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Co-creation Methodologies for Designing Bottom-up Solar Energy Communities: a Case Study From Colombia

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Abstract

Energy communities are collective clean energy generation schemes in which citizens organize to generate, store and manage distributed energy resources, mainly solar power. Although there are few energy communities in the Latin American context compared to the number of cases reported in Europe, there is a particular interest in exploring governance models for community self-consumption from grid-connected solar energy sources that consider local cultural conditions. This paper describes a co-creation methodology based on various existing techniques to be used as a tool for designing bottom-up energy community models. This proposal integrates two problem-solving techniques: design thinking and the 4D model. The methodology was tested in collaborative creation workshops, both with stakeholders and residents of Comuna 13 in Medellín, Colombia, to identify the elements for creating a solar energy community in the Colombian context, ensuring economic and social sustainability. As a result, the participants defined an operating scheme for the solar community that included: a governance and decision-making model, participation commitments, identity strategies, communication, education, and a community fund to share energy surplus benefits. It was evident that trust and engagement between facilitators

and communities, along with energy education strategies in the participatory management of community projects, are essential for building successful collaborative solar communities.

Keywords: Energy communities, Solar energy, Governance, Community self-consumption, Distributed generation, Co-Creation, Design thinking, 4D model, Sustainability, Prosumers, Education.

Metodologías de Co-Creación para Diseñar Comunidades Energéticas Solares de Abajo Hacia Arriba: caso de Estudio Colombia

Resumen

Las comunidades energéticas son esquemas colectivos de generación de energía limpia en los que los ciudadanos se organizan para generar, almacenar y gestionar recursos energéticos distribuidos, principalmente energía solar. Aunque existen pocas comunidades energéticas en el contexto latinoamericano, en comparación con el número de casos reportados en Europa, existe un interés particular en explorar modelos de gobernanza para el autoconsumo comunitario a partir de fuentes de energía solar conectadas a la red que consideren las condiciones culturales locales. Este trabajo describe una metodología de co-creación, basada en diversas técnicas existentes, para ser utilizada como herramienta para el diseño de modelos comunitarios de energía de abajo hacia arriba. Esta propuesta integra dos técnicas de resolución de problemas: el pensamiento de diseño y el modelo 4D. La metodología fue probada en talleres de creación colaborativa, tanto con actores como con residentes de la Comuna 13 en Medellín, Colombia, para identificar los elementos para crear una comunidad de energía solar en el contexto colombiano, asegurando la sostenibilidad económica y social. Como resultado, los participantes definieron un esquema de funcionamiento para la comunidad solar que incluía: un modelo de gobernanza y toma de decisiones, compromisos de participación, estrategias de identidad, comunicación, educación y un fondo comunitario para compartir los beneficios del excedente energético. Resultó evidente que la confianza y el compromiso entre los facilitadores y las comunidades, junto con las estrategias de educación energética en la gestión participativa de los proyectos comunitarios, son esenciales para construir con éxito comunidades solares colaborativas.

Palabras Clave Comunidades energéticas, Energía solar, Gobernanza, Autoconsumo comunitario, Generación Distribuida, Co-Creación, Pensamiento de diseño, Modelo 4D, Sostenibilidad, Prosumidores, Educación.

1. Introduction

Solar energy community initiatives have prospered around the world, suggesting that community energy models can be an important pathway for renewable energy transitions (Mah, 2019). These models consist of citizens who collectively organize to produce, consume and trade clean energy, increasing self-generation, participants' decision-making power and generating income from energy sales (Moroni, Antoniucci & Bisello, 2019). Community energy has been developed in many countries across Europe and Asia as a participatory tool to help complete the transition to a low-carbon energy system (Hoffman, et.al, 2013). However, the deployment of solar energy has remained limited in other countries, and the complexity of these community-level transition processes has not yet been well understood and conceptualized (Mah, 2019). In developing countries, there is little available literature about collaborative, innovative energy models, reason why this research explores distributed community generation on a local level. Community models have faced barriers to their implementation in Latin America due to a lack of public awareness and policy frameworks with limited access to capital, risk profiles of users, and a lack of knowledge and experience in renewable energy projects (IRENA, 2020).

In Colombia, the current regulatory framework has outlined a new stage for the integration of non-conventional renewable energy sources, including solar energy. It also includes the energy-tariff reduction and increased energy efficiency to strengthen the competitiveness of the industry (Congreso de Colombia, 2014). Institutional regulatory efforts, such as the Energy Transformation Mission (*Misión de transformación energética)* created in 2019 by the Colombian Ministry of Mines and Energy, have allowed building roadmaps for the future of energy, focusing on energy

decentralization and digitalization, as well as the efficient management of energy demand (Ministerio de Minas y Energía, 2020). These updates have facilitated integrating distributed generation actors and small-scale self-generators (AGPE, for its acronym in Spanish) into the electrical grid (Gómez, Sandoval, & Coronel, 2018). However, until 2022 there were no existing guidelines or market schemes specifically designed for energy communities in Colombian legislation.

To address some of these issues, this research aims to develop a design process that establishes guidelines for building community solar solutions applicable to emerging economies. The process should guarantee economic, social sustainability, and be replicable in different sites in Colombia and Latin America, encouraging cooperation, commitment, and contributions from possible stakeholders through bottom-up processes, which are used to help innovation spaces yield better project results (Bentzen, 2020). Tools, such as co-creation, allow achieving these characteristics. Co-creation uses collective creativity to create value, innovative ideas, and development opportunities (Sanders & Stappers, 2008). In addition, when citizens actively participate in co-creation, an impulse is generated to revitalize voluntary participation and strengthen social cohesion (Bentzen, 2020).

The solar community design created through the presented methodology was designed during the development of a pilot project in Medellín, the second most important city in Colombia. The co-creation process is being carried out with a community in Comuna 13 (San Javier), where households have a low to medium income level. For several decades, the city was widely known as a victim of the social problems of drug trafficking and violence, and Comuna 13 has been one of the most afflicted areas. These characteristics were key to choosing the community, since there was an existing social cohesion that would facilitate implementing a solar energy community. Even though the design process was carried out completely externally, situations such as the COVID-19 pandemic, social conflicts the country faced in 2021 and internal problems between community members restricted the community's physical implementation. These challenges are further described in detail in this paper.

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In the following sections, the co-creation processes for energy solutions are first explained in detail. Then, previous experiences of co-creation in Colombia and a literature review of co-creation methodologies are presented. With this information, a co-creation methodology for creating solar communities is proposed, which is tested in a case study in Medellín, Colombia. Finally, the paper discussed the results, lessons learned and challenges from the co-creation methodology's implementation.

1.1. Co-creation process for energy solutions

Creating new ways of working collaboratively and interacting with individuals with their own needs, interests, preferences, and personal characteristics increases the complexity of project development. This situation requires methodologies to increase empathy and communication, to meet collective objectives. To do so, there are co-design techniques that allow users to be the protagonists of their own experience, becoming the center of the design when identifying solutions to different challenges (Sneeuw, et.al, 2017). The collaborative design applies to the collective creativity throughout the entire design process. As a result, new concepts and ideas are developed, which respond to the expectations and requirements of society nowadays (Huerta, 2014).

Co-creation is understood as an instrument that allows its participants to "think outside the box" by contributing to a certain design process from their own experiences, needs, opinions, difficulties and ideas (Itten, Sherry, Sundaram & Hoppe, 2020). Co-creation is a problem-solving tool (Sánchez & Prada, 2021) that promotes reactivating and strengthening voluntary participation and social cohesion (Sanders & Stappers, 2008). Likewise, co-creation can stimulate commitment among key actors for better project results (Bentzen, 2020). It is about creating an optimal environment in which continuous dialogue and personalized experiences facilitate the identification of obstacles or inconveniences that may arise. This methodology is collaborative and creative, guided by a common objective, which implies a win-win situation between organizations and the community. Both groups create value, exposing possible

solutions when sharing their ideas focused on the topic of interest (Paredes, 2013).

One prerequisite for a community trust-building process is the presence of intermediaries that coordinate the development of the collaborative project, such as facilitators or moderators (Seyfang, et.al, 2014). This social capital must have specific characteristics to guide the community, where there could be skepticism and resistance to change due to the lack of participants' knowledge (Khrystoforova & Siemeniako, 2019). Co-creation for energy solutions can be found in interdisciplinary studies showcasing techniques for developing and designing intelligent and sustainable energy systems (Dupont, Mastelic, Nyffeler, Latrille, & Seulliet, 2019) (S3C Project, 2015). It is a tool used to adapt a project to the needs and expectations of users, improving the possibilities of the project being accepted and adopted. Likewise, this collaborative creation process allows participants to unleash their individual creativity and share ideas and experiences. Community members, project leaders, developers, and other relevant stakeholders are encouraged to participate in this process. In this way, future users are given prominence, obtaining valuable information about the past participants' experience and their contributions. Participation also tends to enhance feelings of attachment and identification with a project, which generally leads to a greater sense of commitment. Therefore, solutions that emerge from a co-creation approach are more likely to succeed because their added value is more apparent to the users (S3C Project, 2015).

2. Methodological Design

The methodological design included a review of the co-creation experiences in Colombia and a literature review, to then propose a methodology that merged different elements, focusing on the Colombian context.

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2.1. Co-creation experiences in Colombia

As part of the methodological design, the first qualitative interviews were conducted on the experiences of community projects and co-creation processes in Colombia. This step aims to learn about the insights of different organizations in Medellín that have carried out community or co-creation projects as a mechanism for building solutions to the pressing needs of different communities by developing community-strengthening projects and cooperation and community organization models. The lessons learned from both citizen participation projects and co-creation workshops would anticipate risk and success factors, thus increasing the probability of success. The interviewees and objectives of their experiences in community organizations are presented below:

Table 1. *Lessons learned of co-creation experiences in Colombia*

Organization	Category	Objectives of community experiences
Generadora Unión	Energy generation	To survey the baseline and community management and develop hydroelectric power generation projects at a small hydroelectric power plant on a scale of <100 MW.
Grupo Hábitat, Territorio y Medio Ambiente	Protected ecological areas	To work with communities on protected areas and ecological structures, develop watershed management plans and create a participatory diagnosis of the community with respect to their problems, opportunities and perception of the territory.
Low Carbon City	Education on climate change	To work with the public and private sector, the media, universities, schools and communities to promote climate change adaptation and mitigation solutions and seal knowledge gaps by educating, sensitizing and raising awareness.
Sandra Milena Duarte Betancur (Community leader)	Leadership in neighborhoods	To apply community actions through social contracting (a way of contracting a social community through a Community Action Board - JAC, for its acronym in Spanish) for democratic participation in the energy sector.
Casa de las Estrategias de Morada Estéreo	Support for young people	To work with communities that focus on helping young people be active and exercise their citizenship through spaces where they can find support and generate an awareness of the next step of their entry into society.

Table 1. *Lessons learned of co-creation experiences in Colombia*

Organization	Category	Objectives of community experiences
María Paulina Moreno	Education in vulnerable communities	To work with people who provide opportunities to vulnerable communities through an education model.
Agroarte	Cultural activities in vulnerable communities	To provide training guided by psychologists for projects of women recyclers and work with young people in cultural and artistic activities, avoiding violence and conflict in vulnerable communities.
URBAM	Social work in vulnerable communities	To work on social, urban and environmental processes on emerging issues, focusing on risky and vulnerable areas, as well as informal contexts.
University College London (UCL)	Energy transition	To work on participatory methods to discover how people can get involved in energy transition and infrastructure studies.

Results of the interviews

The interviewees highlighted that project developers should first contact the community through a non-profit civic corporation, community leaders, or socially accepted organizations. They also recommended having a clear, defined, and flexible action plan during the community process, leading the project at the beginning and then gradually releasing it to the community, for them to gain ownership of their activities and complete the process with acceptance and commitment.

Several risks were identified in the community processes of the interviewees: a) Loss of participants' interest due to a highly technical approach to the co-creation workshop. b) Groups opposed to the project. c) The community's feeling of invasion and imposition in their spaces. d) Collaborative action plans that are so rigid they do not allow for flexibility in light of unforeseen events. e) The risk of favoritism, thus benefiting certain groups or specific people. f)

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The underestimation of the community's knowledge and capacities. g) Theft and vandalism of assets, tools and equipment used in the workshop. i) Dead hours and indefinite agendas. j) Discouragement, disinterest, and abandonment by the participating community. k) The generation of false expectations by facilitators.

Finally, three relevant factors were highlighted for the success of co-creation workshops:

a) Numerous key steps need to be followed for co-creation workshops: Diagnosis and community outreach to build trust; complementing the workshops with education, awareness, and sensitization programs with topics according to the workshop's objectives; activities that impact participants' lives, generate change, arouse interest, and break the monotony between workshops; and the collaborative construction of solutions, with contributions from all participants and all organizations.

b) Workshop activities should function as proposals that promote healthy discussions, allow for personal recognition and appreciation, and generate an impact through feelings and emotions.

c) Permanent communication is required to enable transparent, accurate and immediate dialogue with the community.

3.2 Literature review: Methodologies for the co-creation processes

Co-creation dynamics are based on active collaboration between different participants to detect problems, find solutions, grow and generate value. A literature review was carried out to manage the diversity of knowledge for specific academic research and find collaborative creation techniques that allow us to choose a methodology that can work hand-in-hand with co-creation. The methodologies that best adapt to needs in designing user-based solar energy communities are presented below:

1. **Design Thinking** is an iterative methodology used to: Empathize with participants, challenge dominant assumptions, and establish

solutions to various interconnected problems (Itten, Sherry, Sundaram & Hoppe, 2020). It is not only a cognitive process or a mindset; it has become an effective toolkit for any innovation process, connecting the creative design approach to traditional business thinking, based on planning and rational problem-solving. Traditionally, design thinking relies on the designer's capacity to simultaneously consider:

- Human needs and new visions of living well
- The available material and technical resources
- The constraints and opportunities of a project or business

The integration of these three factors requires the designer to have the ability to be concurrently analytical and emphatic, rational and emotional, methodical and intuitive, oriented by plans and constraints, but spontaneous (Tschimmel, 2012). In addition, this method includes multi-stakeholder participation and rapid infrastructure design (Itten, Sherry, Sundaram & Hoppe, 2020). The potential of the design thinking process in co-creation allows formulating innovative solutions that arise from listening to the needs of a community and exploring new possibilities for social purposes (Mulgan, 2006).

The process is generally characterized by five stages based on gathering ideas about what people need, generating ideas, and testing or experimenting with what works (Itten, Sherry, Sundaram & Hoppe, 2020). They are explained below:

- **Empathize or understand**: Use interviews to find out what is important to people. Ask for personal stories.
- **Define the problem/Explore**: The interviews help to understand what people's needs are.
- **Ideate:** Challenge assumptions and create ideas.
- **Prototype:** How does your idea fit into the idea of people's lives?
- **Test/Evaluate:** Test the prototype with different users to find out what works and what doesn't work.

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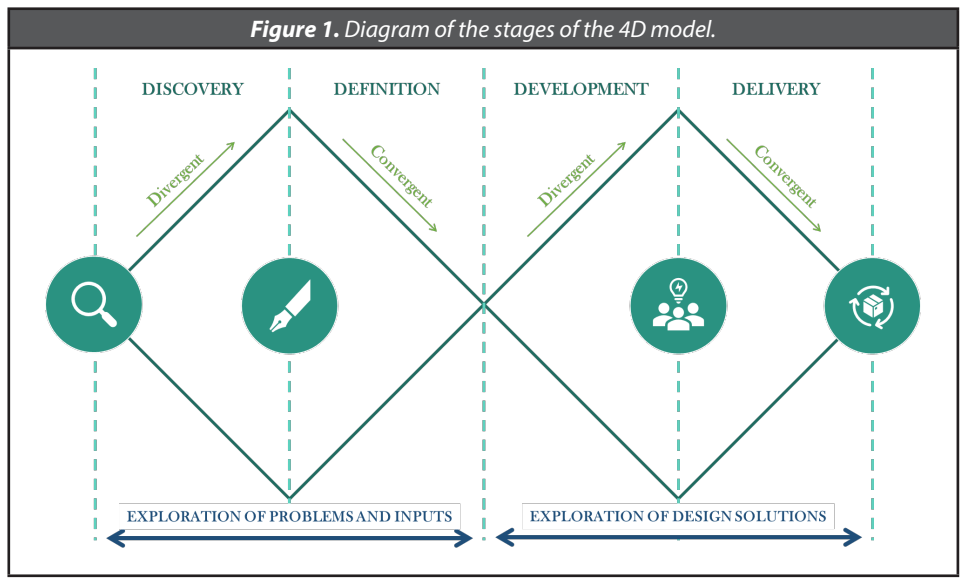
Reported studies -such as the one mentioned by Sinan Erzurumlu & Erzurumlu (2015) show that the generation of social value, stimulated by design, depends on the attention paid to minorities.

2. The Design Council created the **4D Model** in 2005 based on the design thinking methodology. It follows four iterative stages: Discover, Define, Develop and Deliver (Tushar, et.al, 2020) (Brown, & Wyatt, 2010). In addition, it is based on an interdisciplinary and human-centered approach to innovate and address the challenges of complex systems in our world, at the precipice of desirability (empathy), business and technical feasibility (Geng, Feng & Zhu, 2020) (Morrissey, 2014).

   As shown in Figure 1, the 4D method has two phases of divergent thinking (Discovery and Development) and the other two of convergent thinking (Definition and Delivery). Divergent thinking seeks to research, create and generate numerous options among the participants. Conversely, convergent thinking tries to limit and analyze the alternatives to choose the most viable solution, thus allowing advanced design thinking to achieve the established goal. The illustrations -in green- refer to each phase. These two phases are part of the continuous process, so they are within the two spaces of the proposed 4D model: the space to explore interconnected problems and the space for inputs and to explore solutions.

Figure 1. *Diagram of the stages of the 4D model.*



Each stage's objectives are presented below:

- **Discover**: In this phase, opportunities and needs are identified and understood collaboratively through co-creation with stakeholders. For this purpose, essential data collection methods include an approach or field visit for data collection, studying, and users' analysis -and their needs- through design thinking (Tushar, et.al, 2020).

- **Define:** This phase is a kind of filter where the first insights are reviewed, selected and discarded. It also covers the initial development of project ideas, in which the designer must engage with the wider context of the identified opportunity. The objective is to map the user's needs to obtain the data that will serve as input for the following steps; mapping is usually done by collecting information through interviews and surveys. Patterns of behavior are consolidated with the collected data, showing the users' common points. Finally, these data can be graphed into visual models, which frame the fundamental design challenge, answering three questions: What matters most? What should we act on first? What is feasible? (Tschimmel, 2012).

- **Develop:** This phase aims to produce, synthesize, and combine design concepts based on criteria and opportunities to then make a top-down selection based on feasibility. This stage is divergent; it is necessary to go through a creative generation process with essential elements of thought, such as visual, physical, or abstract elements. The concepts are created using tools, such as brainstorming, sketches, scenarios, and prototypes (Tschimmel, 2012).

- **Deliver**: The purposes of the delivery phase are to test the concept with stakeholders, explore potential risks, and show the resulting project to be finalized (a product, service, or environment) and move on to the future stages of production, launch and deployment, among others (Tschimmel, 2012).

The interactive steps are shown in Figure 2 with a summary of the objectives of each stage.

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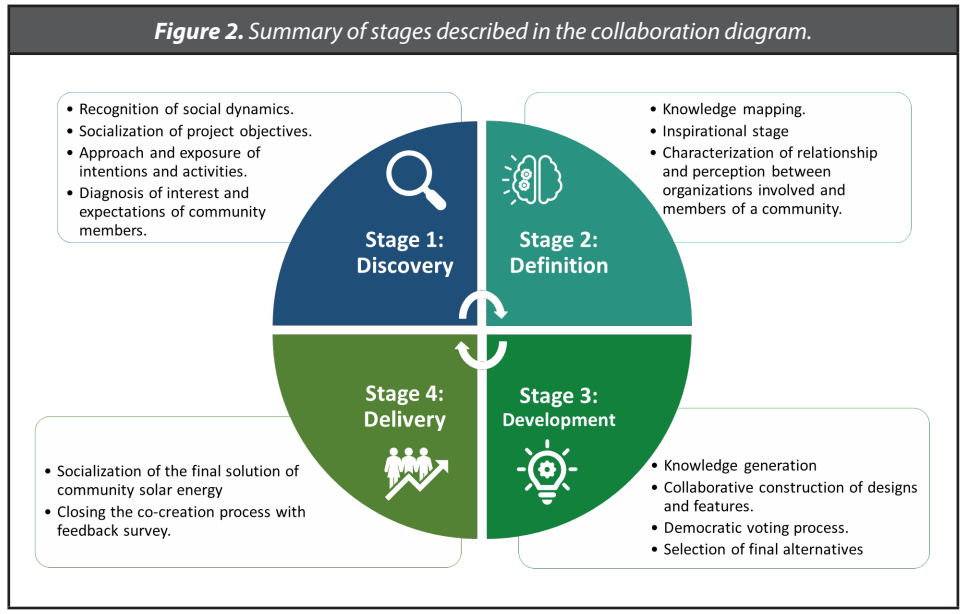
Figure 2. *Summary of stages described in the collaboration diagram.*



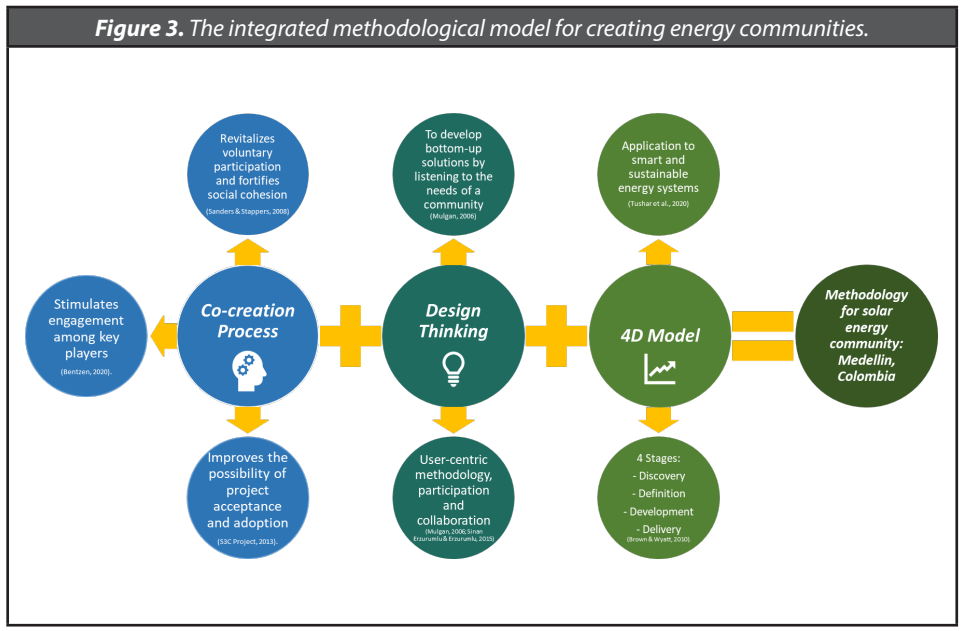
3.3 Methodological proposal for the creation of solar communities

Although there are studies of techniques for energy solutions in the literature, there are no methodologies to our knowledge for designing user-based solar energy communities. This is the reason why the aforementioned methods were integrated as a methodology, combining the Design Thinking technique to develop solutions and the four-step iterative characteristic of the 4D Model to be applied to smart sustainable energy systems. It integrates the ability of co-creation to revitalize voluntary participation, strengthen social cohesion to stimulate commitment among key stakeholders, and improve the possibility of project acceptance and adoption with transformative learning.

Both methodologies are techniques for creative problem-solving, represented by a set of cognitive, strategic, and practical processes by which design concepts are developed. Although design thinking represents a widely used tool to promote and stimulate innovation, the integration with the 4D model allows: (i) following four iterative stages by including interest groups, and (ii) being based on an interdisciplinary and human-centered approach as a key aspect for the project's long-lasting success.

The main scheme of the integrated co-creation methodology can be observed in Figure 3. This methodological proposal is the framework for designing solar community projects applicable to the Colombian context.

Figure 3. *The integrated methodological model for creating energy communities.*



4. Case Study: Medellin

The co-creation methodologies will be applied in the city of Medellin with a community that lives in a neighborhood located in a commune known as Comuna 13. For several decades, the city was widely known as a victim of the social problems of drug trafficking and violence, and Comuna 13 has been one of the most afflicted areas. However, there has been a positive social transformation in recent years. An example of this is the association *Agorarte,* which was formed by members of the Comuna 13 local community to reduce the circles of violence and strengthen relationships within the community's population. Its main objective is to promote learning environments with cultural activities, such as music, planting, art, and acting. One of the subgroups within this association is the *Partido de las Doñas*, an initiative by women who actively encourage support networks among their community residents. This group was chosen to develop the activities since

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they had a defined community structure, they had developed other community projects, they all lived in the same neighborhood, they were interested in implementing renewable energy in their neighborhood and the community leader had participated in a previous pilot project with Transactive Energy Colombia Initiative which motivated the participation of other members of the group.

The following section will provide a use case applied to the *Partido de las Doñas* community in Medellin, Colombia to validate the proposed co-creation methodology. The objective of the case study was to develop a community solar pilot, where the participants would share the benefits from a solar energy system located in a neighborhood. The pilot project's development was led by researchers from two universities, and included the participation of an energy distribution company, a solar energy company, and a digital energy retailer.

4.1. Discovery

Thirteen participants from the community attended this first meeting organized by the research team. To start the activities, the research team used a guided conversation methodology, presenting the reasons, objectives, and scope of the project. They also highlighted the benefits participants would obtain from creating a solar community. Then, there was an open round where the community expressed its main interests, which would then be used as input for the co-creation process. The key points and interests expressed verbally by the participants were as follows:

- Ways to save energy.
- How solar energy works and how to save money.
- What are the existing advantages, disadvantages, and benefits of using solar energy?
- How is electrical energy produced through a photovoltaic solar system?
- Does this type of energy work for all appliances?

4.2. Definition

The purpose of the second session of the co-creation process was to implement activities to generate an environment of motivation and inspiration and map and characterize knowledge related to solar communities that would serve as input for subsequent activities. For this session, a meeting was held with 13 members of *Partido de las Doñas.* For the first activity, the moderator presented five examples of success stories of people working together on energy projects, focusing on this same governance model.

Local story: *The success case of a light bulb for community uses in Comuna 13*: A story of a local community that did not have access to light for half a year due to a lack of lightbulbs. Since they only had access to one light bulb, the community came up with a model to share the light bulb for equal periods and according to each family's needs.

International stories:

Communities united by an energy transition in Denmark: The story of the so-called "green island," Samsø island in Denmark, which initiated a rigorous energy plan with neighbors' participation. Their main objective was to work together with a community with a local and team-oriented mindset, and the project´s motto was "think local and act locally." With this initiative, the town became self-sustainable in energy matters (Nielsen & Jørgensen, 2015).

Students interested in mitigating global warming in the United States: Two alumni of Albemarle High School in Virginia founded the Solar Schools Initiative, which grew into a coalition of hundreds of students, all working on getting solar power for their schools' rooftops (Reverend Daniel Says | Stories of Solar, 2021).

Parishioners united for an energy cause: The story of St. Timothy's Parish in Georgia, which turned their 118-year-old Episcopal church into a solar power generation site, using rooftops to help spark the congregation's interest in protecting the environment (Amory Fischer and Elinor Glassco | Stories of Solar, 2021).

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Solar Communities in Chile: local communities that came together to end the energy crisis they were experiencing, thus forming renewable energy cooperatives that have now taken on significant importance throughout the country (Herrera, 2017).

Energy knowledge survey

Then, a written survey with a series of questions was carried out to identify at what point the education strategy would begin taking into account the participants' prior knowledge of energy issues. The questions and answers provided by the 13 participants in the knowledge mapping can be seen in Table 2.

Table 2. Results of the knowledge mapping created.

Survey question	Answers	Votes	Observations
How do you think you can take care of the environment from your home?	The participants recycle in their homes	9	76% of people surveyed recycle or separate garbage to care for the environment from home.
	The participants separate garbage	7	
	The participants try to save water and electricity	3	
	Doing what each one can do from their home	1	
	Create and implement community actions	1	
Do you know what kWh is?	Yes, they know	5	54% of community members do not know what kWh means in their utility bills.
	No, they do not know	7	
	Did not respond	1	
What is the most expensive utility bill that comes to your home?	Energy	6	46% of people consider energy the most expensive service on their utility bills.
	Gas	1	
	Water	1	
	Equal	5	
From 1 to 5, energy is cheap (1) or expensive (5)	1 (cheap)	0	No participant considered that the cost of energy services is cheap or somewhat cheap.
	2 (somewhat cheap)	0	
	3 (indifferent)	2	
	4 (somewhat expensive)	1	
	5 (very expensive)	10	
Do you use energy-saving methods in your home?	Turn off lights	2	94% of the participants apply some energy-saving method in their homes.
	Turn on the necessary lights	1	
	Unplug appliances	10	
	Consume the energy generated with their solar panels	1	
	Did not respond	2	

Table 2. Results of the knowledge mapping created.

Survey question	Answers	Votes	Observations
Have you seen if energy savings are reflected in your bill?	Yes, they have seen	1	85% have not seen and would like to see their energy-saving actions reflected on their energy bill.
	No, they have not seen	11	
	Did not respond	1	
What do you know about solar energy?	Solar energy works with solar panels	5	33% know solar energy works with solar panels, followed by the fact that solar energy helps save energy, with 20% of the votes.
	Solar energy is produced by the sun	1	
	It is considered the energy of the future	1	
	Solar energy helps the environment	1	
	Solar energy helps save money	3	
	Did not respond	2	
	Nothing	2	
Do you know the benefits of solar energy?	Yes, they do know	10	88% of the participants say they know the benefits of solar energy.
	No, they do not know	3	
What benefits of using solar energy do you know?	Economic savings	10	77% know that saving money is an advantage of solar energy.
	The generated energy is brighter	1	
	There is less impact on the environment	2	
What are you interested in knowing about solar energy?	Interested in knowing how to save more energy	3	36% of the participants are interested in understanding the benefits, advantages, and disadvantages of energy generated from a solar source.
	Interested in knowing how it works	1	
	Interested in knowing how to save	2	
	Interested in knowing the benefits, advantages, and disadvantages	5	
	Interested in knowing if it works for all appliances	1	
	Interested in knowing how it is produced	1	
What is a solar community for you?	It is a meeting of people who want to save	7	54% of the participants have the common idea that a solar energy community consists of people who want to save.
	It is a group of people who want solar energy	1	
	It is a way to be close to the community and to be part of changes	1	
	It is a community that has, produces, and uses solar energy	3	
	It is a group of people interested in solar energy	1	

The responses showed that there is still a great need to improve knowledge related to solar energy issues, energy-savings, and ideas for efficient usage. To this end, the integrated methodology is a way to start discussions on energy education that allow participants to understand the electricity system's transformation in a clear and simple way. In turn, it is important to highlight the impacts of the new approach to providing energy where households and other small generators trade power directly with each other. The aim is to

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find a simple way for people to understand the changing paradigm of how the electrical system has been maintained in recent decades: purchasing and selling energy remain the same, where the end-user buys electricity without the possibility of a sale, track and understand their consumption.

Board game: Watts the Deal

To improve participants' understanding of the electrical system's transformation, a board game called *Watts the Deal* was used as a final activity for the workshop. The board game was developed by researchers at the UCL Energy Institute to show how energy trading between energy users occurs within a solar community. In the game, players assume the role of households in an energy trading system and must buy and sell energy between themselves and the larger grid to meet their daily demand for electricity (Fell & Schneiders, 2020). A moderator guided this game, obtaining the participant's ideas and contributions (Figure 4). The contributions of the mentioned workshop were:

- Creating a joint fund with the possible economic benefits of the Solar Energy Community.
- The willingness of participants to lend money from the fund -or energy, if they were allowed to- in the event of a crisis.
- Being able to work together for more projects and economic activities to increase community funding and strengthen citizen participation.

All the ideas and contributions of the workshop participants were taken into account for designing the solar energy community pilot.

Figure 4. Participants from Comuna 13 playing What's the deal?

4.3 Development

A third workshop aimed at implementing specific activities to achieve collaborative participation in community solar energy solutions and designs, alongside a democratic voting process and an energy education strategy, was held. The first stage included providing informative answers to the common doubts that emerged among participants in the definition stage on the topic of energy. During the learning process, participants learned how solar energy was generated, how their conventional meters worked, and the benefits of switching to a smart meter. The community members asked questions about selling surplus energy and how the utility company recognizes its customers.

When all doubts were solved, they proceeded to the next activity, the idea generation stage, in which the moderator explained the elements of energy communities. Dividing the community members into two teams, the community elements were analyzed through a discussion among the participants. The team discussion worked as brainstorming, where people gave their opinion and contributed ideas to strengthen the proposals. Two alternative solar community solutions were obtained as a result, which were merged to find the best model for creating a solar community. In this way, both alternative responses were analyzed to eliminate duplicated

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information in the responses as a way to find the most viable options between the teams.

4.4 Delivery

After evaluating the proposals considering the context in which the community operates (several participants live in rental or intermediate flats, reason why they do not have a roof available), the insights from the workshop were used to develop the final design of the solar community presented in Table 3.

Table 3. *Final Pilot Governance Model Outline Solution*

PILOT GOVERNANCE MODEL	OBJECTIVE OF THE POSSIBLE COMMUNITY FUND
Committee creation: • Leader: Community representative in charge of the conversations with the project developers. • Secretary: Person organized to carry out records of activities and participants. • Communicator: Person in charge of networks, dissemination, etc. • A possible community bank with an administrator and treasurer.	• The funds would be obtained from selling the surplus energy generated. • A shared fund would help children with school supplies, structural arrangements of green areas, community, and financial aid to the sick. • More projects and economic activities would be created to increase the community fund. • Meetings would be held to evaluate the best way to distribute the benefits.
COMMITMENTS TO PARTICIPATE	UTILITY AND SOLAR COMPANY
There will be a series of commitments from the partners in order to participate: • Show dedication and disposition in the pilot. • Contribute and work from distribution in committees. • Attend regular meetings.	• The public utility company will serve as an advisor, trainer and support ongoing communication. • It will also be a partner and supplier of the necessary equipment for the photovoltaic solar generation system.
GOVERNANCE	LOCATION
• The community's decisions will be governed under a democratic model, where each member has one vote. • Decisions are discussed among the community in regular meetings.	• The generation system's location will be selected according to a technical analysis, identifying the spaces with the most potential. Thus, the roofs of participants will share all the benefits of power generation on their property.

Table 3. *Final Pilot Governance Model Outline Solution*

SOLAR ENERGY COMMUNITY IDENTITY	EDUCATION STRATEGY OF COMMUNITY MEMBERS
• The solar community will have an identity. It will have a name: "Las Doñas del Talego 13"; it will have a motto: "Knowledgeable about memory, renewed through energy. The evolution from stoves to a solar community." • The identity will identify them as pioneers in the history of the solar community.	Partner companies will provide a comprehensive periodic education program for the community to understand renewable energy technologies and achieve energy awareness to save energy.
COMMUNICATION	**ENERGY EXCHANGE**
• There will be a committee responsible for disseminating the solar energy community as the pioneer in Latin America; this will be achieved through dissemination in different media.	- Energy will be exchanges and each participant's energy data will be monitored through a digital platform that allows managing distributed energy resources. - Community users will access a real-time measurement and energy consumption display. The platform sends personalized notifications of energy efficiency and sustainability metrics, allowing the users to set efficiency goals to learn how to consume energy efficiently. - There are still uncertainties regarding the performance and social appropriation of the app, which will be evaluated in the future.

One of the valuable results of this co-creation exercise is that it allowed identifying a set of essential signs for designing a community solar solution in a low-medium income area. Highlighting them is necessary because of their importance for the solar community. The main signs are:

- An internal governance model is necessary for the operation and ownership of the solar community. Therefore, the participating community members proposed a committee model: the leading committee, secretaries, communicators, and administrators of the possible community fund. All members would be distributed into these committees, with a regular rotation.

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- The community must function with a decision-making model to allow all members to participate equally. Therefore, a democratic model definitively won as a unanimous proposal.
- Stakeholders are interested in helping the community take ownership of the project. Because of that, it was agreed to have a comprehensive education strategy with the support of partner companies periodically.

In the current context, there are some restrictions in the internal governance model because energy communities are limited to existing regulatory conditions or intermediaries that represent energy transactions. This restricts their autonomy in decision-making and reduces control over their system, weakening community governance. In other contexts, such as rural areas where their regulatory control on energy issues is not as strong as in cities, the governance model of energy communities could be strengthened. However, in this case study, being located in an urban area limits the community's autonomy because of all the companies and processes involved in the current energy supply.

There were some lessons learned from interactions with the community and the development of workshops, which are highlighted below:

It is necessary to study the historical processes of the community, its limitations and strengths, the elements to communicate, and the identification of previous social projects, cultural activities, and social leaders, to explain situations that may arise throughout the process. It is very important to generate greater interest in the educational program. Considering the participants' responses to what they want to learn, or what they expect from the workshop, allows designing more relevant and helpful training based on these expectations. The relevance of the workshops was verified for the replicability of the methodology in other contexts.

Implementing a capacity-building program and preparation participants beforehand is essential. All stakeholders have to assume the role of guiding teachers throughout the educational strategy process, and project developers must take on a role to supervise, help formulate goals, and provide support in difficulties that arise in

the process to reorient what was learned. This new identity ensures the sustainability of collaborative creation processes, changing the paradigm of top-down development. Making members more aware of the implications of participating before the co-creation process is crucial to avoid conflicts and misunderstandings in the project's development. It is advisable to have a moderator capable of fairly and spontaneously being reactive to unforeseen developments with an open attitude, to create a safe space where participants feel free to contribute in their ways.

The existing processes and structures could influence decision-making in the community group during the co-creation process. The community already had an organization before starting the co-creation process. This prior organization can favor creating solar communities, since it can build on existing hierarchies and processes. However, co-creating a horizontal hierarchy was maintained among everyone, allowing no distinctions, facilitating teamwork, and contributing to all parties.

5. Discussion - Challenges in the development

During the workshops, the lack of contact between energy companies and end-users was evident. This disconnection can generate potential conflicts created by the lack of clarity in the companies' information and the users' prevention of the companies' actions. Traditionally, the electricity sector had not sought to get closer to users because it did not have a latent need to do so, since it was concerned with larger-scale technical issues. However, in the new community energy business models, users become active system agents who interact permanently with the grid. This situation creates an immense challenge for energy education professionals, where aggressive large-scale social appropriation strategies must be designed almost entirely for energy prosumers. Besides this situation, there were some external factors that impacted the process.

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5.1. Impacts of SARS-CoV-2 on the co-creation exercise.

Due to the health emergency caused by the COVID-19 pandemic, strict biosafety protocols were established to avoid contagion in Colombia. Among these were a limit of people meeting in public places, social distancing, and mandatory face masks. A biosafety protocol was developed that had to be thoroughly followed by all workshop participants. The lockdown modified many of the initial plans for the entire interdisciplinary co-creation process, making the dates and agendas of the workshops more flexible. A new vision of digitization had to be adapted, considering the modification of the entire agenda to be carried out virtually. Finally, there was no need to migrate everything to digital, but the vision of adapting these educational strategies to digital was critical due to the current conditions.

The *Partido de las Doñas* neighborhood does not have significant public spaces, such as libraries, parks, or communal rooms that facilitate meetings and comply with biosafety requirements. Some ideal public places for the meetings were proposed. However, the community rejected the idea of moving from their territory because people who are part of this project, in general, are mothers who oversee their housework and must take care of their children. For that reason, the transfer was complicated. The process revealed a situation that was not visible to the research group at the beginning. The Doñas emphasized that it was essential to have most of the workshops in the neighborhood, not necessarily for convenience or to reduce travel, but because, as a community group, their primary place of action was their territory. The workshops in the neighborhood gave the project a greater impact, validation, and appropriation by the community.

5.2. Conflict management

During the workshops, it was evident community members had a predisposition towards the organizing team and pilot due to energy bill issues with the energy provider. In a low-income community, energy costs usually represent a significant portion of family income, and the complexity of the energy bill often makes them hermetic for

regular users. Moreover, there were previous experiences of service cuts due to failures to pay. This created a confidence barrier that the team tried to break via conversations and training for the community members regarding the energy charges and information on electric bills.

Sadly, these efforts proved to be insufficient. The conflicts and confidence gaps between participants and the energy distribution company were not fully solved, and delays in the project's implementation due the COVID-19 pandemic caused many community members to abandon participation in the project. When some key members abandoned the project, there were no available rooftops in the neighborhood to install the solar power infrastructure, and the development team was forced to select a different neighborhood for the project.

6. Conclusions

In Colombia, little is known about the potential of solar communities, and they have faced barriers to implementation due to a lack of public awareness and policy frameworks even though the government is making great efforts to promote the energy transition. To address some of these issues, this research proposed a co-creation methodology considering previous co-creation experiences in Colombia and a literature review to find the appropriate co-creation methodology for user-based solar energy communities. A mix of 4D Model and Design Thinking was chosen, highlighting the inputs of following four iterative stages (Discover, Define, Develop and Deliver). It was to be based on an interdisciplinary and human-centered approach as a key aspect for the project's long-lasting success. This methodological proposal was applied in the city of Medellin in a neighborhood with a low to medium income level.

Although each community is different and there is no universal method for establishing solar communities, the main valuable results of this co-creation exercise after applying the methodology were: having internal governance for the operation and ownership of the solar community to distribute responsibilities, having a decision-

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making model to allow all members to participate equally, and having an education strategy with the support of stakeholders, taking in to account participants' interests to provide more relevant and helpful training. Nowadays, the decisions of energy communities are limited to existing regulatory conditions restricting their autonomy in decision-making and control over their community.

Other lessons learned about developing co-creation workshops in this context are the importance of characterizing the community, including historical processes and social leaders, considering participants' interests in designing training, implementing a capacity-building program to prepare participants beforehand, being clear with the implications of participating in co-creation processes and knowing the existing decision-making structures in the community.

External challenges also came up in the process of applying co-creation methodologies, such as the health emergency caused by the COVID-19 pandemic, which limited attendance to workshops, the location of the meetings because there were no public spaces near the neighborhood, and historical difficulties with the energy provider, which created a barrier between stakeholders and community members. This highlighted the lack of contact between energy companies and end-users.

The main objective of testing the proposed co-creation methodology was to encourage cooperation, commitment and contributions from community members, taking into account their opinions in the final design of the solar community. This evidence would then be used to build a framework for designing solar community projects applicable to the Colombian context, favoring the projects' acceptance. The results show that it is applicable to emerging economies, guaranteeing economic and social sustainability in order to be replicable in different sites in Colombia and other parts of the region.

This solar community design can be useful for other studies due to the socioeconomic conditions of the participants and because of the co-creation methodology that was used. It allowed stakeholders to actively participate, who enriched the design with their ideas and suggestions. It is a first approach for implementing solar communities in the context of emerging economies with low-income

levels. This is very valuable, since several solar communities have been implemented around the world, but in social contexts that are very different from those of Latin America. Furthermore, very little has been reported in the literature on user-centered energy models in emerging urban areas. This is particularly critical for Latin American countries where associative energy schemes are considered foreign, and a strong cooperative culture does not yet exist the way it does in other countries.

7. Ethics statement

The EIA University Ethics Committee oversaw this research as part of the Transactive Energy Colombia Initiative. They designed an informed consent that explained to the community the main objectives of the project, partner companies, activities planned including the co-creation process, and mentioned that participation is voluntary, and they can freely decide to end it without any prejudice. It also ensures that the information provided will be treated confidentially and will not be shared with anyone other than the project. All participants signed the document before participating in workshops and meetings. EPM's legal and customer service departments approved the document content.

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