Energy communities in sustainable transitions: the South American case

Comunidades energéticas na transição para a sustentabilidade: o caso da América do Sul

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ABSTRACT

Energy communities (ECs) have become an attractive scholarly target in recent years since they promote more sustainable, democratic, and decentralised electrical systems. Thus, a new research line around the alignments established by the European Union (EU) has arisen. Conversely, despite commonalities, Latin American initiatives and academic works still lack a standard distinctness. This work studies ECs' experiences in South America yielded in the literature, highlighting lessons, strengths, and weaknesses, under a sociotechnical and political lens. Thirty-eight articles indicated a variety of cases in the region. However, mainly off-grid isolated ventures focused on satisfying basic human needs, employing hydropower, solar, wind, biomass, and biogas technologies. Also, Brazil has indicated more profound advancements in on-grid ECs within urban settlements in the last few years. Nevertheless, there is a vast potential to develop new projects in the region.

Keywords: Energy communities. Energy transitions. Local transitions. South America. Sustainability.

RESUMO

As Comunidades Energéticas (CEs) têm chamado atenção acadêmica nos últimos anos, na medida em que promovem sistemas elétricos mais sustentáveis, democráticos e descentralizados. Um conjunto de estudos vem sendo realizado, acerca da temática, tomando como referência as definições estabelecidas pela União Europeia (EU). No entanto, as iniciativas latino-americanas carecem de um olhar específico, apesar *dos pontos em comum. Para preencher essa lacuna, este trabalho estuda experiências sul-americanas relatadas na literatura recente, enfatizando as lições, fortalezas e fraquezas sob uma lente sociotécnica e política. Trinta e oito artigos mostram uma diversidade de casos presentes na região. Tratam-se, principalmente, de empreendimentos isolados tipo off-grid satisfazendo necessidades humanas básicas, empregando tecnologia hidrelétrica, solar, eólica e de biomassa. Nos últimos anos, o Brasil mostra avanços no relativo às CEs on-grid em assentamentos urbanos. No entanto, ainda existe um vasto potencial para desenvolver novos projetos na região.*

Palavras-chave: Comunidades energéticas. Transição energética. Transições locais. América do Sul. Sustentabilidade.

1 INTRODUCTION

The energy sector became pivotal in a world characterised by the climate crisis, the energy market volatility, and the rapid depletion of non-renewable resources (CHESNEY, 2020; FEIL; SCHREIBER; TUNDISI, 2015; MAX-NEEF, 2010; ROCKSTRÖM *et al.*, 2009). The current sustainable energy transition involves social, ecological, economic, and political dimensions, seeking to reduce carbon emissions by substituting fossil fuels with renewable sources. In the same way, customers' behaviour is changing. Electricity is becoming an essential type of end-use energy due to the high potential to reach high levels of efficiency (electrification of the economy) (RAM *et al.*, 2019; SANTOS, 2019). In 2000, the global share of electricity in final energy consumption was equal to 15%, reaching 20% today, expecting to reach 24% by 2040 if countries maintain their trends. The use of renewable sources, energy efficiency, and the electrification of the economy could account for 94% of emissions reduction committed to achieving the Paris Agreement limits (GIELEN *et al.*, 2019; INTERNATIONAL ENERGY AGENCY, 2020; SOVACOOL *et al.*, 2020).

Between 2007–2017, the Latin American and the Caribbean (LAC) region increased the non-conventional renewable energies (NCRE) use. New solar, wind, geothermal, and biomass projects emerged, but fossil fuels also expanded. Thus, total electricity production increased by 33% (POQUE GONZÁLEZ, 2020). Presently, the region faces at least three challenges: highly-centralised systems associated with mega power infrastructure, unequal access and accessibility, and low diversification of energy sources (IORIO; SANIN, 2019; POQUE GONZÁLEZ, 2020; WORLD ENERGY COUNCIL, 2019). In 2017, at least 12 million people in LAC had no access to electricity. While coverage in urban areas remains at 99%, it reaches 92% in rural areas (ECONOMIC COMMISSION FOR LATIN AMERICA AND THE CARIBBEAN *et al.*, 2019).

To promote more sustainable, democratic, and decentralised electrical systems, some policies – mainly European – have proposed encouraging Energy Communities (ECs) (ARIZTIA; RAGLIANTI, 2020; FUENTES GONZÁLEZ; SAUMA; VAN DER WEIJDE, 2019; GONZÁLEZ; WEIJDE; SAUMA, 2020; HELDEWEG; SÉVERINE SAINTIER, 2020; ROBY; DIBB, 2019). ECs are a group of citizens producing, managing, and using their energy in a defined local, geography, or place; customarily, in a distributed modality, and based on renewable sources (solar, wind, water, biomass, geothermal) and/or energy conservation/efficiency methods/technologies. This concept entails crucial issues such as resources management, social relations, human and environmental well-being, regulations, territorialism, and cultures (CEGLIA *et al.*, 2020; FUENTES GONZÁLEZ; SAUMA; VAN DER WEIJDE, 2019; KLEIN; COFFEY, 2016). Are there ECs in South America? How and by whom are they implemented? Which contexts have triggered these projects? Which lessons could we learn from these cases?

Answering those questions is not a simple task. European Union (EU) has promoted ECs as a pathway to the sustainable energy transition. Nonetheless, South American countries have no standard energy guidelines. Despite the reports of collective power generation projects in Argentina, Ecuador, Colombia, Chile, and Uruguay (FURTADO, 2020; FURTADO; PAIM, 2019), studies on the topic are still scarce. To fill this gap, this study aimed to analyse the literature on ECs' experiences in South America.

Social articulation is a critical issue in ECs configuration; consequently, we highlight sociotechnical and political dimensions, in line with Cherp *et al.* (2018) approach. We limit the analysis to studies focusing on projects with community participation.

This article is structured as follows: Section 2 presents the context of the South American sustainable energy transition. Section 3 shows the methods and materials driving the research. Then, Section 4 offers the main sociotechnical and political ECs' characteristics, country by country. Section 5 develops an interdisciplinary discussion around the main findings. Finally, in section 6, we conclude, encouraging the development of further studies related to the topic.

2 BACKGROUNDS

Energy systems undergo structural shifts in response to the current socio-ecological global challenges. For example, CO^2 emissions, according to 2010 values, must decrease by 45% until 2030 to achieve net-zero emissions in 2050 and mitigate the effects of climate change (BLONDEEL *et al.*, 2021). The current sustainable energy transition has at least four pivotal axes: decarbonisation, digitalisation, decentralisation, and democratisation (CUNHA *et al.*, 2021; GHENAI; BETTAYEB, 2021).

2.1 SOUTH AMERICAN ENERGY TRANSITION

South America has historically had a low-carbon matrix on the power generation side. Nevertheless, renewable sources have not yet displaced fossil fuels. In 2000, 77% of the electricity produced in the region came from hydropower, 20% from fossil fuels, 2% from nuclear plants, and 1% from biomass. In 2019, 57% of the electricity generated came from hydropower, 28% from fossil fuels, 6% from wind, 5% from biomass, 2% from nuclear plants, and 2% from solar sources (OLADE, 2022). Figure 1 shows the evolution of electricity generation in South America throughout the 21st century.

On the demand side, South America's share of electricity in final energy consumption accounted for 16% in 2000, increasing to 19% in 2019. It corroborated the global trend of electrification of the economy (OLADE, 2022). Throughout the 21st century, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela introduced renewable energy targets (KIEFFER *et al.*, 2016). Considering the size of their matrices, Uruguay, Chile, and Brazil were the most prominent in incorporating solar, wind, biomass, and geothermal sources between 2007 and 2017 (POQUE GONZÁLEZ, 2020).

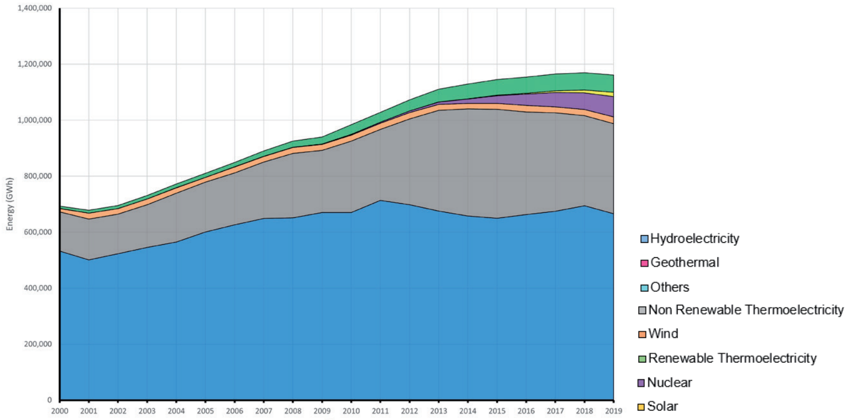

Figure 1 | Electricity generated between 2000 and 2019.
Source: Elaborated by the authors with data from Sielac (OLADE, 2022).

2.2 ENERGY TRANSITION AND ECS

The sustainable energy transition occurs at multiple levels. As shown in Figure 2, ECs are a local vector toward a low-carbon society. Also, renewable and distributed small-scale technologies offer broad opportunities for social empowerment. Moreover, collective, decentralised, and democratic energy projects are critical in the quest for sustainable futures and a just and inclusive energy transition (LODE *et al.*, 2022; THOMBS, 2019). Finally, Lode, Coosemans, and Ramirez Camargo (2022) pointed to socio-demographic factors as critical drivers in developing European energy cooperatives (a type of ECs). Thus, access to advanced education, information and communication, and satisfaction with housing and authorities correlate with the energy cooperatives' emergence.

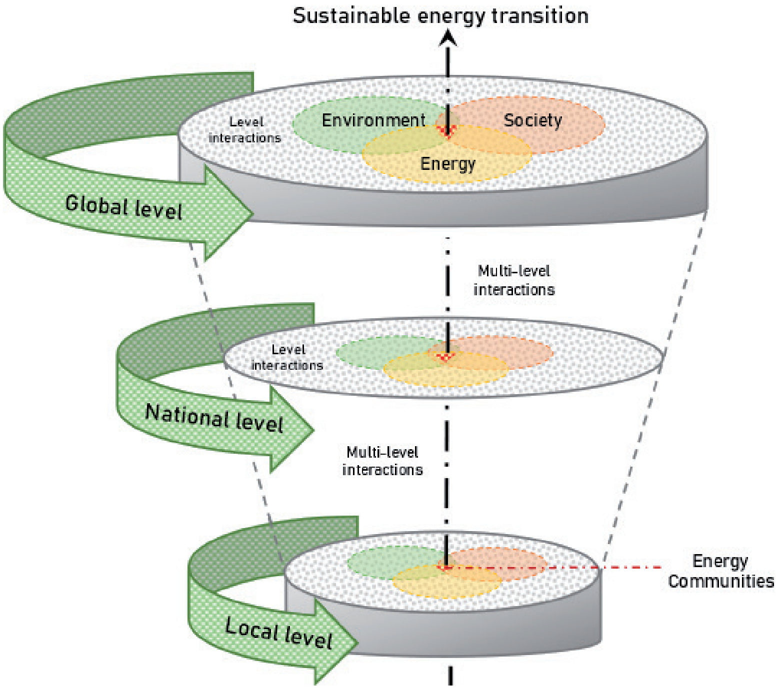

Figure 2 | Sustainable energy transition and the ECs' role.
Source: Elaborated by the authors.

3 METHODS AND MATERIALS

The main objective of this work is to examine ECs' experiences in South America, highlighting lessons, strengths, and weaknesses. We use a sociotechnical and political lens, limiting the search to the studies focused on projects with community participation. Then, a systematic literature review (SLR – (SORRELL, 2007)) tool carries the process of catching critical publications[1] studying ECs in the region. SLR concentrated on academic articles published between 2000 and 2020 on the Web of Science environment. The analysis focuses on electricity as an end-use energy resource; consequently, we do not consider heat-based literature.

To answer the central questions of this research, in a descriptive format, we expose the main sociotechnical and political characteristics of South American ECs. So, we identify commonalities and divergences between local, national, and regional levels. Afterwards, we develop a broad interdisciplinary discussion around emerging topics. Due to the bibliographical nature of this work, there are no ethical compromises or transgressions. We reference all documents used.

4 RESULTS

As shown in Figure 3, academic interest in South American ECs has been growing since 2010, indicating the great potential of this subject. Founded articles concern eight South American countries: Argentina, Bolivia, Brazil, Chile, Ecuador, Peru, Venezuela, and Surinam.

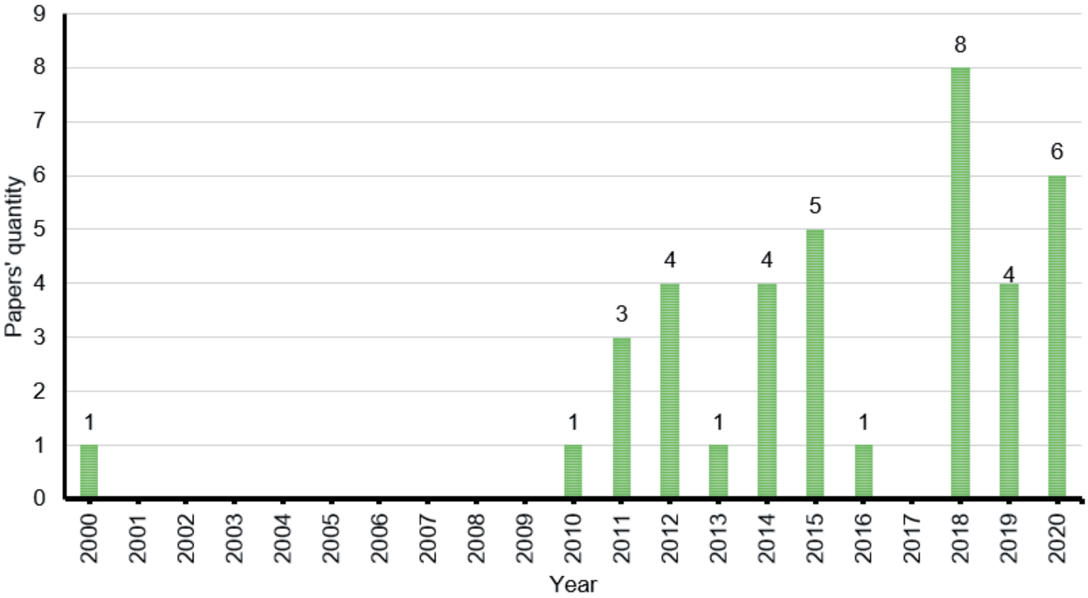

Figure 3 | South American ECs' articles per year.
Source: Elaborated by the authors.

According to the literature on the Argentine context, ECs may trigger a democratic, equitable, and collaborative pathway to the sustainable energy transition, empowering social arrangements. Electrical cooperatives operated in the generation, transmission, and distribution sectors since the 1920s-1930s, especially in small, isolated towns. Nevertheless, these initiatives disappeared over time, absorbed by public and private ventures. However, in the last decade, renewable energy sources and the evolution of power technology have reinforced electrical cooperatives, such as the case of the cooperative-like project located in Armstrong town, in the province of Santa Fé. This project consisted of a smart non-isolated grid composed of a 200-kW photovoltaic plant and 50 distributed solar home systems (SHS) of 1.5 kW (GARRIDO, 2018). Other projects based on biomass, biogas, and wind technologies have emerged under the same scheme. Still, the lack of regulations favourable to promoting ECs comprises a critical hampering factor in the country (KAZIMIERSKI, 2020).

One-third of the Bolivian population, located in rural areas, had no access to electricity in 2010. The literature on Bolivia focused on developing micro-hydropower (MHP) solutions of up to 100 kW to provide electricity for isolated communities. The geographical, economic, and environmental features made MHP a viable alternative to non-electrified remote communities. It facilitates a continuous electricity supply – in contrast with solar systems, which became more expensive due to the need for storage technology. Social participation led to the construction of cooperatives and local arrangements headed and supported by municipalities, non-governmental organisations (NGOs), and academic institutions. Still, disseminating and advancing technical knowledge is a critical issue (ARNAIZ *et al.*, 2018b; DRINKWAARD; KIRKELS; ROMIJN, 2010). As a challenge, local authorities must train operator teams, establish optimal tariffs to create financial reserves for maintaining the infrastructure and rely on the support of technical institutions and governments (ARNAIZ *et al.*, 2018a).

Due to geographical, technical, and economic issues, solutions to the lack of electricity in the Brazilian Amazon are not straightforward. São Francisco de Aiucá, a small floodplain village with 38 houses, is partially electrified by SHS and a communitarian diesel generator (VALER *et al.*, 2014). Regarding photovoltaic solutions, the Aiha Central Indigenous State School, located in Xingu indigenous land, implemented a solar pilot project composed of three 270-Wp photovoltaic panels and enclosed devices to explore this technology and develop local knowledge. This community is isolated from the nearest electrical grid in Mato Grosso, so implementing electricity improved its educational tools (FIGUEIRÊDO NETO; ROSSI, 2019). Despite several Amazonian isolated projects based on biomass, photovoltaic systems, MHP, and hybrid solutions, not all guarantee community participation. For example, in some cases, customers acquire electricity by prepayment systems (SÁNCHEZ; TORRES; KALID, 2015).

There are eight mini-grids based on MHP cooperatives and community projects in the state of Pará, all of which located in Belterra, Santarém, and Placas Pará; namely: Açacal do Prata (80 kVA), Cachoeira Aruã (50 kVA), Corta Corda (150 kVA), Água Azul (120 kVA), Piranha (150 kVA), São João e Santo Antônio (150 kVA), Santa Rita (90 kVA), and Sombra Santa (160 kVA) (VAN ELS; DE SOUZA VIANNA; BRASIL, 2012). We also identified four other isolated projects on the Marajó Island in Pará, demonstrating different levels of community involvement jointly with academic and private entities. These were Marajó (200-kW biomass), Araras I (50-kW solar power), Araras II (25-kW wind power) and Caxiuanã (solar power) (BORGES; BARAÚNA; CHOTOE, 2015; PINHEIRO *et al.*, 2011, 2012). For example, a community cooperative performs the Marajó biomass project operation and maintenance (SÁNCHEZ; TORRES; KALID, 2015). At the opposite extreme of the country, groups of farmers implemented projects to produce biogas from organic waste. Thus, experiences such as those of São Roque Farm in Santa Catarina, and the Ajuricaba Condominium, in Paraná generate electricity by agro-waste (PASQUAL LOFHAGEN; BOLLMANN; SCOTT, 2018).

The adjustment of resolution no. 482 through resolution no. 687, in 2015, created a formal category for condominiums, consortiums, or cooperatives that generate and might introduce energy remains into the public grid; it was a crucial point for Brazilian ECs (LOTERO; DE SOUZA, 2020). As a result, the government registered ten cooperative on-grid projects in 2019. Among these, seven refer to solar cooperatives using photovoltaic generators that add up to 3.7 MWp of nominal power installed. Two hydropower plants add up to 6.5 MW, and one biomass plant is equivalent to 4.9 MW (SCHNEIDER *et al.*, 2019). Conversely, two condominiums in Juazeiro-Bahia installed 9,156 230-W photovoltaics panels on the rooftops of residences in 2014 (previous resolution no. 687) and six 5-kW micro-wind turbines in common areas, resulting in 2.1-MWp renewable generation capacity. However, the sale of energy modality was interrupted due to politico-institutional uncertainties (CUNHA *et al.*, 2021).

In Chile, photovoltaic infrastructure seems critical to ECs due to the country's geophysical features. Therefore, the Ayllu Solar project, located in the Arica y Parinacota region, adopts a co-construction scheme, whereby both the local community and the Energy Center of the Universidad de Chile participate in the design, operation, and final evaluation phases (MONTEDONICO *et al.*, 2018). Following this scheme, the Energy Center undertook the Huatacondo project in the Tarapacá region. This project consists of an isolated smart microgrid, including wind, solar, diesel sources, storage equipment, and demand-side management mechanisms (ALVIAL-PALAVICINO *et al.*, 2011; JIMÉNEZ-ESTÉVEZ, *et al.*, 2014; PALMA-BEHNKE *et al.*, 2011; RAHMANN *et al.*, 2016). It is expected to replicate the same procedure in Mapuche and Easter Island communities (PALMA-BEHNKE *et al.*, 2019).

An example of a bottom-up energy project is the Pan de Azúcar initiative. Here, a local fishermen's community in a coastal town of the Atacama Desert, northern Chile, proposed a shared project. The construction of two off-grid solar plants was driven by the need to provide electricity for domestic use and sustain fishing activities (ARIZTIA; RAGLIANTI, 2020). González *et al.* (2020) demonstrate the economic-strategic viability of community energy projects by comparing Chilean and Scottish institutional frameworks. Studies also indicate the existence of a cooperative in Coyhaique town, the Austral South of Chile, where citizens promote energy-saving and energy alphabetisation initiatives (BAIGORROTEGUI, 2018).

The literary production on ECs in Peru is rather extensive. The El Alumbre, Campo Alegre, and Alto Peru communities implemented three wind hybrid power projects in the Cajamarca region in the Northern mountains of Peru (3,800 – 4,000 m.a.s.l). The venture's management model is based on an independent micro-enterprise articulated with users' committees, municipalities, and NGOs (DOMENECH *et al.*, 2014; FERRER-MARTÍ *et al.*, 2012, 2013). El Alumbre uses micro-wind generators for each consuming point. Campo Alegre combines individual solar systems with a hybrid wind-photovoltaic solution. Due to the dispersion between households in Alto Peru, a wind power microgrid, a photovoltaic microgrid, an MHP, and an individual photovoltaic operate at different consuming points. Moreover, the Chorro Blanco, Tamborapa Pueblo, Suro Antivo, and El Regalado projects in the Cajamarca region employ MHP (FERNÁNDEZ-BALDOR *et al.*, 2014; FERRER-MARTÍ *et al.*, 2012; LILLO *et al.*, 2015a; YADOO; CRUICKSHANK, 2012). Pucara implemented a project that combines sanitation with energy services, employing MHP, separate photovoltaic systems, biodigesters, improved cookstoves, Trombe walls, and solar water heaters. Project administration is way more complex, integrating municipality, NGOs, users' committees, and operator systems (LILLO *et al.*, 2015b). Management and security are critical for the long-term sustainability of all these projects (DOMENECH; FERRER-MARTÍ; PASTOR, 2015).

Venezuela focused on rural and isolated electrification. A study on the theme approached the electrification of a Warao community, in the Orinoco Delta, in 2000 (MASI; CHASSANDE, 2000). According to it, implementing photovoltaic power systems comprised a community project involving culture, environmental matters, and local ecology knowledge, thus requiring the mobilisation of several community actors such as teachers, doctors, and inhabitants. To evaluate rural electrification programs based on renewable sources and investigate a sustainability pathway, López-González *et al.* (2018b) proposed a methodology assessed by four dimensions: environmental, technical, socioeconomic, and institutional. To this end, the authors tested the Sowing Light Venezuelan program for rural electrification launched in 2005, enabling community participation in management, operation, and maintenance through user assemblies (UA) and community councils (CC). Technological advances under such a scheme allow the implementation of hybrid microgrid systems (such as photovoltaic panels, batteries, wind systems, and diesel backup), which are environmentally friendly and socially well-accepted. Another study tested whether off-grid microgrid solutions would be more suitable than individual home systems (LÓPEZ-GONZÁLEZ; DOMENECH; FERRER-MARTÍ, 2018a).

Due to the Ecuadorian geography, the solar resource comprises a positive aspect. Quito's peripheral region lacks public infrastructure, so photovoltaic collective ventures represent a social response to meeting basic human needs such as security, education, and health (CRIOLLO ALVAREZ; MAKS-DAVIS; RODRÍGUEZ, 2020). The Community Access Resource for Electricity Sustainability (Cares) performed rural electrification in Guyana's Amazonian region. It guaranteed a bottom-up design of collective energy ventures while considering environmental, cultural, and identity issues (BLAIR; PONS; KRUMDIECK, 2019).

Table 1 shows works focused on political analyses of ECs. Table 2 points out on-grid projects studied under the sociotechnical lens. Table 3 presents the off-grid projects studied, focusing on Bolivia, Chile, Peru, Venezuela, and Guyana under a sociotechnical lens. Finally, table 4 shows off-grid projects focused on Brazil studied under a sociotechnical lens.

Table 1 | Works focused on political aspects of ECs in South American countries.

Author (s)	*Country*
(KAZIMIERSKI, 2020)	Argentina
(GONZÁLEZ *et al.*, 2020)	Chile

Source: Elaborated by the authors.

Table 2 | Works focused on on-grid projects studied from a sociotechnical perspective.

Project	Technology	Estimated size	Country	Author (s)
Armstrong	Solar	275 kW	Argentina	(GARRIDO, 2018)
Joanes	Hybrid	60.2 kW	Brazil	(SÁNCHEZ; TORRES; KALID, 2015)
Generic case	Solar	-		(LOTERO; DE SOUZA, 2020)
Coober	Solar	75 kW		(SCHNEIDER *et al.*, 2019)
Cooper Sustentável (São José)	Solar	1 kW		
Cooper Sustentável (Arcos)	Solar	0.25 kW		
Enercred	Solar	180 kW		
Compartsol	Solar	1.4 MW		
Sicoob Centro-Serrano ES	Solar	36 kW		
Coopercitrus	Solar	1 MW		
Sistema Sicoob ES	Solar	1 MW		
Juazeiro	Hybrid	2.1 MW		(CUNHA *et al.*, 2021)

Source: Elaborated by the authors.

Table 3 | Works focused on off-grid projects studied from a sociotechnical perspective. Part I: Bolivia, Chile, Peru, Venezuela, Guyana.

Project	Technology	Estimated size	Country	Author(s)
9 PRODENER projects and 1 Government/ private project	MHP	Totalising 353 kW	Bolivia	(ARNAIZ *et al.*, 2018a); (ARNAIZ *et al.*, 2018b)
Epizana, Chapisirca, Pojo, Flor de Mayo, Charía, Agua Blanca, Yanamayo, and Quinuni	MHP	Totalising 372 kW		(DRINKWAARD; KIRKELS; ROMIJN, 2010)
Challapata	Solar/Wind	---		(DOMENECH; FERRER-MARTÍ; PASTOR, 2015)
Turco	Wind	---		(DOMENECH; FERRER-MARTÍ; PASTOR, 2015)
Condor Sustainable Electrification Project - Huatacondo	Hybrid	134 kW	Chile	(ALVIAL-PALAVICINO *et al.*, 2011); (JIMÉNEZ-ESTÉVEZ, *et al.*, 2014); (JIMÉNEZ-ESTÉVEZ *et al.*, 2014); (PALMA-BEHNKE *et al.*, 2011); (RAHMANN *et al.*, 2016); (PALMA-BEHNKE *et al.*, 2019)
La Arena - Patagonia	Solar	17.4 kW		(ARIZTIA; RAGLIANTI, 2020)
Caleta Pan de Azúcar	Solar	---		(ARIZTIA; RAGLIANTI, 2020)
Alto Peru	Hybrid	2 kW	Peru	(DOMENECH *et al.*, 2014); (FERRER-MARTÍ *et al.*, 2012); (FERRER-MARTÍ *et al.*, 2013); (FERNÁNDEZ-BALDOR *et al.*, 2014); (LILLO *et al.*, 2015a); (DOMENECH; FERRER-MARTÍ; PASTOR, 2015)

Project	Technology	Estimated size	Country	Author(s)
Campo Alegre	Hybrid	3 kW	Peru	(FERRER-MARTÍ *et al.*, 2012); (FERNÁNDEZ-BALDOR *et al.*, 2014); (LILLO *et al.*, 2015a); (DOMENECH; FERRER-MARTÍ; PASTOR, 2015)
El Alumbre	Wind	4.3 kW		(FERRER-MARTÍ *et al.*, 2012); (FERRER-MARTÍ *et al.*, 2013); (DOMENECH; FERRER-MARTÍ; PASTOR, 2015)
Chorro Blanco	MHP	20 kW		(FERNÁNDEZ-BALDOR *et al.*, 2014); (LILLO *et al.*, 2015a);
El Regalado	MHP	12 kW		(FERNÁNDEZ-BALDOR *et al.*, 2014); (LILLO *et al.*, 2015a)
Suro Antivo	MHP	---		(LILLO *et al.*, 2015a)
Tamborapa Pueblo	MHP	40 kW		(YADOO; CRUICKSHANK, 2012)
Pucara	Hybrid	---		(LILLO *et al.*, 2015b)
Community of Macareo	Solar	---	Venezuela	(MASI; CHASSANDE, 2000)
Generic case	Hybrid	---		(LÓPEZ-GONZÁLEZ; DOMENECH; FERRER-MARTÍ, 2018b)
Kabakaburi	Hybrid	---	Guyana	(BLAIR; PONS; KRUMDIECK, 2019)

Source: Elaborated by the authors.

Table 4 | Works focused on off-grid projects studied from a sociotechnical perspective. Part II: Brazil.

Project	Technology	Estimated size	Country	Author(s)
São Francisco de Aiucá	SHS	4.6 kW	Brazil	(VALER *et al.*, 2014); (SÁNCHEZ; TORRES; KALID, 2015)
Aiha village	Solar	0.81 kW		(FIGUEIRÊDO NETO; ROSSI, 2019)
Marajó	Biomass	200 kW		(SÁNCHEZ; TORRES; KALID, 2015); (BORGES; BARAÚNA; CHOTOE, 2015)
São Francisco do Paroá	Biomass	80 kW		(SÁNCHEZ; TORRES; KALID, 2015)
Cachoeira de Aruã	MHP	50 kW		
Jatoarana	MHP	55 kW		
Novo Plano	MHP	76 kW		(SÁNCHEZ; TORRES; KALID, 2015)
Lençois	Hybrid	40 kW		
Tamaruteua	Hybrid	51 kW		
São Tomé	Hybrid	29.2 kW		
Praia Grande	Hybrid	22 kW		
Sucuriju	Hybrid	120 kW		
Vila Campinas	Hybrid	147.2 kW		
Araras	Hybrid	21 kW		
Equinócio	Solar	2.4 kW		

Project	*Technology*	*Estimated size*	*Country*	*Author(s)*
Açacal do Prata	MHP	64 kW	Brasil	(VAN ELS; DE SOUZA VIANNA; BRASIL, 2012)
Corta Corda	MHP	120 kW		
Água azul	MHP	96 kW		
Piranha	MHP	120 kW		
São João e Santo Antônio	MHP	120 kW		
Santa Rita	MHP	72 kW		
Sombra Santa	MHP	128 kW		
Araras I - Curralinho	Solar	50 kW		(BORGES; BARAÚNA; CHOTOE, 2015)
Araras II - Curralinho	Wind	25 kW		
Caxiuanã	Solar	---		
Santo Antônio	Biomass	50		(PINHEIRO *et al.*, 2011); (PINHEIRO *et al.*, 2012)
Ajuricaba Agroenergy Condominium	Biogass	83.2		(PASQUAL LOFHAGEN; BOLLMANN; SCOTT, 2018)

Source: Elaborated by the authors.

5 DISCUSSIONS

In this section, we analyse ECs, integrating social, environmental, and engineering fields as the central axes of sustainability science in the Anthropocene era (CLARK; HARLEY, 2020; LEVIN; CLARK, 2010). First, in the core of Figure 4, we resume the main findings of the searching process exposed in section 4. Then, from this diagnosis, we propose new fields to be discussed which emerge as weaknesses identified under the sociotechnical and political lens. Thus, section 5 involves both areas, highlighting emerging topics in a discussion that we do not expect to exhaust in this work.

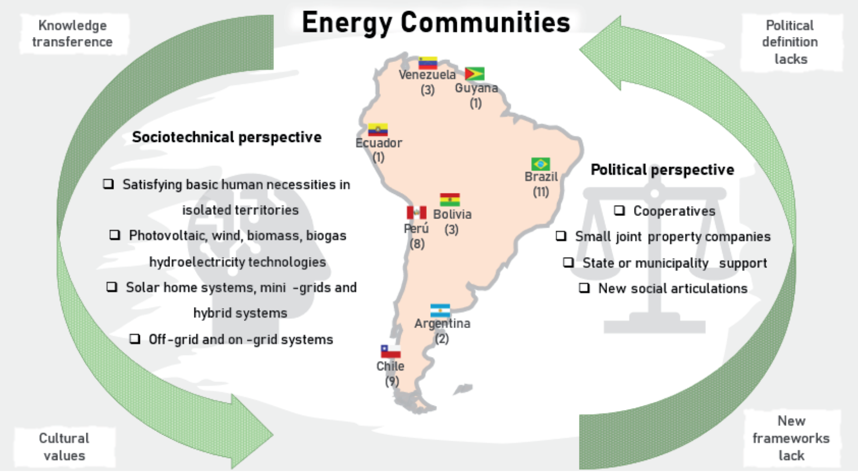

Figure 4 | Critical findings and emergent discussion points.
Source: Elaborated by the authors.

5.1 ENERGY POLICY

The property of essential services such as electricity has been highly discussed in the last decades. In the 1980s-1990s, a substantial part of South American electrical systems transited to liberalisation. Generally, the generation sector opened to competition, the transmission and distribution sectors were submitted to a regulated monopoly, and the States assumed a regulatory role (IORIO; SANIN, 2019). After, in the 2000s, Bolivia and Venezuela nationalised their electrical systems. Meanwhile, other countries in the region maintained their liberalised and hybrid markets, setting reforms promoting the introduction of NCRE, overcoming market failures, and modernising frameworks (BALZA *et al.*, 2020; IORIO; SANIN, 2019).

21st South American regulations generally disregarded cooperative social bodies. Nevertheless, humans are cooperative animals (TOMASELLO, 2014), so issues related to meeting human needs always imply a deep community dimension. That is one of the sustains for ECs in South America. Before the historical lack of formal institutional bodies to govern and stimulate rural, isolated energy projects, local cooperatives emerged as a third way of ECs management (VAN ELS; DE SOUZA VIANNA; BRASIL, 2012). Likewise, South American ECs projects assumed the format of small private companies or were managed by bodies at the state or municipal level (LILLO *et al.*, 2015a).

5.2 HUMAN ROLE

We should understand the community beyond a social body that accepts or rejects a new technical solution designed and implemented by external technicians under co-opting participation schemes (BAIGORROTEGUI, 2018). Energy projects must incorporate local culture, worldviews, and social and environmental features. Local and indigenous communities have specific knowledge to protect biodiversity and ecological and cultural inheritance, which is essential to preserve land and mitigate environmental damages (FERNÁNDEZ-LLAMAZARES *et al.*, 2021). On the other hand, private companies may eventually abandon unprofitable projects, leaving human needs unmet if there are no satisfactory corporate profits (BORGES; BARAÚNA; CHOTOE, 2015).

In introducing new technologies into a community, especially in isolated localities without electrical service, multiple factors must be recognised since it is a cultural, social, and psychological process. Actors providing technical support must consider the specific cultural characteristics of the community (FEDRIZZI; RIBEIRO; ZILLES, 2009). Knowledge transfer is critical, as stated by the Brazilian educator Paulo Freire: "knowledge does not extend from those who think they know to those who think they do not know; knowledge is constituted in man-world relations, transformation relations, and is perfected in the critical problem-posing of such relations[2]" (FREIRE, 1983, p. 22).

5.3 SOME CASES

Most of the Brazilian Amazon zone is not covered by the Brazilian Power Electric System (Sistema Interligado Nacional - SIN). Naturally, this region has received particular academic attention (BACELLAR; ROCHA, 2010). Relying on fossil fuels-based isolated power systems or small-scale hydropower implies complex logistics processes. Cost-effectiveness and environment are critical issues, triggering an endless search for optimal renewable energy resources which demand community participation (ANDRADE; ROSA, 2011; GÓMEZ; SILVEIRA, 2012). The Amazon comprises a region rich in biodiversity and culture, but so do many others within South America. The Peruvian mountains, for example, present rugged geographical areas, which hampers the establishment of conventional energetic solutions and consequently stimulates collective responses. These facts show that the search for energy solutions with low environmental impact and synergic association with local lifestyles is fundamental to preserving human and natural heritage throughout the *Abya Yala*[3] region.

Most of the ECs research focused on the Brazilian and Chilean contexts – countries that have developed an institutional body to govern collective energy projects (POQUE GONZÁLEZ, 2021). In Chile, Law no. 21,118 of November 2018 modified the legislation to residential power generation, providing an institutional definition of collective owners of NCRE or efficient cogeneration infrastructure. These power generators must be smaller than 300 kW (MINISTERIO DE ENERGÍA, 2018). Three years before, Brazil updated the normative resolution no. 482 of 2012, introducing the concept of shared generation. That is, the confluence of consumers into the same concession area through a cooperative or consortium with micro (equal to or smaller than 75 kW) or mini (upper than 75 kW, and equal to or smaller than 5 MW) distributed *generation infrastructure*[4] (AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA, 2016).

5.4 A BRIEF SOCIOTECHNICAL NOTE

Generally, the national energy statistics disregard isolated systems in evaluating emissions, risks, and improvements. However, as demonstrated here, ECs projects promote profound local, sustainable energy transitions. As well as biomass, the photovoltaic, wind, and hydro infrastructure, storage systems, demand response (DR) initiatives, and Energy Management Systems (EMS) might be other shared goods in on-grid ECs (CUENCA; JAMIL; HAYES, 2021).

Also, compared with *off-grid* ECs, *on-grid* ECs studies consider more techno-economic matters, such as energy losses at low voltage networks, additional costs for grid operators, and technical issues related to system stability, like controlling voltage or reactive power (CUNHA *et al.*, 2021). The relevance of having a clear regulatory framework that provides certainty and allows for the development of *on-grid* projects over time is evident in the case of Juazeiro. Moreover, information and knowledge are critical in localities where actors have financial autonomy, such as those formed by communities of farm managers.

Most ECs employ clean distributed resources, reinforce community arrangements, reject ancient pollutant technologies, and consider cultural and environmental issues. Given that local resources meet essential human needs in an environment characterised by a profound collaborative spirit, the focus of ECs agrees with the Human Scale Development of Manfred Max-Neef (MAX-NEEF; ELIZALDE; HOPENHAYN, 1998).

5.5 THE VALUE OF TERRITORIES

Many worldviews proper to the LAC regard the territory as more than physical space. A territory is a place produced from practices, knowledge, and know-how, establishing relations for the reproduction of life. As spaces that foster links, solidarity, exchanges, and communication, collective community learning – such as those in the core of indigenous, Black, peasant, and women's communities – the role of academia, social movements, alliances, and networks are pivotal in South American energy transition (ROCA-SERVAT; PERDOMO-SÁNCHEZ, 2020). Then, sparking a multi, inter, and transdisciplinary debate about LAC's conception of energy tasks is essential. At the local level, ECs articulate a social, ecological, and technical niche to promote a sustainable alternative to established systems (or *status quo* regimes). Further research must assimilate ontological and epistemological dimensions of sustainable joint energy projects (MEYER; VILSMAIER, 2020; TIRONI; SANNAZZARO, 2017).

Abya Yala's knowledge and wisdom urge for the deconstruction of the Western insights of development and sustainable development[5], claiming for a pluriversal world in transition to ethical, just, and socio-ecological sustainability (SOVACOOL *et al.*, 2017; VANHULST, 2019; VÁSQUEZ-FERNÁNDEZ; AHENAKEW PII TAI POO TAA, 2020). An example is the *Buen Vivir* (BV), an Andean and Amazonian traditional worldview whose main axes are identity, equity, and sustainability. BV postulates a lifestyle in harmony with oneself, society, and nature (GUEVARA; CAPITÁN, 2015). The Brazilian indigenous leader Ailton Krenak discloses: "the BV can be the difficult experience of maintaining a balance between what we can get from life, from nature, and what we can give back. It is a balance, a very sensitive balance, and not something that we access by a personal decision"[2] (KRENAK, 2020, p. 8). However, the BV represents a small part of a pluriversal set of rich worldviews from the original population of the region.

6 CONCLUSIONS

The social arrangements configured to generate and manage electricity are a longstanding practice in South America, mainly due to the region's rugged geography and the incapacity and non-availability of extended national grids to reach every human settlement. Thus, initially, ECs literature focused on projects seeking to address the issue of access to electricity in isolated localities (*off-grid* projects). Nevertheless, since 2018, the literature has approached ECs projects as a viable on-grid alternative within urban settlements.

Remote and rural non-electrified settlements still exist, and the region's availability of distributed energy sources is prominent, having a high potential to develop new ECs. Also, there is a possibility of reinforcing ECs due to the emergence of cheaper NCRE technologies (VAN ELS; DE SOUZA VIANNA; BRASIL, 2012). Moreover, grid extensions are not always viable (economically), such as when isolated communities have a low-density population (FERRER-MARTÍ *et al.*, 2012). On the other side, the modernisation of sociotechnical and institutional landscapes has enabled new on-grid initiatives, mainly powered by social, economic, political, and environmental reasons (CUNHA *et al.*, 2021; SCHNEIDER *et al.*, 2019). Nevertheless, there is a lack of political definitions, promotion, and regulatory frameworks for ECs in the region.

ECs projects in South America are complex, implying at least biophysical, geographic, ecological, and social components (RAHMANN *et al.*, 2016). ECs are a core where actors, empowering forces, and social networks interact with technical solutions, the environment, and local resources. Converging toward standard scholarly definitions and interpretations of ECs in South American countries is an exciting challenge. As presented in the discussion section, Brazilian and Chilean political-institutional status on ECs give a chance to develop a starting point for comparative studies.

Before the immeasurable diversity of cases explored, this study does not exhaust such a topic; the field to be explored within the subject is still rather broad. The current scenario is characterised, among others, by the socioeconomic damage arising from the Covid-19 pandemic and the global task of facing climate change (POQUE GONZÁLEZ; SILVA; MACIA, 2022). Thus, the worsening of draughts and shifts in the water cycle and the nuances specific to each South American government pose enormous inter-and transdisciplinary challenges to the science. It could represent an unusual opportunity for promoting pivotal sustainability shifts, a breakpoint to a profound transition (SCHOT, 2020). Going deeper into ECs is a necessary and ambitious undertaking in the South American region.

Electricity can significantly benefit the population's quality of life (BORGES; BARAÚNA; CHOTOE, 2015; DINIZ *et al.*, 2011). Similarly, ECs can improve community health, children's education, household income, comfort, and communication (FERRER-MARTÍ *et al.*, 2012). From this perspective, isolated rural and peripheral urban settlements (typical in South America) such as Brazilian Favelas, often excluded from the technological development of conventional power grids, could find a sociotechnical solution in ECs (DW BRASIL, 2021).

NOTES

1| Searching arrangement: ((Community) OR (cooperative)) AND ((Energy) OR (Electricity)) AND ((Argentina) OR (Bolivia) OR (Brazil) OR (Chile) OR (Colombia) OR (Ecuador) OR (Guyana) OR (Paraguay) OR (Peru) OR (Suriname) OR (Uruguay) OR (Venezuela)).

2| Our translation, from Brazilian Portuguese.

3| The term *Abya Yala* is a Guna Indigenous term used to refer to what is known today as Latin America (VÁSQUEZ-FERNÁNDEZ; AHENAKEW PII TAI POO TAA, 2020).

4| Micro- and minigeneration must be renewable or quality cogeneration. Minigeneration considers hydropower lower than 3 MW.

5| Sustainability has often been defined in two ways: (1) as dynamic stability in social and ecological systems and their interactions and (2) the meeting of the needs of the present human population without compromising future generations (SALOMAA; JUHOLA, 2020). These meanings might be somehow related to the worldviews of *Abya Yala*. Nevertheless, when combined, the terms sustainability and development induce critical divergences, for sustainable development models are usually rooted in Western paradigms (VÁSQUEZ-FERNÁNDEZ; AHENAKEW PII TAI POO TAA, 2020).

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