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Methodology for the Evaluation of Solar Thermal Energy Projects' Sustainability in Peru

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Abstract

This paper presents a new methodology to evaluate the sustainability of projects which involve any renewable energy equipment that take place in rural areas. By using the Star of Sustainability method we are able to see, visually and efficiently, the process of sustainability of technology projects.
The study includes the results of six appropriate technologies and technology transference projects with solar thermic energy done by the GRUPO PUCP during the last five years.
These validated technologies refer to the generation of heat through solar energy, such as Parabolic Cookers, Greenhouse-type dryers, Trombe Walls, Scheffler-type concentrators for coffee and cocoa and Hot Air Parabolic Concentrators for black tea drying; all of them using local materials and labor.

Keywords: *Sustainability, evaluation, qualitative methods, solar thermal energy,solar dryers*

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1. Introduction

The Rural Sector Support Group GRUPO PUCP is an operating unit of the Department of Engineering at the Pontificia Universidad Católica del Perú (PUCP) and has made several designs and implementations of equipment in various areas of Peru. This study considers the results of six case studies conducted by GRUPO PUCP in Peruvian territory during the last five years.

The technologies evaluated are: Parabolic Cookers, Greenhouse-type dryers, Indirect Solar Dryers, Trombe Walls, Scheffler-type concentrators for coffee and cocoa and Hot Air Parabolic Concentrators for black tea drying

Star of Sustainability method that allows us to see, visual and efficiently, the technology projects process sustainability will be used.

Conclusions are analyzed by the QCA method (QUALITATIVE Comparative Analysis), using KIRQ as support free software, these methods are used due to the existence of five qualitative variables: Technology, Economics, Politics, Social and Environmental for each the cases studied.

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2. GRUPO PUCP

The Rural Sector Support Group GRUPO PUCP is an operating unit of Engineering Department at Pontificia Universidad Catolica del Peru (PUCP). Since 1992 we have been carrying out development projects for rural communities, related to applied scientific research, technology transfer and innovation, dissemination and promotion of appropriate technologies and conservation activities natural environment using renewable energy

Our goal is to improve the quality of life of the rural population in the areas of energy, water, agriculture and housing; through the dissemination and application of appropriate technologies to contribute to sustainable development of the rural sector of Peru.

3. Methodology used.

The proposed method, Sustainability Star, allows us to analyze the sustainability process of technology projects and provides us with a clear view to either decide the continuity of the projects or their cancelation. The Star has 5 tips that analyze the Technology (T), Economy (E), Politics (P), Social (S) and Environmental (A) factors which from now own we will refer to as TEPSA (in Spanish) or 5E`s (in English).

We believe it is a good tool to be used in all projects with a technological and political base in their development processes.
This method could also be used in other situations where projects have been completed technological base and gives us a good insight to decide the continuation or closure thereof.

SUSTAINABILITY DEVELOPMENT: TEPSA oR 5 E´s			
T	Tecnología	**E**	Engineering
E	Economía	**E**	Economics
P	Política	**E**	Ethical
S	Social	**E**	Equity
A	Ambiental	**E**	Environment

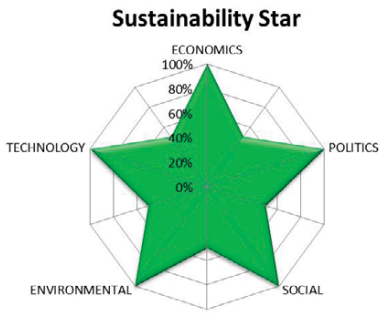

Fig 1: Factors of sustainable development in the Sustainability Star

To analyze the index that corresponds to each tip of the Star, a 25 question survey is made, defining the break percentage of the shape. These surveys refer to TECHNOLOGY (utility, sustainability, operation, reliability, maintenance), ECONOMY (income, employment, savings, affordability, innovation), POLITICS (political interest, acceptance, legal, promotion, and distribution), SOCIAL (compatibility, motivation, life improvement, participation and capacity) and ENVIRONMENTAL (friendly, climate, pollution, awareness, and health).

If all surveys questions have positive answers then the star will be perfect without any break, as shown in Fig. 1 and the project will be considered as 100% SUSTAINABLE .

In order to decide the percentage corresponding to each point of the star we use a survey of 25 questions - see Table 1 - which defines the percentage of the Star break. Negative responses from the survey will fall inside the star percentage values that indicate the failure of the project in each of TEPSA factors.

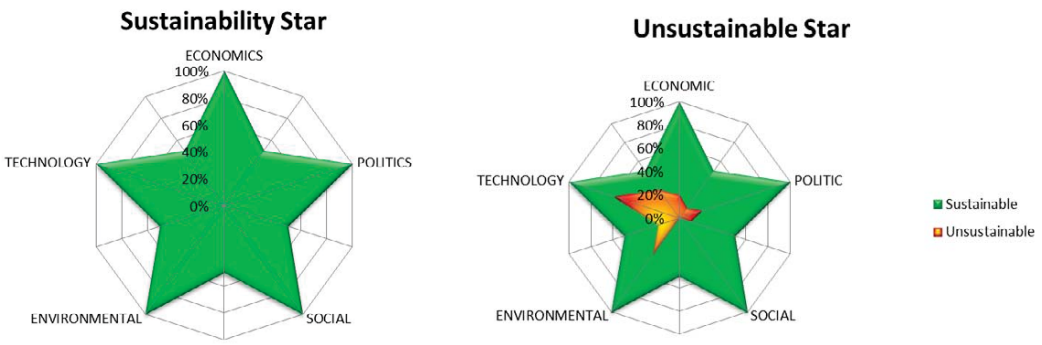

Fig 2: Example of Sustainability Stars – Perfect (left) and Broken (right).

4. Case Studied

We will analyze six case studies of technology projects related to heat generation, such as Parabolic Solar Cookers COCISOL, Indirect Solar Dryers SECASOL, Solar Greenhouse Indirect Dryers INVER, Trombe Walls TROMBEPUCP, Scheffler Concentrators for coffee and cocoa CONSOL and Hot Air Parabolic Concentrators for black tea drying CONPAR.

4.1. Hot Air Parabolic Concentrators for black tea drying – CONPAR

The project "Development and Integration of a Cogeneration System With Solar Thermal Energy for Processing of Black Tea in the Cusco region" was developed in partnership with the company AGROINKA. The company AGROINKA - Herbi brand tea producer - is located in a rural area of the department of Cusco with poor access to other possibilities of energy resources and weak technologies for various processes in the production chain. It is an area dedicated to the processing of tea to supply 80% of the market in the country and works with 750 families dedicated to tea production.

The design sought to solve the problem of shortage of fuel for drying processing in a producing factory for black tea, through the use of solar thermal concentration with the adaptation of the receiver tube of a linear parabolic concentrator for heating air. This is the design of a pilot project to develop and implement in tea enterprise AGROINKA a prototype cogeneration system with solar thermal energy consisted of 6 lines of 10 concentrators (60 linear concentrators). There is a paper describing the behavior of hot air in the receiver tube along a line of 10 concentrators in Reference 30.

Fig 3: Picture of 60 linear parabolic concentrators in AGROINKA tea factory.

Table 1: Model of survey: results for the case of Parabolic Solar Cookers.

					PARABOLICS SOLAR COOKERS
					TECHNOLOGY SUSTAINABILITY
					Survey about machines or project operation
	YES		NO		
1.-	x				**Do you tkink that the machine is going to be useful?**
2.-			x		**Technology (or machine) is constantly being used during the last year?**
3.-	x				**Do you think the machine can easily operate?**
4.-			x		**Do you think is a reliable technology?**
5.-	x				**Do you think that local technicians can repair, copy or modify -all or part- of this machine?**
					ECONOMIC SUSTAINABILITY
					Survey about machines and project cost
	YES		NO		
6.-			x		**Do you see an economic improvement in your life or business when using this technology?**
7.-			x		**It has generated work for someone with the use of this technology in the community?**
8.-	x				**You think that you have saved on fuel or electricity when using this renewable technology?**
9.-	x				**Do you (or your neighbors) purchase or install a similar machine?**
10.-	x				**Do you think that this technology can be produced and sold in your community in the future?**
					SUSTAINABILITY POLICY
					Survey on political and organizational project management
	YES		NO		
11.-			x		**There has been interest in the project or the machine by any political authority?**
12.-	x				**The authorities of the community accept the project? There are requests from the community to some authority?**
13.-	x				**The project complies with the laws and regulations of the community and technical institutions ?**
14.-	x				**Do you believe that the government, person, or institution should promote this technology to other Peruvians?**
15.-	x				**The people of the town know the project?**
					SOCIAL SUSTAINABILITY
					Survey on the perception of the community about the project
	YES		NO		
16.-	x				**The project is accepted "normal way" for the community?**
17.-	x				**There is interest in the community or their neighbors for the proposed technology?**
18.-			x		**The project has improved the standard of living of someone in the community ?.**
19.-	x				**The people have participated in some part of the project or activity?**
20.-	x				**There are people in your community with the necessary capabilities for operation and maintenance?**
					ENVIRONMENTAL SUSTAINABILITY
					Survey on the impact of the project or the machine on the environment
	YES		NO		
21.-	x				**The project is seen as a friendly environment technology ?**
22.-	x				**You do you think this machine is good for our Earth planet?**
23.-			x		**The project has created some kind of contamination in the environment?**
24.-	x				**Mind that this technology is clean rather than other similar package?**
25.-			x		**The use of this technology affects your health?**

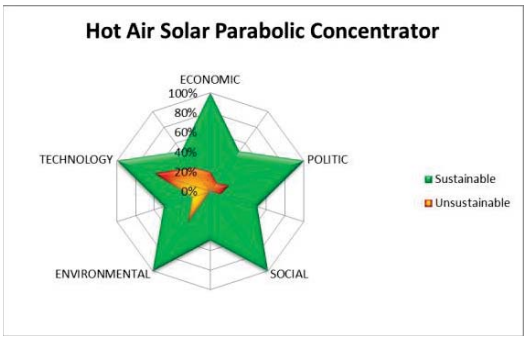

Fig 4: Sustainability Star in Hot Air Solar Parabolic Concentrator.

Sustainability Analysis: In the years 2013 and 2014, GRUPO PUCP has carried out investigations about concentrated solar thermal linear technologies, obtaining good results for toasted black tea. The mistakes observed in the star of sustainability are especially technological due to multiple failures in electronic solar trackers in the project area, especially by the highly voltage fluctuation of electricity.

4.2. Scheffler Concentrators for coffee and cocoa - CONSOL

This new technology is being investigated by the GRUPO PUCP in various applications since 2010, when Dr. Damien Puigserver of France came to Peru for an academic exchange and the first solar concentrator 2.7 m2 Scheffler cooking was built. Later PUCP funded the project to roast coffee with support from Dr. Francois Veynandt, Ing. Julien Delcol, Ing. Juan Pablo Pérez, Ing. Sandra Vergara and industrial designer Luis Miguel Hadzich.

As the results of this research were very positive, we won an announcement FINCYT in 2013 but for roasting cocoa and producing chocolate.
Currently there are two concentrators 8 m2 for this latest project and it is spreading in La Convencion Valley 300 km from Cusco city, with good results. In 2016, with the support from the university PUCP we are working on a prototype of 16 m2 for making orange and pineapple jam .

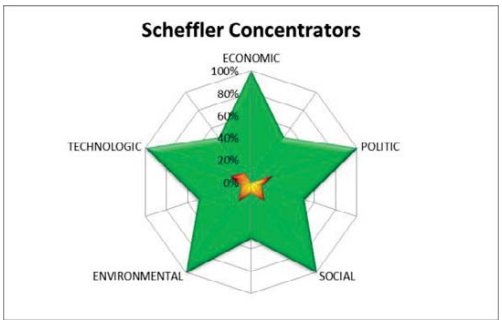

Fig 5: Sustainability Stars in Scheffler-type concentrators for coffee and cocoa

Sustainability Analysis: Since 2013, GRUPO PUCP is researching this concentrated solar thermal technology, reaching good results for roasted coffee and cocoa. We are still working on the improvements on the electronic parts, monitoring of solar concentrator design to improve efficiency. The main difficulty lies in the intermissions of climate due to the rains and the presence of clouds.

4.3. *Solar Greenhouse Indirect Dryers - SECASOL*

For over 20 years we have had good results with solar corn and oragano (wild marjoram) dryers in Moquegua and Tacna in southern of Peru, but one of the drawbacks is due to the low capacity of direct and indirect dryers.

A project that was relatively successful is the one on the use of solar coffee dryers promoted by the technical American institution cooperation USAID since 1990. These dryers were installed in jungle areas in the north and west of Peru in the departments of Cajamarca, Amazonas, San Martín and Piura with good results.

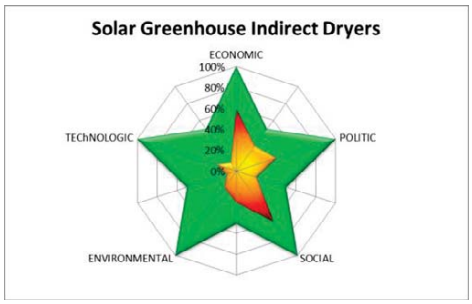

Fig 6: Sustainability Stars in Indirect Solar Dryers

Sustainability Analysis: This technology continues in an experimetal phase according to the capacity of the dryers and quantities of the product. The most used are small and medium dryers because they are cheaper for farmers. We are currently investigating the linear parabolic concentrators for drying tea and aromatic and medicinal herbs and the results will be shown in the coming years.
Research to improve higher production capacities and automatic controllers shoul be on going.

4.4. *Solar Greenhouse Dryers - INVER*

The glass and plastic greenhouses are having very good diffusion in highlands of Peru where the cold is very intense: its use is mainly dedicated to growing vegetables such as lettuce, tomato, pepper, chili and herbs. The lack of control of the temperature inside the greenhouses as well as the difficult control of automatic irrigation systems within them (for lack of electricity) have made this technology to be not as important as it is in other parts of the world. The material used (glass, plastic) has also been one of the obstacles for the successful dissemination and replication. In an analysis of our travels throughout Peru it can be clearly noted that greenhouse projects only last as long as the plastic degrading life timespan.

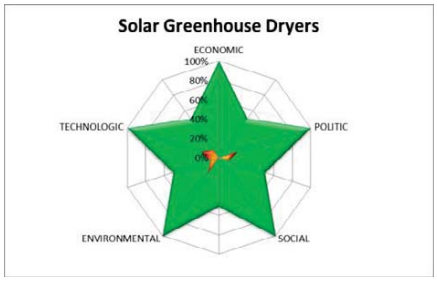

Fig 7: Pictures and Sustainability Star in Solar Greenhouse Dryers

Sustainability Analysis: The star shows us that the political component should mainly be fixed, and technological and economic aspects partially to make it perfect in its execution; It tells us that we need more presence of political authorities to replicate this project for drying coffee, cocoa, fruits in the region of the jungle of Peru. The process of the project was done with the method of participatory design or design thinking method. (Salgado, 2010).

4.5. *Trombe Walls - TROMBEPUCP*

It is a type of greenhouse that is placed on the side walls of the houses to transfer heat from the sun to the inside of the housing, there are those using plastic, polycarbonate and glass materials.
The evolution of this technology by GRUPO was very successful in its dissemination, especially due to the social adaptability of this technology as a counteract against frost and cold spell in the highlands due to climate change. Since 2008 GRUPO has installed more than 600 houses in the departments of Cusco and Puno and is expected to be a model for broadcast as a government policy in the highlands throughout Peru.

Fig 8: Example of Sustainability Stars in Trombe Walls

Sustainability Analysis: One of the ways to measure the sustainability of a product is the feedback of the beneficiaries, in this case the requests for this technology are increasing day by day due to inclement frost and cold spell in the highlands of Cusco and Puno, in southern of Peru.
The combination of four technologies: Sealing doors and windows, improved kitchen, false ceiling burlap and Trombe walls, enable us to reach a difference in average temperatures between the inside and outside of 10 ° C, which is making this technology one of the most successful projects of GRUPO PUCP and with many opportunities to be part of its replicability by the Peruvian government.

4.6. *Parabolic Solar Cookers - COCISOL*

Parabolic solar cookers have been introduced in Peru since 1982 and there have been attempts made to massify their application by several NGOs as GIZ, SOLARTEC in areas of Huancayo, Cusco, etc. The first design came to GRUPO PUCP in 1995 thanks to GIZ which funded part of the cost (50%); the cost of these kitchens was 150 US $. Later in 2004 this technology's demonstration was the starting point for a project with the NGO IAA in Yanaoca, Cusco area where 4 people were trained in the subject but none came to replicate the model.
Currently the only one that can offer this technology is the Renewable Energy& Hassan company that builds kitchens on request, but so far has not received massive orders. In 2012 several of these kitchens were installed in Pisco and Huancavelica by the PROSINERGY company as demonstration centers.

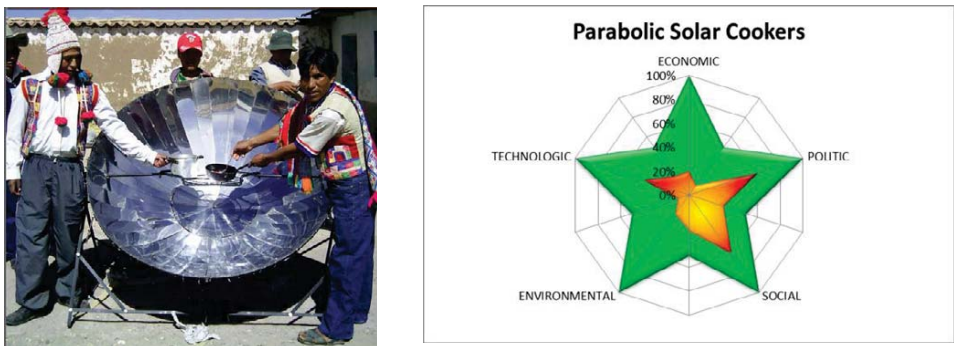

Fig 9: Pictures and Sustainability Stars of Parabolic Solar Cookers

Sustainability Analysis: These kitchens are easy to build and are easy to assemble, but do not have a good reception from women, especially by cultural reasons.
This technology will be sustainable if used in places where there is no wood or manure, when women accept it as alternative, when their costs are lowered and when they can be sold by credit.
The approximate cost of these kitchens is US $ 150, which makes it very difficult for the inhabitants of poor areas to acquire it. The introduction of gas stoves, subsidized by the state, also threaten the spread of this technology.The project is environmentally friendly, the only thing that makes interferes is the climatic variabilities that may occur when operating the kitchens, for example it can start raining or get cloudy or foggy which may result in having food left on it half cooked – this generates distrust in the population towards this technology.

5. Results Obtained

Other than using the star of sustainability that helps us to understand sustainability from 5 views TEPSA there are several versions of software for qualitative analysis to help us in numerical calculations and have been validated in social projects. These are QCA, QCA fs, KIRQ, Tosmana, etc. We decided to use the free software KIRQ due to its simplicity and effectiveness in assessing our case responses. This software is a form of QCA (Qualitative Comparative Analysis) and is suitable for cyclical factors, identifying the necessary and sufficient conditions to enable the performance of some activity by analyzing the probabilities for this to happen. It is used when the variables are dichotomous (YES / NO) as has been developed in the survey of this work.

The methodology allows us to compare the Case Studies and draw probabilities of occurrence with few variables; in this case we will rely on the KIRQ software which has been validated in similar social projects.

The results with the database of surveys give us the following table:

Table 2. Sorted Data Base of sustainability of the 6 case studies.

TECNOLOGIA	UTIL	CONT	OPER	CONF	MANT	ING	EMPL	AHOR	ASEQ	INNO	IPOL	ACEP	~LEGA	DISE	VISI	COMP	MOTI	MEJO	PART	CAPA	AMIG	EDUC	~CONTA	ECOL	~SALU	
CONPAR	1	0	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1	0	0	1	1	0	1	1	1	17
CONSOL	1	0	0	1	1	1	1	1	1	0	1	0	1	1	1	1	0	0	1	0	1	0	1	1	1	17
SECASOL	1	1	1	1	1	1	0	1	0	1	1	0	1	0	0	1	0	1	1	0	0	0	1	1	1	16
INVER	1	1	1	1	0	1	1	1	1	0	1	0	1	0	1	0	0	0	1	0	1	0	1	1	1	16
TROMBEPUC	1	1	1	1	1	0	0	0	1	1	1	0	1	0	1	0	0	0	1	0	1	0	1	1	1	15
COCISOL	1	0	1	0	0	0	0	1	1	0	0	1	1	1	1	1	0	1	0	1	0	1	1	1	1	15

Table 2 gives us some interesting results, such as that the technologies that are transferred to companies are those with the highest index of sustainability and technologies that have been donated by public institutions or NGOs are the ones with worst sustainability acceptance.

From the technological point of view, the best machines turned out to be the ones massively distributed such as the Solar Dryers and Trombe walls for heating homes in highlands. Economically, politically and socially the best technologies proved to be those where local materials and communities where involved during their construction and development, respectively. From the environmental point of view every case resulted to be good for the environment but none of them passed the survey as totally clean.

6. Conclusions

The influence of the 5 factors TEPSA (Technology, Economy, Politics, Social and Environmental) in each of the cases presented has its relative importance in the final results of sustainability, since, in one way or another it influences the success of the implementation of technological projects in poor rural areas of Peru.

The proposed methodology for the evaluation of technological projects has proven to be a good tool for decision making, since it allows us to evaluate the results of a project by analyzing it's sustainability.
The evaluation of the sustainability of projects depends not only on technological and economic conditions of the equipment that works with renewable energy but also depends heavily on the social and political situations of the places where these projects are to be implemented.

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