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Co-construction of energy solutions: Lessons learned from experiences in Chile



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ABSTRACT

The Energy Center has developed a co-construction methodology to address the challenges of technology transfer-based on distributed generation projects- in the context of energy transitions in isolated locations. Based on the experiences developed between 2010 and 2017, this paper analyses the process of preparing the Co-construction methodology. New tools were identified under the light of a theoretical-methodological reflection and a new version of co-construction methodology is proposed from this discussion. This learning process combines academic research and applied projects. It has provided Energy Center with an improved set of tools for current projects, and also contributed to a theoretical-methodological discussion based on new research activities. The main problems of method faced are presented during interdisciplinary work, such as: common understanding of fundamental concepts (sustainability, participation, community); the domination of one discipline over the others; the different visions of the priorities within the same project. And those problems given by the participation process under the paradox of “framing-overflowing”, where the constraints of actual projects (deadlines, budget, and specific KPIs) could limit the possibility of performing in depth diagnostics and building trust. One of the main challenges identified is that an actual impact on the overall experience is only feasible if lessons can be translated into concrete products (best practices, guidelines, tools), so can be adopted by future project developers.

1. Introduction

One of the biggest challenges in the development of technology transfer projects is their post-implementation sustainability [1,2]. In this regard, certain authors [3,4] coincide in identifying social dimension as a critical variable for the continuance of projects over time. In this context, community participation and interdisciplinary work appear as desirable attributes for this type of initiative. The former assumes that a greater participation by the benefited community will enable better appropriation of the implemented technology [5], while the latter is presented as an attractive response to address the challenge of sociocultural complexity faced by these types of projects [6].

Nonetheless, these attributes face a series of barriers that limit their inclusion. Usually, project timeline and work logistics expected by funding agencies; as well as the governance structure of the projects, impair the possibility of developing participatory work with communities as well as carrying out interdisciplinary work by the

implementation team.

Distributed generation projects implemented by the Energy Center (EC) of the University of Chile, not only seek to generate sustainable technology transfer processes over time, but also aim to develop niches of technology innovation that promote a sustainable sociotechnical transition in the energy field.

Given this ambition, it has been necessary to create an interdisciplinary project development methodology. This methodology integrates the beneficiary communities into the decision-making processes from the inception of the project, laying the foundations for its sustainability. The methodology has been the result of continuous iterations between empirical applications and a systematization of experiences based on theoretical-methodological reflections of the EC's professionals from various disciplines; such as, engineering, agronomy, anthropology, sociology, and geography. These experiences provide the opportunity to analyze the EC's case and the process for creating a Co-construction methodology. The overall objective of this methodology is

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to achieve a high level of participation and engagement of communities during the development of a project. Further, these experiences offer the opportunity to analyze the complexities of developing an interdisciplinary work while implementing a participatory methodology in a context dominated by engineers. This allows us to identify both internal and external limitations and contradictions. This paper analyzes the problems that have been identified in the methodology over time and the manners in which they have been approached in the new version of the methodology.

This paper is structured as follows: Section 2 presents theoretical and methodological tools in which a common language across disciplines has been defined for the elaboration of the methodology. Section 3 shows the evolution of the interdisciplinary experiences, including the EC's participation; as well as, the analysis of the identified problems. Section 4 describes the current version of the co-construction methodology considering its four stages. This section also points out how the identified problems have been addressed in this new version. Finally, Section 5 summarizes the main conclusions and future research activities.

2. Theoretical-methodological approaches

2.1. Interdiscipline

In order to address the challenge of promoting technology transfer initiatives, which consider local conditions and allow the installation of capacities to keep initiatives in place, it is required to review the paradigms from which projects are built. This creates the necessity to build work teams with professionals from various disciplines and with people from the local community, therefore addressing the challenges of transdisciplinarity.

In the energy field, a transdisciplinary approach should be considered as a solution for moving towards sustainable energy systems and transforming their productive matrices. This is due to the fact that it involves not only a question of technological transformation but also a question of cultural, political, and economic development in a given territory. In this sense, the different perspectives under which these problems are analyzed are as important as the development objectives that underlie them [7]. Therefore, the evolution of the energy sector is profoundly relevant as it determines how future societies will be constituted. Stirling argues that a transdisciplinary approach in the energy sector is necessary to achieve effective transformations, particularly in the institutional sphere and the challenge of energy governance. In the same vein Spreng [8], aims the energy sector aims at oversimplification, given the fact that technology is fundamental for generation and use of energy, and has led to a misinterpretation of the problems surrounding supply and consumption as if they were merely technological. Thus, research in the energy field has fallen into simplistic ways of interpreting the phenomena that concerns it, hence, becoming a science that is focused on energy technology and not on its interactions with sociopolitical, environmental and cultural spheres; even though, these social sciences could be inserted into the collaborative and transdisciplinary energy debate.

Epistemology refers to the problem of 'how do we know', which in turn implies asking about what is truth and objectivity; and what are the most appropriate methods to achieve them. Particularly, constructivist epistemology states that all knowledge of reality is a construction of its observers [9]. Constructivism derives from an evolution that took place among multiple scientific fields where the processes of knowledge generation themselves are problematized, reflecting their biological and philosophical limits. This paradigm has played a very important role in the processes of changing society experiences as a consequence of modernity: increased complexity, loss of confidence in explanations and universal reasons and, therefore, fragmentation of rationalities and epistemologies.

In this context, the adoption of relativist and pluralist approaches in

social phenomena has been favored. Problematizing the subject-object relationship and denying the monological self-descriptions of society demand a clear indication of the point of view from which every observation is made (considering that each point of view has also its own limitations).

Transdisciplinarity incorporates the challenges related to these limits of knowledge by proposing a revision of the role and form of science. The emergence of a 'knowledge democracy' characterized by the creation and massive availability of knowledge [10]; an increase of social relations complexity and uncertainty, institutional permeability and increase of self-organization of social actors; and an emergence of new forms of economic rationality and new ways of seeing time and space [11]; have forced science to profound paradigm transformations. In this context, we move from a 'normal' science -oriented to 'puzzle solving'- to a 'post-normal' one, which recognizes that all knowledge is generated on the basis of a limited number of rules and hypotheses determined by a particular point of view. This view can never be considered neutral whenever values, objectives and elections are in dispute, and must therefore be communicated transparently to the public.

As a result, the science used must be based on the notions of unpredictability, value burden, and plurality of legitimate perspectives. Further, it must be able to face the judgment of an extensive community of citizen 'judges' who are not exempt from biases, political struggles or external influences, and who will ultimately assess the quality of the scientific studies proposals [12]. In opposition to technocratic arrogance, this unravels a 'technology of humility', which takes over the uncertainty and ambiguity of all knowledge, while avoiding presuming objectivity and making its own normative presumptions clear as well as its ways of framing the problem for public debate [13].

Unlike disciplinary sciences that possess a higher level of methodological sophistication, transdisciplinarity has tended to be classified as a "not so scientific" form of research due to its inherent difficulty in encompassing diverse theoretical and methodological fields from dissimilar disciplines. In addition, transdisciplinarity faces the challenge of not only achieving methodological coherence, but also assembling each piece into a whole [8].

This challenge entails a risk of oversimplifying the knowledge relevant to each discipline at the moment of generating frameworks meant to integrate them. This is mostly due to the dissimilar use of core concepts (such as time and space) among disciplines of natural and social sciences. In this sense, a great challenge for transdisciplinarity lies in achieving a comprehensive conceptual framework acceptable to the participating disciplines and communities. This framework should aim towards common denominators or describe the topics to be dealt with in a highly aggregated form [14]. In addition, it is essential to generate institutional transformations to achieve such governance that allow the development of a transdisciplinary field for an effective participation of scientific and non-scientific actors and communities in the search for sustainability [7,14].

It should be noted that the work developed by the EC over the past years is only an approximation towards an ideal form of transdisciplinarity. As of now, it has been a successful method for the various disciplines to work with.

It is possible to argue that transdisciplinarity foreshadows a kind of science democracy, as it involves arguments between proponents of different methods and; therefore, can be more sensitive to problems arising from those methods. In fact, an articulation of perspectives and methodologies allows addressing the complexity of a problem with a higher intervention [15].

The proposed methodology we have revised considers transdisciplinarity as one of its pillars. Since the objective is to co-design a technology, it is a requirement to have local and practical knowledge from the people involved to generate the necessary strategies so that they can take part in the decision making process.

2.2. Participation

In both dimensions, science and politics, there is a converging tendency towards the idea that sustainable development can only be achieved through a greater participation of territorial leaders and organizations in the decision-making process. At a scientific level, in order to find concrete solutions to the problem of sustainability, we propose the creation of a new field of study oriented to sustainable development (sustainability science). This field will provide integrated analyzes and assessments by interacting in a reflective, iterative and participatory way between knowledges (considering scientific knowledges of different disciplines as well as local knowledge) and actions (considering public policies at different levels) [16,17,42,43]. These integrated analyzes and assessments should also consider a pluralization of actions and policies, as they are rarely integrated and uniform.

Additionally, several studies have shown the need to consider, not only technical factors, but also the distinctive characteristics, expectations and specific needs of citizens and local communities during the design and implementation of these initiatives [18,19]. The studies also consider the challenge of integrating national objectives and citizen's opinion with local energy planning [20]. Other works note that there are interrelated technological, social, political, and economic barriers that require integrated assessments, which take stakeholder perceptions into consideration [21]. Modern efforts towards citizen participation during the design and assessment of energy policies and projects could then be seen in part as a positive reaction to a failure of the classical models of governance. This is due to the fact that they establish a more friendly relationship with the environment, which is led by a central government and based on expert judgment [22].

Participation in community development contexts is defined as “a voluntary process consciously undertaken by a group of individuals that attains a systematic development over time and space in order to achieve objectives of collective interest and whose strategy must be held as an instrument fundamental to the organization” [23]. This process requires a minimum of unity and wholeness in local communities, which is one of the great challenges in this kind of intervention. This process “involves an expresses interaction between social institutions, the State and actors of the civil society” [24] to influence government decisions regarding the design, implementation and assessment of public policies or instruments alike.

In 1977, following the publication of the “Participation Consultation Book”, the Inter-American Development Bank (IDB) defined a standard consisting of six participation mechanisms, including three mechanisms of influence, decision and control, and other three related to information and learning mechanisms [25], see Fig. 1.

This differentiation is interesting in that it distinguishes two elements: the mechanisms of participation for decision-making and the mechanisms of participation for information and learning. Upon viewing the examples suggested, it becomes clear there are actions focused on informing project beneficiaries, while there are others focused on making decisions with them. Both can be understood as participation.

These two pillars of participation emerge as recommendations of good practices by the IDB. However, they do not escape from the paradox of “framing-overflowing” [26] that any participatory process entails. In other words, much of the participative instances we generate with the “gameplay”, content, duration and call, may define the actions of the participants; therefore, running the risk of trending their responses to pre-chosen alternatives dictated by the government, the technical team and/or the team responsible for developing the methodology. Also, as more freedom and flexibility is given to the participants, the potential for missing the original purpose increases, diverting from the objective and the decision-making process. Consequently, the interest of those who were called may decrease, extending the process of decision-making and decreasing the call on the road. There is also the possibility that, due to format and time flexibility, certain voices may be

overrepresented if there is, for example, a problem with the moderation of the discussion.

2.2.1. Participation in Chile's Energy Agenda

Energy policies in Chile show that, prior to the second half of the 1990s, the context did not provide local communities with entities who could demand rights and participation when a private or state intervention (i.e energy project) occurred [27]. Those interventions were decided by small groups of experts based on the availability of energy resources and the profitability of the investment. In addition, the country was returning to democracy after having lived one of the fiercest dictatorships in Latin America, with high levels of poverty and low coverage in health and education. Further, the country was left with a constitution based on market economic development models whose priority was to strengthen domestic industry via private investment and its insertion in major international markets [28]. In 1994, law 19.300 on the general foundations of Environment, emerges with the objective of generating administrative instruments that regulate the responsibilities regarding environmental harm, promotion of sustainability and, above all, compliance with international standards the global market was demanding to primary exporting companies [29]. Citizen participation was only required for Environmental Impact Studies once the project had already defined its layout. In this regard, the modifications citizens could make had no impact on the technical decision-making process; rather, they were limited to defining the magnitude of the compensations and reparations for the impact made. After 10 years of being in effect, the administrative gap in the law raised a wave of questions regarding participatory processes by the communities affected by energy projects. This gave rise to unprecedented massive social movements in Chile; such as, as the “Dam-Free Patagonia” [30], which questioned the instrumentalization of participation mechanisms by companies and the lack of participatory methods that would recognize local communities and different stakeholders in the decision-making process on energy projects and public policies in general.

In response to the socio-political concern President Michelle Bachelet introduced the “Energy Agenda” during her second term. The objective was to design a socially-validated energy strategy and an “inclusive energy development” ([41], page 86). Based on this agenda, the national and regional energy policies of 2025 and 2050 were designed using participatory methodologies that would bring together the different territorial organizations and stakeholders. These policies make the decision-making processes of the experts transparent, socializing energy potentials of the territory and the types of technologies available and desirable for each group. This period of public energy policy is known as the “participatory turn” [26], and it is also the context in which the EC leads the first experiences of participatory design of public policies. The co-construction methodology is fed by these learnings, and goes a step beyond citizen participation in public policy, proposing a way for local communities to pave the road for the design of technology transfer projects described in the next sections.

2.3. Socio-technical systems

Socio-technical systems refer to the interrelation between actors, technology and social structures developed around its operation [31–33]. It is a technological and social framework of elements, such as technical devices, organizational decisions, involved roles and social practices in the implementation and use of technology [34,35]. They are systems oriented towards goal fulfillment related to or made possible by a specific technology. Social structures constructed in this framework are comprised of decisions, therefore generating a type of organizational system that orients its communications towards the accomplishment of goals.

In this way, it is useful to study the course of technological changes and sociocultural factors associated with them; such processes have

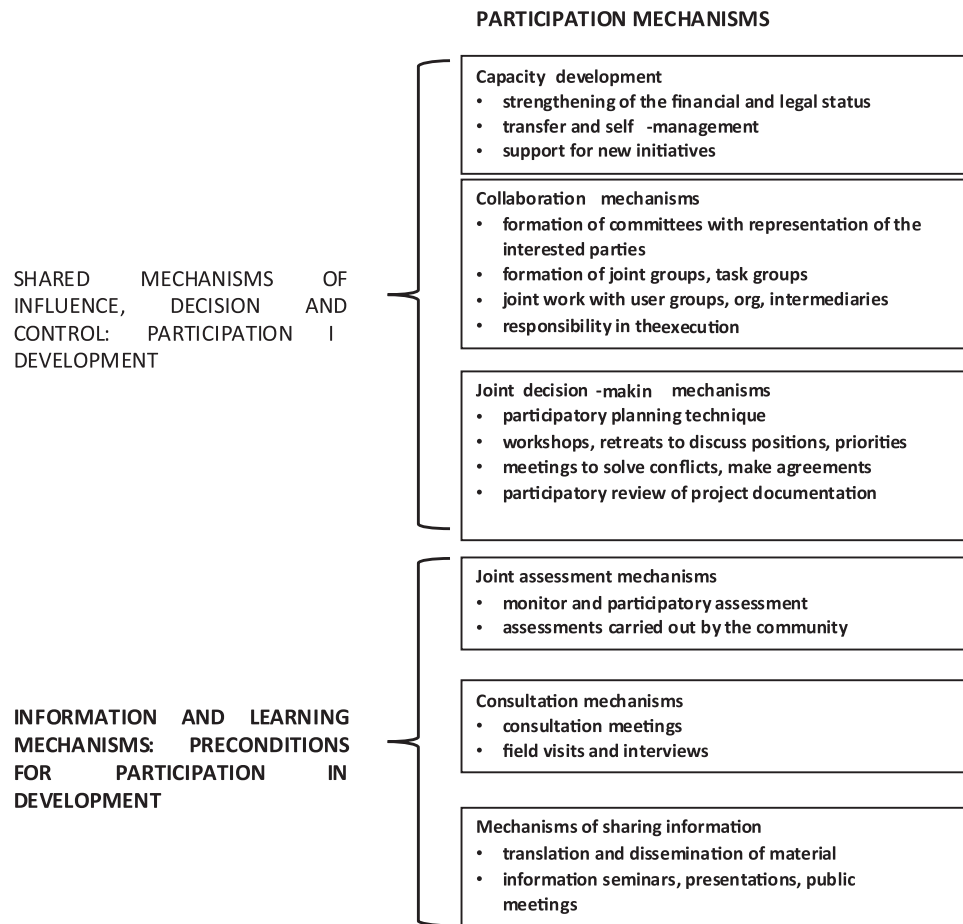


Fig. 1. Participation Mechanism of IDB [25].

been called socio-technical transitions. These refer to such moments of reconfiguration between technological development and broader adjustments in science, industry, market, politics and culture necessary for the creation of new productive trajectories [36]. A socio-technical transition entails a change in the system, while involving technology substitution and transformation in related social structures. Such reconfiguration processes do not occur easily, since the elements present in a socio-technical configuration are all linked and aligned with each other. New radical technologies have difficulties to break through, as regulations, infrastructures, user practices and maintenance networks are aligned with the existing technology. This meso-level of linked structures is called “regimes”.

While regimes often generate innovations in the framework of long incremental processes, radical innovations are generated in niches, which are fundamental since they provide the seeds for change, by generating spaces for learning processes. In this context, it is at the meso-level of the socio-technical regimes where the stability of the existing technological development and the emergence of new trajectories are generated, while the macro-level (landscape) refers to such external factors that change slowly, providing the gradients for the trajectories that emerge in the regime. It is at the micro-level of niches, where radical innovations are generated.

Another problem here is that identifying hidden niches, allow them to be infiltrated through the systems of power and stability. This is specially the case when they are built by established powers. Precisely because of this issue, it is important to develop several niches at the same time. The articulation between them can favor transformations to grow from within the fissures of the regime.

It is therefore essential to develop protected spaces that allow technological experimentation, along with a co-evolution of user

practices and regulatory structures. If niches are properly constructed, they can act as building blocks for broader social changes, moving towards an energy transition within the framework of sustainability objectives [31,36,37].

3. The process of co-construction methodology development: interdisciplinarity and participation at the EC

The objective of this section is to review the process of developing the co-construction methodology from the genesis to its current state under the light of three case studies conducted at the EC where the methodology has been implemented and has recursively affected the development of the co-production model.

The process is shown as an ongoing learning and evolution inside the EC (first steps, scope extension, consolidation, and current challenge), affecting different aspects; such as, team building for project management, methodologies used and EC governance.

The EC, established in 2009, holds the development of an energy supply applied project in the field of distributed generation as its first major objective. This objective was materialized upon developing the project of the first microgrid in Chile, in the town of Huatacondo. A development track in the field of distributed energy solutions begins to consolidate based on this experience.

3.1. First steps

The Huatacondo project (2010 to date), is an applied project developed in the north of Chile by the EC. Its objective, centered on a technical approach, was to design and implement an isolated microgrid with local operation and remote control to supply electricity to the

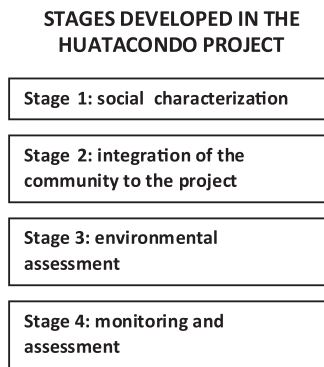


Fig. 2. Main Steps developed in the Huatacondo Project's participatory process.

location. When confronted with the situation of an existing project, and alerted by the experience of community work of the mining company that funded the project, the EC introduced the concept of “community participation” for the first time. This is how, in 2010, the first participatory methodology proposal emerged, which included the 4 stages depicted in Fig. 2.

Upon analyzing the Huatacondo project, we can identify several problems related to interdisciplinary and participatory work developed jointly with the community and the professionals from the EC. Some of them were during Stage 2 “community integration to the project”: first, the focus of a participation mechanism was more related to establishing mechanisms of dialogue, information and learning than to making decisions along with the community. This partly happened because of the lack of time devoted to sharing the concepts required to make informed decisions.

In this context, the only element defined in a participatory fashion was the location of the microgrid components (PV system and wind turbine). The lack of participation probably resulted in low community motivation in the initiative.

Another problem was related to local microgrid management: the goal of a remote control of the network was solved by training a villager who effectively managed the components to make the power system run. Nonetheless, over time the operator was overwhelmed with this new workload generated by an exponential increase in energy demand, which was accompanied by failures of the generating units.

Moreover, the definition of a local management structure or collaboration mechanism that could define the administrative responsibilities of the community while providing a business model to finance operational expenses was not considered during the participation process. In fact, actual system costs were never assumed by the community, which continued to pay the same fixed rate that only managed to finance four hours of daylight. Because of this, the economic dependence on the mining company that provided the initial investment continued. The company has permanently assumed maintenance costs, including the increased amount of backup diesel. This can partly be explained due to the fact that the project was born as part of a corporate social responsibility policy of the Collahuasi mining company. This determined the role of the community with regards to the project, largely because the microgrid became one of the elements of a negotiating table between the community and the mining company.

In Stage 4 “monitoring and evaluation”, other problems developed: The community became used to living with energy 24 h a day. This produced an increase of energy demand, and a change of consumption habits and home appliances. At times, this increase of energy demand caused the system to fail. This failure was addressed by using diesel as a backup source of energy. Due to a higher system energy demand and higher energy consumption, this failure resulted in the consumption of extra liters of diesel.

Such periodical failures produced a transversal distrust between the community and the EC's technical team, resulting in the community's

Stages of the methodology for intervention

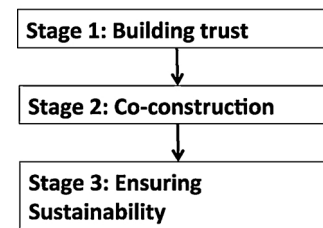


Fig. 3. “Community engagement for smart microgrid”, a new version of the participatory methodology in EC, developed in 2011 by Alvial-palavicino et al.

questioning of the relevance of its implementation in the first place.

As for technical assistance, there is a constant dependence on the professional team of the EC but not on the company. During the installation process of the project and even during its operation, the methodology did not consider building skills inside the local population or developing a connection with a local company which could be capable of solving technical problems. Instead, repairs were performed by the professional team of the EC, who had to travel to the location every time a major failure occurred.

Taking these lessons into account, the EC hired a new team of young professional with backgrounds in natural resource sciences in order to improve the first version of this methodological proposal, which has been synthesized in Alvial-Palavicino et al. [38] (see Fig. 3). The new version considered three stages; 1) “Building trust”, which implies a diagnosis and understanding of the community and the actors; 2) “Co-construction”, which raises vision and narrative discussions between actors while working in an action plan without going into technical details; and 3) “Ensuring sustainability”, to identify potential project impacts, including sustainability indicators developed through a participatory assessment approach.

The main objectives of this new version of methodology were to enhance community engagement and to build a monitoring system based on sustainability indicators along with the introduction of smart grids.

It is worth mentioning that the EC's process of reflection during this period led to a boost in the incorporation of new professionals related to sustainable development subjects, and in the establishment of co-operation with the social area faculty.

Since then, there have been difficulties in developing an interdisciplinary work. This is mainly due to the significance and scope this new group of professionals integrating the EC should develop, and also in setting the grounds for a common understanding of fundamental concepts.

In order to build a common understanding about what participation is, what sustainability is and how they should be performed, an internal workshop was developed in 2014 aimed at identifying the different perspectives of the future of the Huatacondo project. The main question was “how do you see the Huatacondo project in five years?” Every professional involved in the project participated. Their answers to this question showed very different perspectives about the future of this project and the understandings of the meaning of sustainability. Three possible outcomes could be envisioned. First, Huatacondo becomes an autonomous and self-managed community without economic dependence, i.e. sustainability is understood as financial autonomy. The second possibility identified the town as having 100% renewable energy production, waste management and water management. Thus, sustainability was related to a reduction of environmental impacts and management of the carbon footprint. Finally, the third vision understood sustainability as being at the technological vanguard, i.e. Huatacondo as an example of development and innovation in the

region.

This diversity of visions within the team had an influence on planning, prioritization of annual activities, and the overall impact of the project in the territory. Therefore, interdisciplinarity was never a given quality as it has to be managed on a constant basis. In this sense, it is critical to define at the beginning of any interdisciplinary process, which are team expectations and the scope of community member participation.

3.2. Extending the scope

Encouraged by the Huatacondo experience, the EC took part in different initiatives where participatory schemes were stimulated. Along with the design of other rural energy supply initiatives reported in Jiménez-estévez et al. [5] and the support provided to the Ministry of Energy to perform a cadastre on isolated energy systems, it is relevant to mention the following activities:

- MAPS Chile (Mitigation Action Plan and Scenarios). This project follows the international design based on the experience in South Africa. Two main project components constitute a rigorous research effort: scenario modelling and long-term mitigation options, and a facilitated multi-stakeholder participatory process. In this way, the MAPS Chile Project contributed to the decision-making process regarding the mitigation of greenhouse gas (GHG) emissions, and offered options for a low-carbon development plan for the country (www.mapschile.cl).
- A new Energy Agenda was presented to the President by the Ministry of Energy in May of 2014. It proposed seven major objectives within the action step titled “A New Role for the State”. One of the goals was a “Preparation of a State Energy Policy with social, political and technical validation”, where the State committed itself to discussing the key issues arising from the Agenda which defined energy sector planning. The preferred method used to prepare this Energy Policy was not random: The Ministry of Energy decided to adopt international practices on this matter. Therefore, the Ministry launched the “Energy 2050” initiative in July of 2014, conceived as a participatory process to build an Energy Policy. The EC supported this process not only through the development of technical studies, but also through being part of the participative process while also playing the role of facilitator (<http://www.energia2050.cl/en/>).

In the context of this extended scope, and with the incorporation of senior professionals involved in the mentioned initiatives, the EC proposed a third version of the methodology in 2014 [5] comprising new stages (see Fig. 4), i.e., it maintained the application context (isolated

microgrids) but addressed some of the issues that were identified.

A Stage 0 has been introduced upon considering the challenges identified during previous projects regarding interdisciplinary work, based on the need to embrace greater perspectives for a more comprehensive work with a team selected for that purpose.

The diagnosis stage has been maintained (Stage 1) confirming the vital importance of having a deep understanding of the territory and the social characteristics of the local community.

The co-construction stage was also maintained. However, its name was changed to (Stage 2) “Participatory Planning”. It includes considerations arisen from the points of view of local actors regarding project design in addition to a vision and narrative discussion. This element shows a progress compared to the decision-making mechanism of the previous proposal, and its main objective was to enhance community interest, responsibility and sense of belonging regarding the project.

An intermediate stage has been added: Stage 3 “First Impression”, which considers a first assessment after construction. This assessment could provide valuable information in order to improve any problems identified at the very beginning of the operation. Such assessment takes technical and social issues into account.

Finally, lessons from the monitoring mechanism (ensuring sustainability) presented in the 2011 paper, gave rise to Stage 4 “Trial Phase”, which shows the action plan performance. This stage also considers the preparation of a financial structure that includes the search for funds to ensure economic sustainability.

In this new version of the methodology, the stage responsible for designing monitoring systems was replaced by an almost completely pre-designed monitoring tool, which should be adapted to each context (nonetheless, such adaptation was not enough and the tool in this case lacked pertinence in the specific territorial context). The remote monitoring tool is called Social SCADA and is part of stage 4 “Trial phase”. It tried to provide the community with a more comprehensive overview of the energy system, more autonomy in system operation and enhanced project motivation.

Although this was its initial objective, the Social SCADA did not achieve the expected remote control and appropriation, despite having been used by the neighborhood council as an interactive tool that allowed them to explain microgrid components within the framework of academic purposes or possible tourism development.

3.3. Consolidation

The EC began a process of institutional maturing in various senses, which led to a revision of its internal structure. Although there is no unanimity on the relevance of deepening the understanding of social and environmental elements among the members of the EC, this vision is shared by the majority. A socio-environmental area of the EC was formally established at the beginning of 2015. The objective of this area was to develop appropriate technological and sustainable solutions by integrating historical, cultural, political and environmental dimensions. The area pursues appropriateness and long-term sustainability of projects at all stages. It addresses issues; such as, adaptation to, mitigation of and resilience to climate change, territorial governance, and social welfare in their multiple dimensions, in joint efforts with other EC areas.

Subsequently, the last version of the methodology was implemented for the first time in the project: “Development of energy alternatives in Easter Island”. The Polynesian island of Te Pito or Te Henua or “navel of the world” is known as Rapa Nui or Easter Island by the western world. It is located in the Pacific Ocean 3700 km off the Chilean coast of Caldera and has been annexed to the Chilean territory since 1888. It has an area of 166 km² and a population of around 5000 inhabitants, mainly concentrated in Hanga Roa, the only existing town on the island.

Among the main sociocultural features of the island are that the

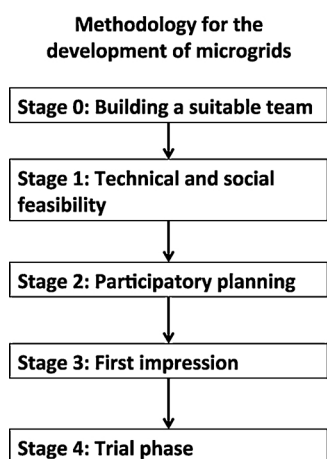


Fig. 4. Social SCADA and approaches for community engagement in isolated microgrids.

older adults are held in high respect and as living referents of the ancestral culture. For these reasons, they are very important to the Rapanui. And, in the case of those who hold representative positions, they constitute leadership figures that become a reference for the inhabitants of the Island, turning themselves into relevant actors that must be considered for any type of initiative that requires citizen participation.

Participatory planning poses a great challenge due to the wide cultural distance among the Rapa Nui people identified during the diagnosis stage. This allows to get deep in the “energy workshops” (education) as previous step to the discussion of alternatives, which aim to reduce both cultural and technical knowledge gaps, in order to incorporate the local perspective in project design.

On the one hand, the outcome regarding the application of this methodology was the co-design of three energy matrix scenarios, in addition to the co-design of cross-cutting energy development initiatives. On the other hand, a local team was formed by the EC team: a support professional from the municipality of Eastern Island and a Spanish-Rapa Nui translator. This experience facilitated the activities proposed in the methodology and constituted an approach of the EC towards transdiscipline.

Finally, energy workshops delivered at Easter Island involved the use of facilitating objects referred to as “Boundary Objects”. These objects inhabit various intersecting worlds, and have the quality of adapting to local needs and constraints, but they are robust enough to maintain a common identity through both spaces [39]. These boundary objects used in the framework of the Easter Island project allowed common codes to be agreed upon, catalyzed and simplified, and allowed knowledge and experiences to be articulated. The objects built envisaged three types of models: First, an Easter Island model at 1:7000 scale that simulated a 3D image from a satellite view. The objective of this model was to identify the types of energy to be used in the island, as well as their trajectories and common uses. The second island model was scaled to 1:25,000, where territorial restrictions were projected. These restrictions indicated the impossibility to install any type of structures in some places: such as, the Airport, lands with archaeological value, highly eroded lands and the boundaries of Rapa Nui National Park. In addition, a third model included a projection of potential places where solar and wind resources could be better exploited. These two elements crossed over each other, generating an interesting discussion around the areas that were appealing. The third of the scale models of renewable energy generation technologies was the one used. All of the models included a number of figurines representing people at the same scale for reference. The models also used didactic elements to help people understand the operation of wind turbines and photovoltaic solar energy, demonstrating the phenomena that occur throughout its use. This approach comprises a set of tools aimed at energy education, which is integral part of the EC co-construction approach.

3.4. Current challenge

Previous experiences, including the development of a solar area inside the EC, have allowed the Center to face the most ambitious participatory project it has ever experienced: the “Ayllu Solar project” (www.ayllusolar.cl). The objective of this project is to foster a sustainable development of both urban and rural communities in the Arica and Parinacota region in the north of Chile by means of the use of solar energy for productive purposes. Project phases are to be developed over a five-year period over which Ayllu Solar project will expand its reach from a local community level to the whole region. The Ayllu Solar project proposes the use of “reference projects” that have been defined as replicable and scalable solar energy projects built around a specific productive process. The development and installation of such reference projects have followed the last version of the co-construction methodology (described below). Reference projects harvest solar energy and use it to provide electricity and heat to power machinery, water

treatment systems, and pumps, among other services.

Similar to the Huatacondo project, interdisciplinarity has been a very complex endeavor from project inception, mainly due to the willingness of professionals from different disciplines to engage in dialogue. For this reason, dialogue is a matter that should never be taken for granted. On the contrary, it should be pursued on a constant basis.

The region of Arica and Parinacota is located in the northern-most tip of Chile, near the border of Peru and Bolivia. It has an area of 16,873.3 km² and a population of 226,068 inhabitants according to the census conducted in 2017, where 91.7% of people are concentrated in the city of Arica. A relevant feature of this region is that 35.7% of its inhabitants identify themselves as indigenous people [40]. These characteristics establish a territory that stands out for its cultural diversity as a result of constant migratory flows with neighboring countries and a significant presence of indigenous population in the region.

In the Ayllu Solar project, there were conceptual problems with the scope of the participatory process, specifically with the time assigned to energy education and workshops, as well as, the selection of the technical elements to be discussed with the community. In this manner, the previous definition of the so-called “margins of co-construction” becomes relevant. Fig. 5 shows the dimensions that are to be defined with the participation of the community.

4. Proposed co-construction methodology

This section describes the current version of the methodology and its main updated features.

The co-construction methodology is a transdisciplinary and participatory approach that considers local knowledge in addition to formal knowledge. This method goes beyond social validation, since it involves the community from the inception of project's conceptual design, throughout its implementation and operation, to conclude with an assessment phase. It considers active participation of the community in relevant decisions during all project stages. This methodology aims for a resulting product that should be developed together with the beneficiaries and adjusted to local conditions, taking into account their cultural, social, environmental and economic characteristics. Thus, this methodology promotes an appropriation of the newly generated energy system and sets the conditions to foster project sustainability over time.

In addition, the proposed methodology is oriented in involving the community from the inception of the project in different areas, in order to enable technology appropriation through process participation. However, technical support is assumed to be required concurrently.

The methodology proposed considers four stages, where the lessons learned from the methodological problems as well as the successful events found in previous projects have been taken into consideration: (1) Sociotechnical diagnosis and team building, (2) Socio-technical system design and sustainability plan, (3) Implementation and first impression, and (4) Operation, assessment and dissemination. These four stages focus on a collaborative knowledge and learning process,

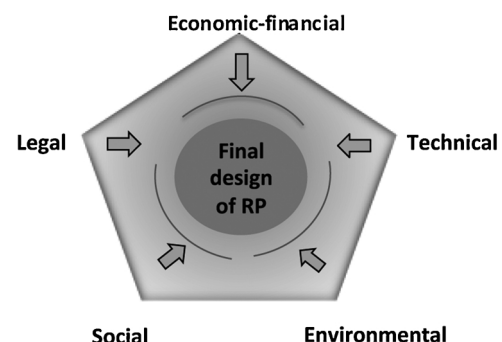


Fig. 5. Co-construction methodology margins in the Ayllu Solar project.

Table 1
Co-construction methodology for energy solutions.

Name	Objectives
Stage 1: Socio-technical diagnostics and team building	● Define technical-structural borders (co-construction scope) ● Represent diversity and local leadership ● Share transdisciplinarity principles
Stage 2: Socio-technical system design and sustainability plan	● Train participants on informed decision making and acknowledge local knowledge ● Identify desired scenarios ● Jointly define technical and organizational characteristics ● Develop a sustainability plan and resilience indicators
Stage 3: Implementation and first impression	● Implement project with an active participation of the community ● Register first impressions and feedbacks ● Technical and organizational skill building for solution management
Stage 4: Operation, assessment and dissemination	● Follow-up and monitoring ● Project assessment ● Develop strategies to tackle weaknesses ● Project dissemination

while considering a flexible and participatory design, involving both the specialists in charge of the initiative and the community at which the project is directed. The following table (Table 1) summarizes these four stages and their objectives:

Stage 1, “Sociotechnical diagnosis and team building” addresses the difficulties found in previous experiences related to a lack of knowledge of the territory in terms of cultural, social, and economic aspects, among others. In this sense, the methodology includes from the very beginning a mechanism to understand eventual interests and priorities of the local community towards the project. The stage considers the development of several elements that enable the delimitation of a general action framework, both for implementing technicians and for such communities to be probably involved in the project. Firstly, it is necessary to define the technical margins of co-construction, i.e., identify those elements that will remain flexible to changes and those that should remain invariable due to the basic requirements of the project. Secondly, transdisciplinary team building composed of key local technicians and actors (e.g. municipal workers, leaders of territorial organizations and regional authorities) is considered, who will act as counterparts during the first breakthrough into the territory. Note that the team is established once there is an initial work with the community. Thirdly, the conduct of a participatory sociotechnical diagnosis that allows to identify critical socio-cultural, economic and technical conditions for project implementation, and the preparation of an initial proposal for energy solution, considering possible scenarios for the future energy transition.

This stage takes over a large part of the problem identified in the Huatacondo project, regarding the lack of a common understanding about project continuance, as well as about a divergence of conceptual notions within the technical team.

In the case of the Ayllu Solar project, experience has shown that it is essential to get an exhaustive diagnosis that allows us to identify precisely the sociocultural dynamics of the communities, while trying to understand those relevant elements of their identity in their daily life, and also their worries and expectations for the future. It is also essential to know those dimensions that may eventually affect the relationship between the technological solution and the territory: i.e. local governance, productive chain, use of the territory, etc. At this point, ethnographical and territorial analysis techniques have turned out to be highly useful tools for understanding socio-cultural dynamics of communities.

In this stage, meetings held with communities in order to build a

local team are relevant. Also relevant are diagnostic activities, since they allow an early bond between the technical team and local actors; hence, facilitating trust-building.

Stage 2, The “Sociotechnical system design and sustainability plan” addresses such problems identified on the relevance of the proposed solution (project) and is probably the key stage of the process. Here, the flexibility of the technical teams is tested in terms of their openness to the local knowledge of the communities involved. The expected result of this stage is to have a co-developed technical design, highly relevant to local productive and cultural characteristics, a design of a management model that organizes activities that try to enhance energy solutions, and a sustainability plan that allows sustaining the project in the long term. Joint development of this design facilitates the appropriation of the project by the communities involved, while understanding the intricacies of the technology used, defining the business model required to maintain the project over time, among other relevant topics. The development of a sustainability plan and its implementation strategy occur once socio-technical system characteristics have been defined.

This stage addresses the lack of community influence on technical decisions observed in the Huatacondo project. It also integrates the successful events of the Easter Island project, in terms of delivering energy education workshops upfront in order for the community to make informed decisions. The use of boundary objects as a mechanism to address cultural and informational gaps and the openness to learning local territory concepts, were crucial to influence the final design. Likewise, this stage addresses problems such as the absence of a management system and a business model where the actual costs of the proposed socio-technical system were foreseen.

What has been represented by Social SCADA in Huatacondo, becomes a co-construction of a sustainability plan, where the contents are more related to local governance rather than to a measurement of standardized parameters (such as quality of life and human development index), unlike the previous approach. The plan also seeks to avoid the trend to an explosive increase in energy consumption (as seen in Huatacondo). Hence, a sustainability education process which considers energy efficiency and adaptation to climate change among others, accompanies project implementation. The integration of an IT-solution (Information Technology) for system monitoring has not been discarded.

In the experience of the Ayllu Solar project, in order to build trust while maintaining community motivation on the go, it is essential that the definitions of the technical design margins to be co-constructed respond to local interests and knowledge.

Once the margins of community participation in the technical design of the solution are defined, it is possible to identify precisely those aspects of the design where dialogue and deliberation should occur. To develop this participatory process to design a socio-technical system, a working structure is used where two types of activities are developed for each of the aspects of the design to be discussed. First, an education workshop with the community, oriented to deliver knowledge and basic tools that reduce information asymmetries to then advance to a deliberative plenary where the project team presents a proposal with relevant arguments and discusses it with the community that makes decisions about the design, through their own deliberative mechanisms.

Once defined the technical design of the technological solution, it is possible to proceed with the process of preparing a sustainability plan. First, a plenary for indicator validation is held, where the team presents a proposal and the community validates it and includes those indicators that seem relevant to them and discards the others. Then, out of the indicators that were validated, the team prepares a sustainability plan proposal that is discussed and validated in another plenary session with the community.

For instance, in the case of the Ayllu solar project, one of the reference projects to be implemented in the region consisted of a technological solution for the processing of alpaca fiber, which included a collection and fiber processing center for top manufacture powered by

an off grid photovoltaic solar plant and a transportation system for moving the fiber from the rooms to the center by the use of electric vehicles. Because of the workshop and the plenary process, the community defined the need to make some adaptations to this proposal: i) Remove the electro-mobility system for two reasons: first, the orographic characteristics of the territory (highland area with dirt roads of limited accessibility) prevented service performance to most of the farmers and second, the traditional way in which they carry out the shearing process (according to their own times and means available) did not adjust to a more centralized scheme like the one being proposed. ii) Incorporate spinning machines into production line. This adaptation mainly responds to the sociocultural value assigned by the communities to the traditional weave of textiles acknowledged as part of the cultural heritage of the Aymara people in Chile. Since this activity is mainly developed by women from the Aymara highland communities, the integration of artisans into the co-construction process was revitalized thanks to this adaptation to the technical design of the project.

Step 3, “Implementation and first impression” aims at incorporating the need to build skills in the beneficiary community in order to achieve a satisfactory system operation; in this sense, during this stage, those definitions established in the previous stage are tested. In this context, it is key for the technical team to record the first impressions of the stakeholders involved in the project, to make the necessary adjustments and amendments that allow a better adoption and operation of the technology. At the same time, training is delivered on sociotechnical system operation and maintenance (including technology and management systems).

In this stage of the Ayllu project there are three processes developing concurrently. First we have technology implementation. In this line, it is highly sensitive to keep an ongoing dialogue with the community and its representatives due to the possible unforeseen events the construction process may entail.

The second process refers to the implementation of a local governance structure legitimized by the community and capable of supporting the technology implemented. For this, it is necessary to structure a work plan jointly with the community in order to clearly identify the organizational needs demanded by the project, the alternatives of existing mechanisms to meet those needs and the products to be achieved at the end of the process, which must allow for a institutionalization of roles, responsibilities and regulation frameworks according to project's challenges.

For instance, in one of the reference projects consisting of a plant for dehydrating and processing fruits and vegetables, the local farmer community defined the need to create a cooperative to be the governance structure of the project. In this process, the implementation team assumed the role of facilitator and advisor of the new governance

structure, which began to take over the management of the project.

The third process developed in this stage consists forming human capital at a local level. The objective is to settle the skills to understand, operate and maintain the technology implemented in the territory of the project.

Stage 4, “Operation, assessment and dissemination”, intends to address those problems identified with the lack of monitoring and betterment of the project by adding this stage to the methodology. This stage aims at a self-learning of the socio-technical system installed, sustainability indicators are measured here that will result in strategies and plans to continue with an ongoing energy transition. At the same time, it is expected an implementation of the dissemination strategies in order to connect the technological project with its local environment as well as with its regional environment, with the purpose of promoting the replicability of the proposed energy solution in such territory by means of connecting the community involved with other similar experiences regarding energy transitions.

The process of evolution and update of this methodology has been developed in the framework of the EC work force, which has the characteristic of combining academic research and applied projects. This quality gave the opportunity, on the one hand, to improve a set of tools for current projects (such as Ayllu Solar) and on other hand, to focus on a theoretical-methodological discussion based on new research activities.

5. Conclusions

The main problems of method faced during these experiences can be summarized on the one hand in those problems presented during interdisciplinary work, such as: common understanding of fundamental concepts (sustainability, participation, community); the domination of one discipline over the others (in this case engineering); the different visions of the priorities within the same project (e.g. building technical solution vs. building community trust). On the other hand, there are those problems given by the participation process under the paradox of “framing-overflowing”, where the constraints of actual projects (such as, deadlines, budget, and specific KPIs) could limit the possibility of performing in depth diagnostics, building trust and developing dialogue about knowledge with community. This could end in rushed solutions. Moreover, the appropriation of the project by the community could be affected when the technical solution is defined by the supporters rather than by the community itself. In contrast, when the participation is in a completely free and flexible context, the project can miss its original purpose, diverting from its objective; while in the decision-making process, certain voices may be overrepresented.

These problems observed empirically during 10 years in the participative processes of design and implementation of distributed energy

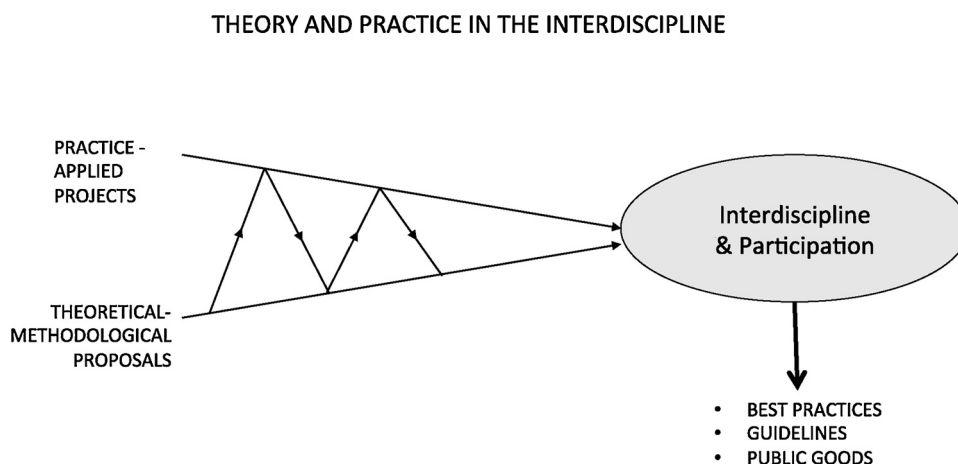


Fig. 6. Evolution of the co-construction approach at the EC.

solutions as developed by the EC, have allowed a continuous learning process based on the interaction between practice and theory. The following figure shows this learning curve (Fig. 6).

The training and learning experiences achieved throughout the years have been due to the opportunity provided by an engineering center devoted to applied science activities, which faces actual projects with unique characteristics and conditions. This would not have necessarily happened if people working on these projects had not had the availability to implement the whole methodology, because of problems; such as, misalignment between project proposals and funding parties, budget limits, and short-timed horizons.

Furthermore, a development focused on new theoretical-methodological approaches is the natural way of working of a group of professionals within a university context (unlike for example, the use of a pre-established framework implemented by a consultant company).

This process enabled convergence toward a shared vision that recognizes the need of interdisciplinarity & participation as two key factors in the creation of sustainable distributed energy solutions. During this process, the maturation of both the professional team and institution was observed.

These types of processes require the support of local authorities, hopefully seed money beyond those provided by each project's budget. This support is key for removing barriers and uncertainties that the change of paradigms and energy transition involve. As experienced by the EC, young professionals are more open to facing these types of challenges and will probably play key roles in the creation of new institutions.

The process carried out within the EC is not exempt from the problems of participation mentioned throughout the paper, i.e. project implementers are constantly struggling with dialogue compartmentalization and methodology inflexibility while at the same time being concerned about having a too flexible methodology that runs the risk of losing continuity, focus and support, and significantly increase implementation costs in isolated locations.

An actual impact from the overall experience described in this paper is only feasible if lessons can be translated into concrete products. For instance, best practices, guidelines, and tools, among others. These products (public goods) can then be adopted by future project developers (e.g. companies, communities, municipalities, associations), thus avoiding such failures and delays hereby captured in the co-construction approach proposed thanks to the learning process of the EC. Additionally, the human capital developed throughout the projects will also support new developments. Thus, a higher probability of success regarding the scalability and replicability of distributed energy solutions can be expected.

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