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Sustainable Energy: A Case Study of an Alpaca Wool Production Unit in Cashapata San Mateo-Huarochiri-Peru

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In Peru, with the world's largest alpaca population and as the world's leading producer of alpaca fiber, many rural families in high Andean areas depend on alpaca raising and the sale of their fiber as their main source of income. The Cashapata production unit in the rural community of San Antonio, San Mateo district, Huarochiri province, Lima department, is made up of 45 families that sell the fiber at very low prices to the collector. Lack of access to electricity has hindered the transformation of fiber into yarn. This case study focused on the adoption of solar technology to address this transformation challenge. The solar resource and community readiness were assessed. The results showed an on-site solar radiation of 5.26 Kwh/m2.day, with each transformation process such as shearing, terma, dryer, carder and solar spinner being successful. In addition, by recognizing and valuing the traditional knowledge accumulated over generations, it facilitated the adoption of solar technologies for fiber processing. This participatory approach promoted collaborative learning and community empowerment, highlighting the potential of solar energy to drive sustainable development in alpaca wool production.

Keywords: Alpaca fiber, Cattle clippers, Renewable energy, Solar energy.

1. Introduction

Currently, the global population of alpacas exceeds 6 million, distributed across more than 60 countries on 5 continents. Peru has the largest population with 71.7% [1], and it is estimated that alpaca producers reach 92,700 agricultural units dedicated to raising 4,384,846 alpacas, of which 76% (70,452) are small producers and 24% (22,248) are medium and large producers

[2]. Peru is a country with a significant percentage of low-income inhabitants with limited access to energy, particularly in remote rural areas and marginal urban areas, where they meet their needs with traditional energy sources, such as biomass [3]. Arimborgo et al [4] have develop and test an air solar heater for a San Juan de Tarucani community in Arequipa, where the air is heated by solar energy and its movement is thought natural convection. Whith this arrangement is possible to increase the temperature inside the alpaca`s shed. As a continuation of this previously research, that prototype was analyzed since of the thermodynamical point of view in a coastal laboratory for the determination of the angle change that optimize the heat [5]

The rural community of San Antonio, in the Cashapata production unit, San Mateo district, Huarochiri province, Lima department, is among the small producers. This community comprises 3 sectors (Chocna, San Mateo, Caruya), forming 45 families dedicated to this activity. The alpaca production chain is not profitable for families with small herds, as they care for, feed, and shear alpacas ancestrally, obtaining a minimal profit of USD 8.7 (S/31.3), with each animal producing 2.3 kilos of fiber annually in the local market [5]. The San Antonio community faces three significant challenges: being small alpaca producers, lacking access to energy, having low economic incomes, and being located at 4100 meters above sea level. Research revealed that they do not participate in the fiber transformation process into yarn due to the lack of energy to perform this task. It should be noted that they earn USD 1.62 (S/6.00) per kilo of fiber annually, and both their animals and themselves are exposed to harsh climatic conditions, leading to extreme poverty for the small producers of San Antonio.

One of the main challenges in the sector is the need to increase the economic income of families dedicated to raising alpacas [6]. Therefore, a pilot project was initiated to demonstrate that small producers can participate in the fiber transformation process by utilizing the abundant natural resource in the area, "solar energy," generating electricity and heat to be integrated into each transformation process and transferring the knowledge and application to the small producers.

Vaidehi Pathak and Sameer Deshkar indicate that [7] 21st-century rural development demands a new sustainability paradigm capable of addressing challenges and leveraging opportunities, such as climate change, demographic shifts, international competitiveness, and rapid technological progress. Considering this, a participatory approach was emphasized to promote collaborative learning and drive technological transfer in the San Antonio rural community. Chambers [8] indicates that technological transfer is essential for rural development and improving living conditions in agricultural communities. The participatory approach in these processes not only facilitates the adoption of new technologies but also promotes community empowerment.

2. Methodology

First Stage

Harold Richins states that [9] community governance and the development of local human capacities have been considered means to address, improve, and preserve important resources. Similarly, we refer to Freire [10], who indicates that the participatory methodology involves community members at every stage of the project. This methodology is based on the principles of participatory action research (PAR), which promotes collaboration between researchers and participants to co-create solutions to local problems. Therefore, the project began with field visits, identifying key community members knowledgeable about the fiber transformation process and understanding their limitations for this activity. This was done through interviews with leaders, surveys, and community meetings, with key questions including:

1- Is your knowledge about the alpaca fiber transformation process technical (equipment-based), ancestral, or neither?

Obtaining the detailed results in Fig. N°1.

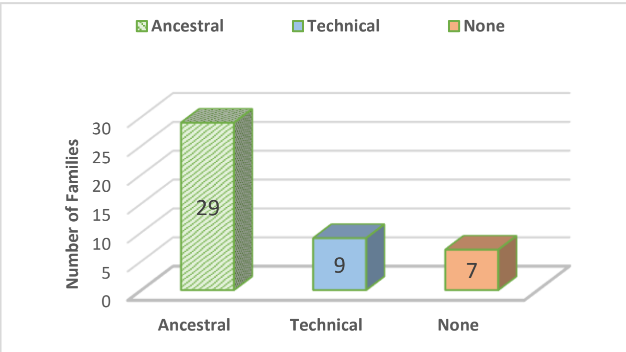


Fig.1: Number of families versus fiber transformation process

Source: Research Group

2- Do you want to learn to use equipment powered by solar energy to carry out the fiber transformation process?

Obtaining the detailed results in Fig. N°2 below:

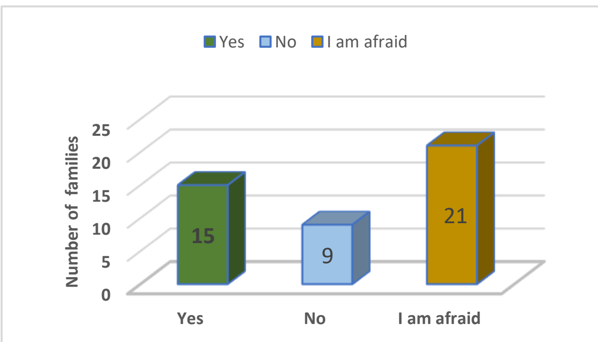


Fig.2: Number of families versus technological equipment

Source: Research Group

The community president, Walter Suarez, mentioned that approximately two years ago, they sheared alpaca and sheep fiber with scissors, but now they use external services (hired personnel) for this activity. He also emphasized that the fiber prices from collectors are very low, a sentiment echoed by other community members, who state that the price of alpaca fiber is approximately S/6.00 soles per kilo.

The only economic income for the rural community comes from raising alpacas, sheep, and their fiber. As a result, young families often migrate to the city in search of other incomes, leaving the care and shearing of alpacas to older adults (60, 65, 80 years) and sometimes women with children dedicated to herding.

The project team surveyed the area where community members deliver their alpacas to the collector for shearing (number of alpacas: 800). The collector shears all the alpacas in three days, negotiates the fiber price (average S/6.00 soles per kilo), and then leaves with all the sheared fiber. This procedure can be seen in the following Fig. N° 3 below:

Fig. 3: Alpaca shearing and fleece collection

Source: Field visit photos.

This visit confirmed that the San Antonio rural community, comprising 3 sectors (San Mateo, Chocna, Caruya), does not participate in the alpaca fiber production chain.

Understanding the community's situation and simultaneously identifying community leaders, roles were defined and shared. The active participation of the community president, Walter Suarez Gómez, and leaders Américo and Eddy generated the trust and legitimacy essential to mobilize and ensure the commitment of the community members for the technology transfer process. The community meetings organized by the president allowed everyone to feel like an integral part of the project, and clear and open communication channels were established, enabling a constant flow of information and feedback.

Second Stage

The process of transforming alpaca fiber into yarn involves the following stages:

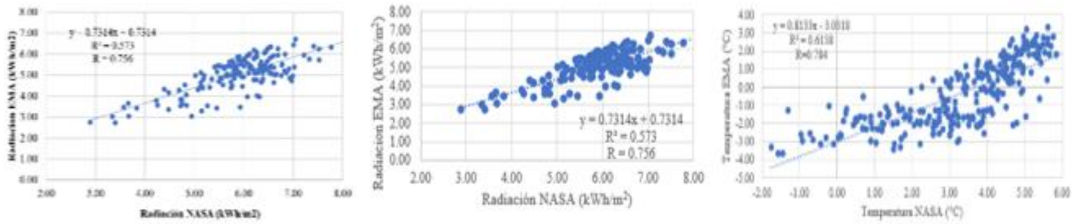
Shearing → Washing → Drying → Carding → Spinning

Each stage corresponds to a piece of equipment that will be adapted or designed to operate with solar energy and meet the transformation process requirements.

Solar energy has the potential to meet the world's energy needs […] It should be noted that annual solar resources vary considerably depending on several factors such as proximity to the equator, cloud cover, and other atmospheric effects [11]. Peru's solar potential is influenced by its orography, climate, oceanography, and other factors, creating large natural regions: Coast, Highlands, and Jungle […] Annually, the area with the highest solar energy potential is the southern coast, with 6.0 to 6.5 kWh/m², the northern coast and much of the highlands have 5.5 to 6.0 kWh/m², and the jungle region records lower values of 4.5 to 5.0 kWh/m² [12].

The study area is in the highland region (mountainous terrain), so a weather station was installed to quantify the availability of solar radiation, its temporal distribution, and to observe the behavior of these variables over a 10-month period due to the scarcity of meteorological stations in the area. Local information was supplemented with nine years of historical data extracted from NASA's POWER application for auxiliary measurement points located throughout the district.

The data on the behavior of the variables during the work period were subjected to statistical analysis to visualize their influence in determining the solar potential. Therefore, the values obtained were correlated, showing their validation in Fig. Nª. 4. according with the next description about measurement: (a) Maximum temperature, (b) Minimum temperature and (c) Average Radiation [14].



a b c

Fig. 4: Validation of Temperature and Radiation.

Source: Research Group

For the statistical data obtained, the following models were used:

Bristow and Campbell Model

This model is based on two assumptions: one is the relationship between absorbed and incoming solar insolation, and the other is neglecting the heat flow from the ground during the daily period, as it is close to zero. Ideally, the temperature is minimum just before dawn, resulting in a significant difference between the daily maximum and minimum air temperatures. This phenomenon allows for modeling solar insolation based on temperature differences [14].

$$\frac{H}{H_0} = a_B * \left[1 - e^{(-b_B * \Delta T^{c_B})}\right]$$

The coefficients a, b, and c are empirical, representing the maximum relationship between extraterrestrial solar insolation b and c how quickly the maximum value H/H_0 is reached with the change in ΔT [9, p.35].

Hargreaves-Samani Original Model

This model is based on the effect of clouds on the solar radiation reaching the ground. It uses the difference between the maximum and minimum temperatures as an indicator of the amount of solar radiation reaching the ground [15].

$$\frac{H}{H_0} = a * (T_{max} - T_{min})^{0.5}$$

Annandale et al. Modification

Annandale et al. [16] modified the Hargreaves-Samani model by introducing a correction factor for the parameter "a" to account for the effects of altitude reduction and the atmosphere.

$$\frac{H}{H_0} = A * (1 + 2.7 * 10^{-5} * z) * (T_{Max} - T_{Min})^{0.5}$$

The most optimal model was found to be the Bristow and Campbell model. Therefore, the spatial and temporal distribution of incident solar radiation was performed by interpolation in the free software QGIS, generating a grid with sufficient resources to model radiation in annual, monthly, and seasonal periods. Whose distribution can be seen in Fig. Nª 5.

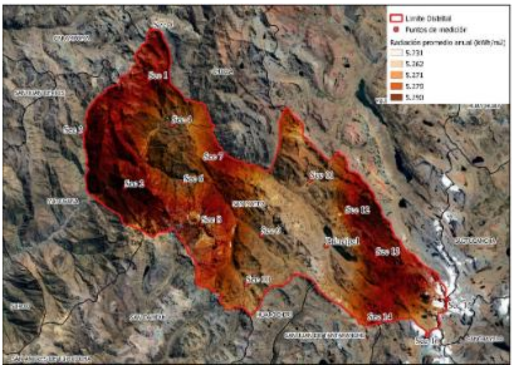


Fig. 5: Annual Distribution of Incident Solar Radiation in San Mateo

Source: Andia M. et. al [17]

The figure shows areas with the highest and lowest annual variation of solar radiation received on the surface, registering between 5.23 to 5.29 kWh/m2.

Third stage

Walter Vasquez [18] says that Energy increases productivity, increases the income of the population in rural areas, creates sources of permanent work, and allows working together for the common good. What has been stated is true, but generating energy through solar radiation means dependency between both and the user, since they are important factors that must be taken into account since the sun's energy is intermittent, it varies according to the season of the year, to climate change etc.

Rural areas of Peru do not have access to the use of machinery or equipment that helps generate productivity and it is much more acute in remote high Andean areas, such as the case of the Cashapata production unit - the rural community of San Antonio, a place where alpacas are raised and not There is an electrical network, which is why the solar energy study was carried out with favorable results, since the estimated radiation oscillates between 5.23 to 5.29 kWh/m2, and is corroborated by the local community members, manifesting itself in the following way:

"Here in Cashapata, in winter the sun shines for a few hours (2 to 3 hours) then there is immense cold, it rains or hails, one winter dawn you can see that everything is frozen. In summer there are more hours of sun (sunshine) in the afternoons it is cold, it rains but it is not as intense as in winter, and it also dawns with the green grassland that is food for the alpacas."

Under this context, the solar energy of the place will be used, transforming it into solar thermal and electrical energy, taking into special account the critical and non-critical loads for the operation of equipment that will be used in the process of transforming alpaca fiber into yarn.

To this end, continuous visits were made in order to observe the activity of the community members (men and women), which is very necessary for the subsequent design process of the equipment, which responds to specific conditions, guaranteeing the active participation of each of them. . The designed and adapted equipment that uses photovoltaic electric energy is the shearing machine, carding machine and spinning machine, and the equipment that uses thermal energy is the solar thermal system.

3. Results

DESIGN AND CONSTRUCTION OF EQUIPMENT

Cattle Clippers

The shearing process consists of cutting the alpaca wool with manual scissors or a shearing machine. This is done once a year in order to remove the wool that has grown one year. This management has several advantages such as productive use. of wool [19] an alpaca shearer is a tool that is used to cut the wool fiber, a task that must be done without damaging the animal's skin. There are shearing scissors on the market and conventional electric ones such as the Heiniger Xpert 2-speed, it is a very Powerful and professional 250 watt alpaca shearer with two speeds: 2500 – 2800 RPM, with a power of 250 W and Voltage: 220-240V, 50 50-60Hz [20].

For the project, a commercial shearing machine was taken and an adaptation was made to the electrical system, so that it works with the photovoltaic system, that is, with 12 volts and direct current, as shown in Fig. Nª 6.

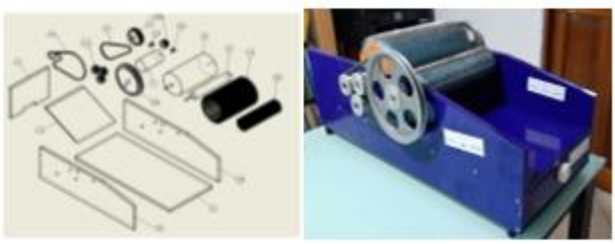
Fig. 6: Clipper with 12 volt adaptation

Source: Preparation of research group

Carding Machine

For the design, the various types of carders that exist on the market were analyzed, such as: Compact card, The feeding-disintegration group is characterized by being able to arrange the entry table in an inverted direction with respect to the usual one so that the disintegration of the layer is oriented in the longitudinal direction of the fiber [21] Standard drum carding machine, with 12 mm and 10 mm high-strength drawn steel axles, drums mounted on sealed bearings that do not need lubrication. Cabinet: made of dryer-dried and varnished coigüe wood [22]. Carder with motor, motor and speed of 180-250 rpm approx. High resistance drawn steel axles, drums mounted on sealed bearings that do not need lubrication, cabinet made of dry coigüe wood, duco varnished [23].

After having analyzed each of the existing carding machines on the market, we proceeded to the design and construction of the carding machine for the project, which consists of a main structure of plywood, consisting of a pair of rollers (larger and smaller), a system regulation, 250 W brushless electric motor with an electronic controller that allows speed regulation and works with energy from the photovoltaic system. Observe the design in figure Nª 7 where we can show a) Parts of the carding machine and (b) Carder built.



a b

Fig. Nª 7. Carder Design.

Source: Own elaboration.

Spinning Machine

Spinning is the final stage of transformation, the input of material is the ribbon of parallel fibers, then twisting and twisting is carried out to then obtain the artisanal yarn [24], the main drawback that occurs in spinning so Traditional is that to obtain a thread of a desired thickness, it only depends on the pulse of the person who spins it [25]. For the design of the spinning machine, commercial spinning machines such as the Ashford 3 Electric Spinning Wheel with the following characteristics were analyzed. in wood, weighs 2 kg, variable speed from 0 to 1800 rpm, 12-volt DC 1.25 amp 70w motor. Suitable for 220 volt current [26] Kiwi Super Flyer, comes as a kit and is very easy to install, has a huge 27 mm (1 inch) hole, includes 3 large coils that have a capacity of 500 gr [27].

The design of the project consists of a structure made of wood and reinforced plastic, ball bearings and a 100 W brushless electric motor with an electronic controller that allows the speed to be regulated and works with energy from a photovoltaic system with a speed regulator. The accessories, the flywheel, the supports, as well as the reels are made of plastic, two aluminum arms that serve as a thread guide and a cylindrical head that houses the retaining ring with the main stainless steel shaft. All this structure serves to twist the wool fiber. This design can be observe in figure No. 8 where we can show a) Parts of the spinner and (b) Spinner built.

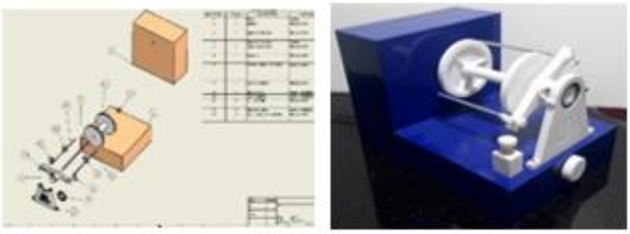


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Fig. 8: Spinning design

Source: Own Elaboration

Photovoltaic System Design

The parameters obtained in the study of the climate are the input surfaces for the design of the Photovoltaic System, in which we will take into account the energy used in the housing facilities, as well as those used in the different environments, a table of consumption and times evaluated for each activity taking into account the best configuration for optimal operation and lower energy consumption according to each month of the year.

In order for the energy loads to be covered by the production of the solar panels, a list of devices to be used must be made, as well as the usage times of each of them must be estimated, so that the maximum consumption time is say when all devices are working together. The Table 1 presents the energy requirement needed to process alpaca fiber for 8 hours (one workday).

Table No.1. Energy Requirement

Environment	Quantity	Appliance	Powers (Watts)	Usage time (hours)	Energy (Watts /hour)
Lighting	2	Spinning workshop	8	2	32
	1	Bedroom	5	2	10
	1	Kitchen	5	2	10
	1	room	5	3	15
	1	Bathroom	5	2	10
	3	Outside	3	6	54
Workshop	1	Workshop	200	6	1200
	1	clipper spinner	100	6	600
	1	Carder	250	6	1500
	1	laptop	80	6	480
			661		3911

Source: Own Elaboration

Note: The energy required for lighting the rooms was 99 w-h, likewise, the energy required for the operation of the work equipment was 3780 w-h, therefore the total energy required was 3911 w-h.

The total amount of energy required uses 8 photovoltaic panels of 100 WPico, placed on the roof with an inclination of 15° towards the north, on a wooden base bolted to the main beams to give security to the system, 4 batteries of 200Ah, a load controller. Figure No. 9 shows the installation of photovoltaic panels.

Fig. 9: Installation of photovoltaic panels

Source: own elaboration.

Solar Thermal

One of the ways of washing alpaca wool is done in tubs using water at high temperatures, with the purpose of eliminating all foreign matter from the skeins, discarding all dirt that comes from the raw material and other processes [28]. The next way is using solar thermal baths, made up of a set of collectors, which are responsible for transforming the radiation alone into heat, a thermos tank that preserves hot water from one day to the next, a system of pipes for the circulation of the water. heated and support system which orients the entire system from north to south and gives an installation angle according to the place of operation. Because it does not have moving parts, operation can be guaranteed for at least 15 to 20 years [29].

The design of the solar thermal heater for the project had the following conditions;

The processing of the fiber requires 8 liters for each kilogram of washed fiber, therefore, the required volume is 400 liters of hot water per day, for the cleaning of the staff (5 people) 40 liters each are required, it would have 200 liters, so the water heating system should have 600 liters at a minimum of 55°C over the course of the year. The data on temperature variations allow us to calculate the size of the solar system, specifically the collection area in square meters of solar collector, which allows raising the water temperature from T_Minimo to T_Maximo, whose design temperature is T_Max=55 °C the minimum temperature is the one that changes during the year. The other parameter that directly influences the behavior of the solar collection system is the solar radiation that was quantified working with the averages for each month.

$\forall = 600\,\mathrm{l}$

$\mathrm{T_{Desing}} = 55°\mathrm{C}$

$\mathrm{T_{Average}} = \mathrm{T°\ avarage\ water\ temperature\ throughout\ the\ year}$

C_p = Heat capacity of water

$Q_{entrance}$ = Energy received by the system

Q_{Output} = Energy used by the system

Efficiency = System Global

The amount of energy required to heat water is calculated each month, therefore the energy is:

$$Q = V * C_p(T_{Design} - T_{Initial})$$

The ambient temperature has different values each month, obtaining the data in Table Nª. 2 and in Table No. 3, the energy requirement values throughout the year.

Figure No. 10 shows a graph showing the lowest and highest energy requirements, as indicated in Table 3.

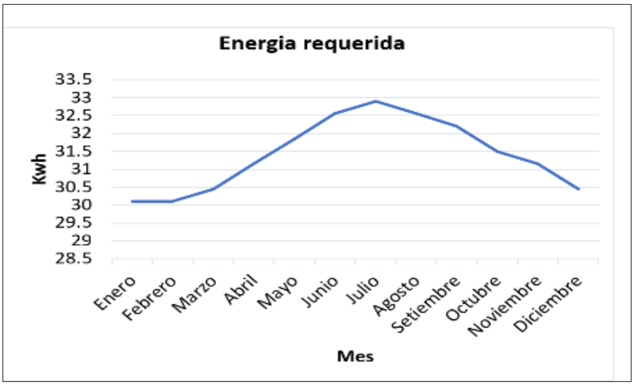

Fig. 10: Energy requirement in the year.

Source: Own Elaboration.

The next parameter is what determines the size of the solar collector, the equation that governs its operation is given by:

$$\text{Collector area} = \frac{Q}{\text{Rad} * \text{efficiency}}$$

Performing the calculations for each month, the Variation in the size of the collector throughout the year is obtained, represented in Figure Nª11.

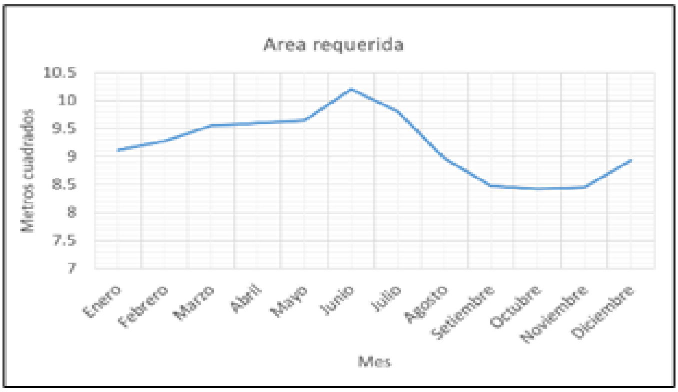

Fig. 11: Variation in collector size throughout the year.

Source: Own Elaboration.

From the analysis conducted on the behavior of the climatic requirements for optimal functioning, the one with the largest area will be selected. Therefore, for the requested area, modules of 2 m² will be constructed to facilitate transport and installation. For which, a solar water heater has been planned. See Figure Nª 12.

The solar water heater consists of:

- 5 solar collectors, each 2 m²
- A reinforced thermoplastic tank with a capacity of 600 liters
- 15 cm thick expanded polyurethane insulation
- Connections with ¾ inch hot water pipes throughout the installation

Table 2. Monthly Average Temperature Variation

Months of the year	E	F	M	A	M	J	J	A	S	O	N	D
T_{design}-$T_{average}$	48	48	48.5	49.5	50.5	51.5	52.0	51.5	51.0	50.0	49.5	48.5

Source: own elaboration.

Note: It is observed that (T design –T monthly average) has the lowest value in the month of January of 48°C and the highest value in the month of July with a value of 52°C.

Table 3. Energy requirement values throughout the year

Months of the year	E	F	M	A	M	J	J	A	S	O	N	D
Energy (Q)	30.1	30.1	30.45	31.85	31.85	32.5	32.9	32.5	32.2	31.5	31.15	30.45

Source: own elaboration.

Note: The energy to cover the hot water requirement is 30.1 Kwh in the month of January (the smallest of the year) the greatest energy need corresponds to the month of July with 32.92 Kwh.

Fig. 12: Installation of the water heater (2 tanks of 300 liters, 5 solar collectors)

Source: Own Elaboration.

Community participation

Training and practical demonstrations were conducted in the same environment where the technologies would be used, facilitating the contextualization and practical understanding of the equipment. The community members actively participated in the use and management of the equipment, allowing learning through direct experience.

Some opinions of community members when carrying out the significant experience of using equipment that works with solar energy.

Using the solar clipper

The community member stated that the activity of shearing with large traditional equipment using gasoline to operate said equipment will remain in the past, I do not imagine that a shearing machine can operate with the energy of the sun and works the same as a traditional one. Observe Figure Nª 13.

Fig. 13: Community members using solar clipper.

Source: Own Elaboration.

Using the solar thermal

The community woman stated that she never imagined that at 4,100 meters above sea level they could have hot water without using the stove and that the water was heated with the energy of the sun. Figure No. 14 shows the community using solar energy to wash alpaca fiber.

Fig. 14: Community members washing alpaca fiber (solar thermal)

Source: Elaboration of the research group Source.

Using the solar carding machine

The community member stated that it is important in this transformation process because the fiber must be soft and uniform and can only be obtained with industrial machines, however it can also be obtained with solar equipment. Observe figure No. 15.

Fig.15: Community members carding alpaca fiber

Source: Prepared by the research group

Using the solar spinning machine

The community woman stated that she spins with a spinning wheel and that once they brought her spinning equipment, but she had to pedal and it ended with pain in her legs. The solar spinning equipment is very easy to handle, practical and does not cause pain to any part of your body. Observe figure No. 16

Fig.16: Communal Member Using the Solar Spinner.

Source: Own Elaboration

The study of solar radiation at the Cashapata production unit shows that the estimated models obtained the behavior of this incident radiation in the study area. Additionally, the simulation verifies its thermal amplitude during the solar day.

The photovoltaic system generated sufficient energy for the Cashapata production unit, providing lighting for the people in charge of safeguarding the unit.

The participatory approach ensured that the technological solutions were sustainable in the long term, as the community was committed and trained to maintain and improve them. The collaborative experience strengthened community bonds and promoted a spirit of cooperation and mutual support.

Mutual learning facilitated a faster and more effective adoption of new technologies. There was an increase in efficiency, as practical training and teamwork led to greater efficiency in tasks such as alpaca shearing.

Solar radiation in the Cashapata production unit, a farming community in San Antonio, demonstrated that it is possible to use this natural resource in high

4. Discussion

A participatory methodology has been followed with the San Antonio community of the San Mateo district, designing and building equipment based on renewable energy, as well as training the community for its use.

Involving the community as indicated by Freire (11), has meant an openness to the integration of academic knowledge with the community's local knowledge.

The work carried out is relevant for providing a better economy to the community based on renewable energies, as well as affordable and non-polluting energy (SDG-7)

Levin [30] proposed similar previous work with the participation of small communities in Norway, based on dialogues, meetings and the construction of a new local theory. In this sense, our work has also managed to energize and integrate local women leaders.

5. Conclusions

Andean areas (4100 meters above sea level). It concludes that this is a significant contribution to promoting investment in research on the use of solar energy, which allows the development of vulnerable high Andean rural populations.

The technologies developed during the project met the objective of transforming alpaca fiber into yarn at the place of origin, adding value to the raw material locally. The technologies developed include the shearing machine to obtain the fiber, the water heater to wash it at the required temperature, the carder to card the fiber, and the spinning machine to convert it into yarn usable for making garments.

The participatory approach allowed members of the San Antonio community to be active participants in the technology transfer, which was crucial for the project. This approach proved the effectiveness of participatory and collaborative methods. It not only facilitates the adoption of new technologies but also promotes the empowerment and sustainable development of the community. Members not only learned to use the new technologies but also took ownership of them, increasing their commitment and responsibility. This enabled them to make informed decisions about the use and maintenance of the introduced technologies, fostering a sense of ownership and sustainability for the project.

Acknowledgment

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