electric generation system. This system was powered by sun and air, and the possible locations were in different places in Puno city. The research found that the efficiency determinants were the area characteristics. Hence, the most critical factor was that the possible site had high radiation and powerful winds.

Cusco also shares some geographical similarities with Puno, but its clime has more humidity. Hence, Pérez (2019)aimed to study the viability of an off-grid photovoltaic system to light the houses of El Vallecito. The project was economically viable thanks to the FOSE, a subvention system since the population saved almost 77.5% of the costs.

In Lima, which is a place with little sunlight for most of the year, Castañeda (2016) proposed a solar system to supply the energy demand of the Nacional Agraria La Molina University laboratory. The objective was to employ the photovoltaic system to provide electricity for lighting and telecommunications. Hence, the research proposed an off-grid system compound of 76 solar panels. After that, the analysis showed that the system could save up costs of about six thousand dollars in energy in twenty years. Moreover, it positively impacted waste management since some materials were reused for panel elaboration. Also, in Lima, Valdiviezo (2014) proposed an off-grid photovoltaic system to supply energy to fifteen computers in the Pontificia Universidad Catolica del Peru. The research suggested a system with 24 panels and 12 batteries. Although there were emission savings of 4.35 tons of CO2, the project was not economically sustainable.

In a hospital setting, Poclin (2021) designed a photovoltaic system for the Regionalde Moquegua Hospital employing radiation in this part of Peru. The approachproposed in this research was one of on-grid. After an exhaustive analysis, theresearcher found that this system was viable since the on-grid system does notemploy as many storages as an off-grid system which increases costs.

Quispe and Poccori (2021) analyzed a photovoltaic design for an Institute in Cusco. The researchers proposed an on-grid system that lowered the conventional energy consumption of the institute. Moreover, a further investigation proved that it was profitable in a 10-year evaluation as long as it used LED technology as a lighting device. Also, Pareja and Pareja (2019) analyzed an electric generation system for the San Antonio Abad University campus. Hence, they designed an on-grid system to generate electricity for the lighting of the campus areas. In this analysis, the researchers found that the project can be profitable only after 20 years due to the high costs.

Muñoz (2019) analyzed the implementation of a photovoltaic system in-home complex in Yarabamaba. Then, the researcher chooses an on-grid system to complement the energy from the conventional power lines. The analysis found that this project was sustainable for the savings of energy of a traditional design. However, it was necessary to educate people about the importance of energy-saving.

3.2 Business application

Photovoltaic energy has applications for business as an alternative to conventional power sources. In the case of transport, photovoltaic energy can replace fossil fuels. For instance, Espinoza (2021) designed a charge station powered by solar panels to supply energy to vehicles using two alternatives based on an on-grid and an off-grid system. Although both projects were costly, they remarked on the CO2 saving of about one and two tons per alternative. Of course, the off-grid model was more expensive than the on-grid system.

Similarly, Mamani (2018) evaluated a photovoltaic system to improve the energetic independence of an electric vehicle. The vehicle chosen for this purpose was a 1976 Volkswagen model bumblebee. The off-grid recharge system allowed the car to have 2 hours of autonomy with a charge of 10 hours.

Guerr (2021) created a photovoltaic system for the fishing industry. The proposed model was an alternative to supply the energy demand of the stationary boat "Chata," which serves as a mobile storage in the sea. The study found that the model was sustainable in a twenty-year scenario and could supply 64% of the total energy demand for the download of the fishes, lightning systems, and the two electro pumps. Cueva (2019) intended to design a catamaran for public transportation in the Amazonas river on another transport facility. The proposed system should have met the velocity requirement from eight nodes and a navigation autonomy of five hours. After the analysis, it was shown that the proposed 270 solar panels catamaran could be profitable in a ten-year horizon transporting up to fifty passengers from Iquitos to nearby locations. Moreover, it saved the emissions of 193.05 tons of CO2 per year. Consequently, it was an environmentally friendly proposal, which reduced emissions and sounds, and was profitable.

In industrial scenarios, Chero (2021) studied the flicker effect of an ice cream shop supplied with a photovoltaic system. The photovoltaic system was proposed as an alternative to the conventional power lines. This system was intended to provide energy with the same quality as a traditional source. Therefore, the flicker effect of both sources was evaluated, obtaining that the photovoltaic energy lowers the flicker effect. Another study carried out by Uriol (2020) in the same ice cream shop showed that an on-grid photovoltaic system started to be profitable in about fourteen years. The research pointed out that an on-grid system is cheaper than an off-grid one due to the savings in batteries.

Camasca (2022) applied an on-grid system to improve the energetic efficiency of a textile business. The analyzed company had problems with its energy supply since it was costly. Consequently, the photovoltaic system helped lessen its energy costs and avoid the energy supply, and it was proved to be profitable in ten years. Likely, Ramos (2017)studied a proposal of a loom powered by solar energy in a rural area called Tarucani. As stated before, the rural Andean regions have high radiation indexes, making them attractive for projects of this nature. It was found that the proposed machine could make up to twenty blankets of sheep and alpaca in four hours. However, this investigation did not make any economic analysis.

Loja (2019)analyzed the design of a drying system of coffee beans powered by solar energy. The requirement for the coffee dryer was that the coffee beans had a humidity of 11% with a working temperature of 35 grades or less. For location requirements, the system was an off-grid photovoltaic model. The analysis showed that the system met the criteria, but it was not possible to find an economic profit because of the high cost of the off-grid model. Similarly, Prada et al. (2019) analyzed the effectiveness of a photovoltaic-powered coffee drying system. Here, the main requirement was to obtain a humidity of 12% through a machine of continuous air. It was only possible to design an off-grid system like the previous study due to the place's characteristics. The study found that the system could process the coffee beans in temperatures from 42 to 49 degrees without altering the humidity significantly. A similar machine was proposed by Camayo et al. (2021)to dry aguaymanto. However, the offered machine was multiple, i.e.; it employed both thermal and off-grid photovoltaic solar energy. Also, the analysis showed that the proposed machine could work appropriately and meet the sector's requirements. Although the previous two studies showed that the photovoltaic system efficiently met the need, they did not prove economic sustainability.

Cruz (2021) also intended to diminish the conventional electrical consumption by a photovoltaic on-grid system. The analysis proved that the on-grid system could supply about 25% of the total demanded energy and that from the seventh year, the investor could start gaining profits from this system.

3.3 Sanitation application

Photovoltaic energy is also an alternative to provide solutions to water distribution. There are many rural areas with a lack of water distribution for consumption and agriculture. Also, many of them do not have electric power lines, which only leaves them with the option to buy fossil fuels to power water pumps. This alternative is both contaminant and expensive since it is difficult to arrive in those places for their inappropriate or inexisting road systems. For instance, H. Mamani (2022) built a pumping water system for a rural location in Puno. This investigation planned to propose a solution for the sanitation needs of Morocco, which lacks an appropriate drinking water distribution for its 20 families. Therefore, the study found that implementing a water pump system powered by off-grid photovoltaic energy is cheaper than employing fossil fuels. Similar research was conducted by Medina (2019) in Chaupi Sahuacasi, where more than 107 families live. It is a place with complex geography, making it necessary to pump drinking water to supply the demand. Therefore, both the off-grid and on-grid systems proved sustainable in a twenty-year horizon and cheaper than the conventional power lines. Also, D. Choque (2018) studied a water pump system powered by an off-grid photovoltaic system and compared it to a traditional fuel-powered system. The research found that photovoltaic energy is more profitable than the conventional power source over a twenty-year horizon. Also, the study stated that the photovoltaic system was safer and easier to use and maintain than the other alternative. Sosa

(2017) tried to provide a solution to the water distribution of the Quenafajja town. The research found that for the town's demand, the water pump powered by an off-grid photovoltaic system saved about half of the operative costs, prevented water losses, and was able to supply the request if the population increased. Hancco (2017) designed a water pump system to provide drinking water to Cachuyo Saolloccotaña. This town does not have any source of clean water, which causes illness to its population. Hence it was necessary to provide a submersible water pump to catch and clean water. The economic analysis showed that the cost each month per family would be 0.5 dollars to maintain the system. A watermaker prototype was necessary to clean up the water for human consumption in all those researches. Here, Benites (2019) designed one employing the off-grid photovoltaic system. This prototype provided water to a small population of 100 families in climate conditions similar to Piura for eight continuous hours.

Furthermore, Ahumada (2017) designed a water pump device for a sewage treatment plant in Vilavila. Since the system was off-grid, the design did not have economic viability. Nonetheless, it had a performance similar to devices powered by conventional energy.

In a laboratory setting it is also necessary to have a continuous supply of water. For this reason, D. Choque & Ramos (2018) designed a control module for the pumping water system for a laboratory at the Nacional del Altiplano University. This module was off-grid powered and proved efficient for the laboratory's needs. Also, (2020)designed an off-grid system to build a module that could automatize the water pumping system in real-time. This system showed that the existing pumping system was inefficient.

Also, the pumping water can be employed for agricultural purposes. Vilca (2021) studied implementing a pumping water system powered by an on-grid photovoltaic system. The Rosaspata agricultural community mainly produces alfalfa in silage and bale. Then, the research proposed a system compound of eighteen solar panels with a potency of 320 w and no battery use. After implementing the proposal, the analysis estimated that the number of crops would grow two times. The project will have a profit rate of 30% on average in the ten years horizon. Similarly, Andrade & Quispe (2016)designed a hybrid system to improve the water pump of Chinumani. Such a system would be a compound of an off-grid photovoltaic device and an air one. Although they found that the project would increase the productivity of the crops, the project was not profitable.

Tinta (2017) analyzed the application of solar energy in an impulsion line of a sanitization system on Soto Island. Puno hosts the Titicaca lake, where people live on natural and artificial islands known as "Uros." About 120 families live on Soto island, where there are no power lines, and fuel is their only source for getting energy. Therefore, the project designed an off-grid impulsion line with a power of 300 w. This proposal had a low cost of maintenance and provided a solution for the sanitization problem of the island.

3.4 Plant application

There is also an industrial size application of photovoltaic energy. These plants are in charge of producing enough energy for human settlements, a novel phenomenon in Peru. Torres (2021)designed a plant connected to a power line in Sora. Hence, they proposed a plant of 1852 modules with the capacity to produce 1 901 849.06 kWh. This energy was able to reduce 14 tons of CO2 per year. Also, A. Quispe (2017) proposed an on-grid system to build a plant that provides power to Micra. The plant was composed of 4472 panels with a capacity to provide 1118 kWh. Hence, the economic evaluation showed that the plant was profitable in an evaluation horizon of fifteen years with a payback of four years.

Furthermore, Choque (2017) proposed an on-grid photovoltaic plant in Challapalca. The proposed plant could provide 25 000 Kwh ready for distribution to the Puno region. The investigation stated that the reason behind the choosing of Challpalca was because this place had a high radiation index and was large enough to host a plant of such dimension. Hence, what can be the criteria needed to put a photovoltaic power plant in the best place? For this, Rodriguez (2020) employed a multicriteria analysis to choose the best place to put an energy plant in Arequipa. Consequently, the research found that the place called La Joya had the natural and infrastructure facilities to host an on-grid photovoltaic plant.

The design of industrial facilities to generate energy to supply other industries was studied by Huamonte (2019), who aimed to design a photovoltaic on-grid system to provide power to a plant in Peru. The analysis showed that the system was safe since no risk of a short circuit was found. Moreover, this system could supply the increments of energy demand without increasing the cost of employing the power lines and making the electric system more efficient. Also, Vásquez & Zúñiga (2015) analyzed the implementation of multiple solar facilities in a mining community in Huancavelica. The proposed model was a thermal and an off-grid photovoltaic facility compound. They found that the thermal facility could meet the demand of 82% of total energy consumed in the mining community; however, the photovoltaic system was not economically feasible to meet the 18% demand left. That finding was that the energy from a hydroelectric plant was cheaper than the photovoltaic energy. Therefore, the research mentioned above stated that only the thermal energy saved the electricity costs, but the employment of both sustainable fuels improved the mine's corporate image. Finally, Flores (2019)also studied the proposal of a hybrid system to supply the energy demand of a mine placed in Lucma. The studied system was off-grid and employed both sun and wind energies. Consequently, the research found that it was necessary to invest a high quantity of money with a payback of 44 years to cover 40% of the energy demand. Hence it was not attractive to private investors.

3.5 Dwelling application

Most Peruvian homes get their energy from hydroelectric and heating sources, as stated in the introduction. However, in places where the power lines cannot arrive, photovoltaic energy came as a solution for houses without electricity. Hence, Yancachajlla (2021) designed a hybrid system powered by sun and air sources. The solar system was an off-grid device, and the composition was able to provide 3,68 kWh, which was the most economical design. This system was able to supply energy with a cost of 0,335 dollars per kWh and a capacity of 9,49 kWh per day. (Parraga et al., 2020) also analyzed the viability of a photovoltaic system for a rural house. The proposed approach was 0.75 kWh per day and provided a minimum of 0.43 kWh per day. Economically, the cost was 0.28 dollars per kWh and in horizon evaluation of 20 years was viable for the family. García (2018) employed an on-grid photovoltaic system to analyze how solar energy can economize the costs in an urban situation. The research found that the person would be able to recuperate its prices in the ninth year only if the cost of conventional energy is 0.3 dollars per kW in an evaluation horizon of twenty years. Finally, this investigation pointed out that if the system is off-grid, the costs can grow by 25%, putting at risk the economic profitability of the proposal.

4. Discussion and conclusions

The literature analysis showed a variety of applications of the photovoltaic system in Peru. It was seen that the majority of studies took place in locations that had high radiation indexes like Puno and Piura. Then this technology is not novel for these parts of the Peruvian territory. Also, it was noticeable that the off-grid system was not profitable for all applications except sanitation, and the on-grid one was the most powerful in economic terms. According to the literature, the explanation was that battery costs make any photovoltaic project more expensive. However, it was not true for the majority of sanitation projects. Those projects employed off-grid systems and still were profitable. According to the literature, such behavior was that the other alternative, i.e., fossil fuels, were more expensive. Additionally, all the projects were in rural areas with a complex or nonexistent road system. Then, fossil fuels in those places are likely to be more expensive than in big cities because of the transport costs.

Also, the literature showed that in Peru, the hybrid system was a compound of solar and air energy. There was no mention of geothermal, biodiesel, or even natural gas. Then, it is necessary to expand other forms of sustainable energy, especially in places where it is difficult to get both solar and air energy. In cases where it is not technically possible, the government should support the acquisition of necessary equipment to obtain photovoltaic, thermal, and air energy. It can be done through taxes, exoneration of such equipment and strengthening the FOSE program.

Furthermore, solar energy plants must be considered a solution to thermal energy, a contaminant. Although it is claimed that those plants burn clean gas, they still generate pollution that contributes to air contamination. Moreover, they depend on the building and maintenance of costly pipelines and cannot reach them easily due to the Peruvian geography.
Finally, we believe that photovoltaic electricity generation must be expanded in urban areas because it can alleviate the costs of energy increase due to the domestic and international context. Hence, efforts should be made to spread the long-term benefits of the photovoltaic system for more people and businesses to start using it.

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