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# Distributed photovoltaic generation in Argentina

An analysis based on the technical innovation system framework

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# Distributed photovoltaic generation in Argentina: an analysis based on the Technical Innovation System framework

## Abstract

In Argentina, renewable energies are promoted as a way of decarbonising the electricity mix and providing reliable energy services. The national goal is to generate 20% of electricity from renewable sources by 2025. However, despite significant natural potential, solar photovoltaic still represents only a small share of Argentina's total electricity generation. Although this picture may look bleak, a wide range of market segments relating to decentralised photovoltaic generation in Argentina have developed. The general objective of this study is to examine the dynamics that currently enable or constrain the diffusion of distributed photovoltaic systems in Argentina. By applying the Technical Innovation System (TIS) approach, the aim is to understand which functions of the system are strong/weak and how these are influenced by endogenous/exogenous system strengths and weaknesses. To that end, a mixed method research strategy is applied. The exploratory sequential research design allows first to explore system strengths and weaknesses based on qualitative approaches, and then to further analyse the contextual embeddedness and the level of importance of the identified variables using quantitative survey instruments. Thereby, this study provides an important analytical method that contributes to a more nuanced understanding of the interdependencies of the TIS. The empirical results indicate that system weaknesses are shaped to a large extent by the overall contextual dynamics – such as political instability, energy subsidies and high inflation rates. System strengths relate to both the TIS itself (particularly knowledge development through pilot projects and market formation through provincial and national support programmes), to contextual relationships (linked to the availability of educational institutions that enable the rapid diffusion of knowledge) and to the importance of rural areas as protected spaces for the application of photovoltaic systems. Consequently, the study highlights the challenges to overcome for the broader diffusion of distributed photovoltaic generation.

## Keywords

- Argentina, photovoltaic systems, distributed generation, sustainability transitions, Technological Innovation System, TIS contexts

# 1 Introduction

Argentina's power system has faced many challenges in the first two decades of the 21st century. Its development has been shaped by a continuous increase in electricity demand, recurring power deficits, increasing dependence on fossil fuels and Argentina's commitment to the Paris Agreement [1,2]. In the light of these circumstances, two key measures for diversifying the energy mix and increasing energy autonomy were introduced. On the one hand, the expansion of renewable energies with the aim of generating a 20% share of electricity by 2025 was announced as a central energy policy goal [3,4]; on the other hand, the extraction of shale gas in the Neuquén Basin (Vaca Muerta) was promoted to avoid the need to import liquefied natural gas to meet domestic demand [5].

Of all the Latin American countries, Argentina is second only to Brazil in terms of its renewable energy potential [6,7]. This potential stems from a combination of wind capacity [8,9], convenient solar irradiation for photovoltaic projects [10,11], hydropower [12] and significant opportunities for biogas [13]. After years of stagnation, the clear development of renewable energies was stimulated by the national support programme, RENOVAR, in 2016. As a result, the share of renewable energy in the electricity mix increased from 2.4% in 2018 to 9.5% in 2020 [14]. This development was mainly driven by centralised large-scale projects. The legal national framework for the decentralised<sup>1</sup> feed-in of renewable energy was initially established at national level in 2017, with the target of reaching 1,000 MW of distributed renewable generation capacity by 2030 [1]. Before these national regulations came into effect, some provinces had already implemented programmes to enable electricity users to install renewable energy technologies and to feed electricity into the public grid (examples include Santa Fe and Salta). Through further additional provincial support programmes, a market for decentralised on-grid photovoltaic systems has begun to emerge in Argentina. The off-grid market niche (PV systems in isolated rural areas) has an older trajectory: between 1999 and 2012, 25,711 photovoltaic systems were installed under the PERMER<sup>2</sup> programme for the electrification of private households and state schools [15,16].

The general objective of this study is to examine the current dynamics affecting the diffusion of distributed photovoltaic systems in Argentina. In order to determine the necessary conditions for further advancing the diffusion of distributed photovoltaic systems, the first specific objective is to identify the main endogenous and exogenous influential factors and analyse these in the context of the performance of the individual functions of the TIS. To that aim, we apply the Technical Innovation System (TIS) framework, which recognises innovation as the outcome of a systemic interplay of supportive actors, networks, institutions and technologies [17–19]. The framework is based on the fundamental assumption that technology diffusion is driven by the fulfilment of key activities and processes, referred to as system functions. These system functions represent a further research focus of this study [20]. Most TIS studies examine the development and diffusion of new technologies in relation to systemic change processes (such as the transport, energy and heat transition) in the geographical context of developed countries. These include wind energy [21–23], photovoltaic systems [24–26], biomass and biorefineries [27–30], hydrogen [31–33], power-to-X [34] and heating systems [35,36]. Recent research studying the diffusion of novel technologies in the context of developing countries has highlighted the importance of context-related factors<sup>3</sup> [20,37–39]. In order to contribute to this discourse, this study employs the TIS framework to investigate the current prospects for the diffusion of decentralised photovoltaic systems in Argentina and, in doing so, develops a deeper understanding on a theoretical and empirical level of the context interaction

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<sup>1</sup> In this study, decentralised power systems are understood to be modular power generation plants located close to energy consumers (i.e., in contrast to centralised power plants, where the electricity often has to be transmitted over long distances).

<sup>2</sup> *Proyecto de Energías Renovables en Mercados Rurales* (Project of Renewable Energies for Rural Markets).

<sup>3</sup> Also known as macro or exogenous factors.

dynamics. This study is based on the application of an exploratory mixed method research strategy combining qualitative and quantitative data collection methods. For this purpose, the investigation is guided by the following research question:

“How do the functional dynamics and the related endogenous/exogenous system strengths and weaknesses influence the diffusion of decentralised photovoltaic systems in Argentina?”

This paper is structured as follows. Section 2 aims to provide a general overview of the current state of the electricity system in Argentina and of initiatives promoting the diffusion of photovoltaic systems on a provincial and national level. Section 3 sets out the theoretical background and introduces the TIS framework. In section 4, the mixed method research strategy is presented. Section 5 deals with the results from the TIS analysis and describes key system strengths and weaknesses. Section 6 discusses how endogenous and exogenous factors hinder or support the dissemination of decentralised photovoltaic systems in Argentina and how the applied framework could be further developed. Finally, the conclusions are presented in section 7.

## 2 The Argentinian power system and photovoltaic energy

The electricity system in Argentina began to take shape at the end of the 19th century when private companies, linked to foreign investors, installed the first generation plants. These plants were coal-fired and were intended to supply energy to large cities. Later, electricity cooperatives started to provide electricity services in rural villages. In the 1960s, electricity generation and transmission were nationalised, while distribution remained under provincial administration. With the successive interconnection of hydroelectric plants and nuclear stations, a national interconnected system was developed. In 2013, the final section of the Patagonia electrical grid was connected and the Sistema Argentino de Interconexión<sup>4</sup> was established. The system is interconnected through a transportation network of 28,000 km of high voltage lines.<sup>5</sup>

In the 1990s, the vast majority of the electrical sector installations were under private ownership, and generation, transportation and distribution became independent segments. These three sectors and the large electric users, who together formed the Associations of Generators, Transporters, Distributors and Large Users (AGEERA, ATEERA, ADEERA and AGUEERA, respectively), are the agents of the Electrical Wholesale Market. This market is managed by CAMMESA<sup>6</sup>. The historic evolution of the Argentinian electrical system has delineated regional inequities in terms of access to electricity. Even though the grid reaches 98% of the country's population, approximately 145,000 households still lack access to electricity [15]. In rural areas, electricity is still a secondary power source and, in some cases, remains non-existent [40].

Hydroelectric and hydrocarbons have become the main electricity sources in the Argentinian electricity mix. To meet the growing demand of the last 20 years, efforts have been made to strengthen the generation capacity by introducing thermoelectric generation using gas and oil derivatives. The role of fossil fuels has become even more significant considering the exploitation of unconventional hydrocarbons in the Vaca Muerta basin. As a result, gas accounts for 60% of the electricity mix, used as the main fuel in both conventional and combined cycle thermoelectric plants [14].

In addition to this fossil fuel dependent model are the deficits caused by a lack of investment in the energy transmission and distribution networks, coupled with growing demand. As a result, energy

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<sup>4</sup> Sistema Argentino de Interconexión (Argentine Interconnection System).

<sup>5</sup> It is operated by Compañía de Transporte de Energía Eléctrica en Alta Tensión TRANSENER S.A., and six other companies: TRANSBA S.A., TRANSNEA S.A., TRANSNOA S.A., DISTROCUYO S.A., TRANSPA S.A. and TRANSCOMAHUE S.A. [95].

<sup>6</sup> Compañía Administradora del Mercado Eléctrico Mayorista (Argentine Wholesale Electricity Market Clearing Company).

services have decreased in quality and some of the population still lack access to electricity. Faced with this scenario, and given the international commitments made in 2015 to reduce CO<sub>2</sub> emissions under the framework of the Paris Agreement, Argentina faces the challenge of reducing its consumption of fossil fuels, which are responsible for 53% of greenhouse gas emissions [41]. To achieve this, Argentina seeks to stimulate adaptation and mitigation measures within the framework of the National Energy and Climate Change Action Plan. This plan promotes: (1) energy efficiency; (2) the use of renewable resources; and (3) distributed generation. These three angles imply not only changes in the origin of the energy source but also, and fundamentally, changes in how the energy circulates and the roles played by the actors involved.

The valorisation and harnessing of the renewable resources available in Argentina opens up a pathway to a more diverse, sustainable and decentralised system [42,43]. In 2021, of Argentina's 41.95 GW of total installed capacity, thermoelectric plants account for 60%, hydroelectric for 26% and renewable energies for 10%<sup>7</sup>. Photovoltaic energy represents 18% of the total renewable installed capacity for electricity generation [14], amounting to 759 MW. In terms of photovoltaic potential, in the north of the country global horizontal irradiance (GHI) reaches 7.5 kWh and 4.0 kWh per square meter per day (kWh/m<sup>2</sup>/day), during the summer and winter months respectively. In the central provinces, such as Buenos Aires, Córdoba and Santa Fe, GHI fluctuates between 6.5 kWh/m<sup>2</sup>/day in summer and 2.0 kWh/m<sup>2</sup>/day in winter [11]. The first implementations of photovoltaic technologies were off-grid installations in isolated rural areas, carried out under the PERMER framework. In these areas, photovoltaic technology has enabled the population to access energy services. Since the 2010s, stimulated by the provincial regulatory frameworks, mini solar plants have begun to proliferate in small towns, as well as domestic photovoltaic installations for self-consumption (with the possibility of feeding surplus into the low or medium voltage grid network). Eight provinces have their own regulatory systems for energy exchange between users and electricity distributors. The provinces of Buenos Aires, Córdoba and Santa Fe, which are the focus of this paper, are the forerunners of distributed generation in Argentina. Santa Fe has been a pioneer province in terms of enabling distributed generation, Córdoba leads in the number of user-generators and Buenos Aires promotes small photovoltaic plants (between 200 kW and 500 kW) through the PROINGED programme.<sup>8</sup> In order to provide a unifying national framework, and to guarantee the effective application of future distributed generation facilities, a national regime to promote the generation of distributed energy from renewable sources was established (Law 27,424 / 2017) and a net billing system was created (Regulatory Decree 986/18). These initiatives supported photovoltaic technology to increase to 3.7 MW of installed capacity [44].

### 3 Theoretical framework

This research draws upon the Technical Innovation System (TIS) framework, a field within innovation and sustainability transitions studies. This framework is capable of breaking down the complex and multi-dimensional nature of the emergence and dissemination of novel energy technologies. The reasoning of the TIS framework builds on the work of Carlsson & Stankiewicz [45] and evolutionary and institutional economics [46,47]. The underlying causal mechanism implies that the close interaction of system elements generates positive feedback effects that foster the emergence of interdependencies from which various forms of systemic synergies can evolve [48,49]. The framework is a fruitful heuristic for the purpose of this research as it not only focuses on novel technologies, but also provides insights into the institutional and organisational changes required for the evolution of emerging technological fields [29].

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<sup>7</sup> In Argentina, large hydroelectric plants are not considered as renewable sources. However, according to Law 27,191, an exception is made for small hydropower plants (< 30 MW).

<sup>8</sup> *Programa de Incentivos a la Generación Distribuida* (Incentive Programme for Distributed Generation).

One of the main advantages of the TIS framework is that it combines structural and functional analysis, which leads towards a dynamic view of innovation systems. This study benefits from the ability of the structural analysis to incorporate a broad spectrum of elements that shape the innovation system. A TIS conceptualises the development, diffusion and use of new products (goods and services) and processes as a result of the systemic interplay of actors, networks, institutions and technologies in a particular technological domain [17–19]. In this context, networks (formal associations, communities, etc.), institutions (regulations, norms, cognitive rules, etc.) and infrastructure/materials (physical surroundings, financial systems, etc.) form the structural environment in which the actors' activities take place [39,50]. The complementary analysis of system functions allows for a better understanding of the performance of the innovation system, which should be seen as an emergent property resulting from the interplay between the structural elements and the wider context [51]. Hence, the system functions are emergent sub-processes of the overall innovation dynamic and, moreover, intermediate variables between the structure and the overall system performance [17,52,53]. The analysis of the performance of each system function allows this research to obtain a dynamic view of the diffusion of distributed photovoltaic systems in Argentina and to identify the factors that inhibit the diffusion of the technology. In recent years, an increasing volume of literature has provided evidence that the relevance of key processes differs during the distinct development phases of a TIS [39,54,55]. Based on previous findings from the industry and technology lifecycle literature, Markard [48] developed a TIS lifecycle framework that distinguishes between four key phases of TIS development: emergence, growth, maturity and decline. Moreover, the functions of a TIS do not develop independently of each other, but rather interact with each other in positive or negative feedback loops [21,56]. Changes in the TIS can induce variations in other areas, resulting in a series of actions and reactions that can either drive the system forward or cause it to fail [17]. In the foregoing studies, the specific functions in the TIS analysis vary slightly. This study builds on the definition of system functions as developed by Hekkert et al. [57] (defined in Table 1):

*Table 1: The seven TIS functions [57]*

<b>Functions</b>	<b>Definitions</b>
Knowledge development	Encompasses R&D and knowledge development in the form of 'learning by searching' and 'learning by doing'.
Knowledge diffusion through networks	Exchange of information in networks. Includes 'learning by interacting' and 'learning by using'.
Entrepreneurial activities	Turns the potential of new knowledge networks and markets into concrete action to generate – and take advantage of – new business opportunities.
Guidance of search	Those activities within the innovation system that can positively affect the visibility and clarity of specific wants among technology users. Represents the process of selection between various technological options.
Market formation	Creation of a protected space for new technologies.
Creation of legitimacy	Creation of legitimacy for a technological trajectory by advocacy coalitions putting the new technology on the agenda and lobbying for resources and favourable tax regimes.
Resource mobilisation	Allocation of sufficient resources; both financial and human capital.

A systematic literature review by Bergek [53] on the TIS framework found that the length of the published studies are empirically dominated by case studies in the European context. Furthermore, Bergek [53] concludes that the TIS framework should be adapted and further developed to adequately address the context of developing and emerging countries. The relatively few recent studies that have used the TIS framework to examine technology diffusion in developing countries all highlight the relevance of national specific context factors [39,58–60]. Since innovation systems do not develop in a vacuum but are embedded in existing configurations of socio-technical systems, the analysis of contextual relationships plays a crucial role in deepening the understanding of TIS dynamics [39]. The lack of consideration of these contextual interactions is a recurring criticism of

the TIS approach [18,61]. In response to this criticism, TIS scholars have recently proposed a classification of context interaction patterns enabling a differentiated analysis of TIS influencing factors: politics, established sectors, other TISs and geographical context [62]. By proposing further analytical categories that address the context interaction domains, we aim to further narrow this gap in the literature. With its geographical focus on Argentina, this study aims to contribute to the further enhancement of the TIS framework so it can be applied more adequately outside the European context.

Guided by the question of the extent to which actors in a TIS can or cannot influence the underlying context elements, a distinction is made in the literature between two types of TIS context interactions [62]. By differentiating between "external links" and "structural couplings", attention is drawn to the varying degrees of interdependence between the elements of the TIS and the context. Structural couplings describe interactions in which TIS elements are typically embedded in several different contexts simultaneously [62]. In terms of a two-way interaction, structural couplings can lead to interdependent dynamics between a focal TIS and different context structures [18]. In this respect, developmental dynamics within the context can lead to changes in the TIS and vice versa. External links, on the other hand, describe monodirectional influences from a contextual element on the developmental dynamics of the TIS. An additional characteristic of this interaction pattern is that this influence cannot be affected by the agency of the TIS actors [62]: the performance of the TIS is influenced by shifts on the macro level, such as financial crises or changes in government.

In the course of our research, these theoretical considerations of the interaction between the context and the TIS are incorporated into the analysis which identifies the endogenous and exogenous factors that determine the performance of the TIS with respect to the key processes presented in Table 1 [61]. In order better understand the performance of the individual functions, a central focus of analysis in the TIS approach is the identification of both system strengths and weaknesses. In line with S. Jacobsson & Bergek [17], we use the concept of "system weakness" to describe endogenous and exogenous factors that have a negative impact on various functions. Inspired by the approach of Hellsmark et al. [29], another focus of investigation is the identification of "system strengths". On the one hand, we agree with the authors of that study that system strengths show what actors can individually achieve within the system [29]. On the other hand, examples such as "passive protective spaces" or the prominent role of incumbents from transition research show that exogenous factors can also positively influence the diffusion of new technologies [63,64]. Therefore, we include both endogenous and exogenous factors in our analysis of system strengths.

## 4 Methodology

The methodology applied in this study to put the TIS theory into practice is a mixed methods approach [65]. In order to create socially robust knowledge and review the validity of the results, a four stage research process (Figure 1) was used incorporating quantitative and qualitative methods. The exploratory sequential design method is one of the main strengths of this approach, as it allows first to explore a phenomenon using qualitative methods and then further analyse the exploratory variables identified by surveying a larger number of participants using a quantitative instrument [65].

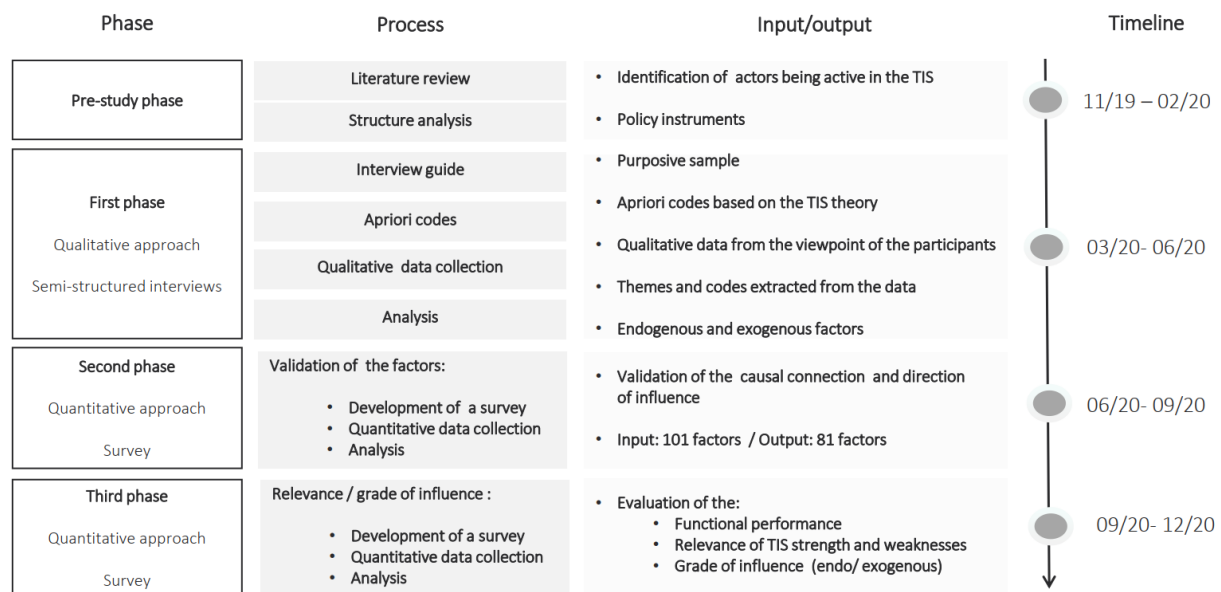


Figure 1: Schematic description of the applied methodology

The preparation phase of the investigation constituted desk research (analysis of academic and professional journals, reports, newspapers and websites) to identify the main actors, networks and institutions which shape the current configuration of the Argentinian PV TIS on both the demand and supply sides. This research included defining their scope of action (national, provincial or local level) and the sector to which they belong (public sector, science, entrepreneurial or end-user) (see Table 2). The results of this structural analysis provided the empirical database for the selection of study participants for the subsequent qualitative and quantitative research steps.

The second phase focused on the performance of individual system functions and the identification of the formative endogenous and exogenous factors. The qualitative expert interviews were used to gather specific information, as well as to incorporate a broad spectrum of different perspectives on the development of the Argentinian PV TIS. For the purpose of this research step, qualitative data was collected via 14 semi-structured research interviews between March 2020 and June 2020. This method not only enabled participants to respond to a set of standardised questions, but also created the opportunity for the conversation to encompass new ideas during the interviews. An interview guide (Annex A) was used to ensure that specific topics (functions of the TIS as well as contextual dynamics) were discussed so the results of the interviews could be compared [66]. Most interviews were face-to-face, although due to the Covid-19 pandemic some interviews were conducted by telephone or videoconference. All the interviews were carried out in Spanish and, whenever possible, were recorded and later transcribed; otherwise, notes were taken and later summarised. Building on the findings of the structural analysis, the participants in this study were carefully chosen using a purposive sampling strategy and, therefore, the results are illustrative rather than representative [67]. The objective was to consider the viewpoints of a broad spectrum of different stakeholders (manufacturers, equipment suppliers and importers, project developers, members of congress, installation companies, lecturers, research institutions, energy cooperatives and public energy companies<sup>9</sup>) involved in the development of the Argentinian PV TIS in order to identify a wide range of relevant influencing factors. These factors were further investigated in the subsequent research steps. The multi-stage process of qualitative thematic text analysis, according to Kuckartz [68], was applied to the text material that emerged from the interviews with the main actors. The focus of the thematic text analysis is the development of a category system and, as described by Gibson & Brown [69], the analysis comprises the process of inductive category development

<sup>9</sup> In Córdoba, the public energy company (EPEC - Empresa Provincial de la Energía) is in charge of distributing the energy both generated in the province and bought on the wholesale market.

(empirical codes) and deductive category application (apriori codes).<sup>10</sup> For the qualitative thematic text analysis, the computer programme MAXQDA was used to uncover phenomena hidden in the text material and to systematically analyse recurring themes. Based on the process described by Kuckartz [68], in the first coding process the text material was coded on the basis of the apriori codes previously defined. Based on the selection of excerpts identified through this procedure, in the next step the endogenous and exogenous factors were inductively identified as empirical codes that positively and negatively influence the development of the Argentinian PV TIS. The international and interdisciplinary research team (the authors of this article) paraphrased the text passages associated with each influencing factor and jointly developed a coding scheme through reflection and discussion. Due to its empirical significance, one outcome of this discussion process was that two new higher-level main categories should be added to the coding scheme to better capture the contextual interactions: “macro-economic context” and the “education system”. After successfully defining the empirical codes all the data was coded according to the elaborated category system, with the empirically developed influencing factors assigned as sub codes to their respective main category.<sup>11</sup>

*Table 2: Overview of the affiliation of the experts and stakeholders interviewed for this study*

Type of actor	Name of organisation
Cooperative	Cooperativa de Servicios Públicos y Sociales de Luque Ltda.
Company	MeschEnergíasRenovables
Company	QMAX
Company	Iris Energía
Company	ICSSA
Association	Foro Regional Eléctrico de la Provincia de Buenos Aires FREBA
Public Company	Empresa Provincial de Energía de Córdoba
Company	Hitt - Sistemas De Energía Solar
Company	ML-ingesol SA
Ministry	Ex Secretaría de Estado de la Energía de la Provincia de Santa Fe
Politics	Honorable Cámara de Diputados de la Provincia de Buenos Aires
Research & Education	Municipalidad de Pilar
Research & Education	Instituto Nacional De Tecnología Industrial
Research & Education	Observatorio de Energía y Sustentabilidad. Facultad regional de Rosario. Universidad Tecnológica Nacional

To further cross check the influencing factors derived from the interviews, the factors were validated in an intermediate step using a heterogeneous expert control group.<sup>12</sup> The survey participants were

<sup>10</sup> In this study, in accordance with the underlying theoretical framework, the following apriori codes were defined as main categories:

(a) Functions of the TIS: (1) knowledge development; (2) knowledge diffusion through networks; (3) entrepreneurial activities; (4) guidance of search; (5) market formation; (7) creation of legitimacy; (8) resource mobilisation;

(b) Contextual embeddedness: (9) interaction with relevant sectors; (10) TIS-TIS interaction; (11) interaction with the political context; (12) geographical context structures; (13) system strength; and (14) system weakness.

<sup>11</sup> Illustrative example: The empirical code “unstable value of the national currency” was assigned to the main codes “system weakness”, “macro-economic context” and “market formation”.

<sup>12</sup> Thirteen experts participated in this survey, with their stated involvement in the relevant areas as follows: research (7.69%); manufacture of components for photovoltaic systems (7.69%); politics (15.38%); supply of components for photovoltaic systems (30.77%); importation of components for photovoltaic systems (15.38%); planning of photovoltaic projects (53.85%); installation of photovoltaic systems (53.85%); after-sales service for photovoltaic systems (53.85%); advocacy or association work (23.08%); and photovoltaic system operator

able to rate the extent to which they considered the influencing factor to be present using a Likert scale. Each factor was represented by the definition established in the coding process. The result of this intermediate step was that 20 of the 101 factors were rejected by the participants of the study.

The third empirical phase, conducted by way of a structured questionnaire, aimed to assess the performance of the different functions and to determine the significance and degree of contextual embeddedness of each influencing factor. The survey is characterised by the fact that the 32 experts who participated are from different fields within the Argentinian PV TIS, thus reflecting a broad spectrum of opinions.<sup>13</sup> Consequently, this work represents one of the first attempts to empirically apply the concept of structural couplings and external links to investigate the contextual embeddedness of a PV TIS. In order to assess this quantitatively, the experts were asked to evaluate each factor according to the following two questions: 1) “To what extent can this factor be influenced by the actors of the Argentine PV sector?” (0: very low level of influence / 4: very high level of influence); and 2) “How important is this factor for the diffusion of photovoltaic systems in Argentina?” (0: very low level of importance / 4: very high level of importance). The values shown in Figures 3 and 5 are the statistical mean values of the criteria “grade of influence” and “grade of importance” of the respective factors. In addition, the participants were asked to rate the performance of the respective functions. Based on the statistical mean values, the respective functions were assigned to the following categories: weak function, intermediate function and strong function. To depict which factors influence the respective functions positively (system strength) or negatively (system weakness), Figures 2 and 4 combine the function performance with the factor attribution of the qualitative thematic text analysis.

## 5 Results

### 5.1 Functional assessment of the Argentinian PV TIS

The rating of the seven functions gives an indication of the system performance and to what degree the functions contribute to the diffusion of PV systems in the Argentinian context. The strength or weakness of a given function is caused by the interplay of a variety of factors. Each factor, as illustrated in the following subsection, can be influenced (to different extents) by the TIS actors. Therefore, the analysis requires the consideration of their contextual embeddedness. The results of this research demonstrate that even within a function that is perceived by the actors as weak, there are factors with a positive impact on the diffusion of distributed PV systems. However, overall it is clear that perceived internal deficits and contextual factors are predominant in the actors’ discourse.

As shown in Figures 2 and 4, the function with the best performance rating relates to “knowledge development” processes. The functional strength results from the R&D efforts of Argentinian companies (for example QMAX) in combination with knowledge gained from actual experiences from an increasing number of installations. The interviews highlighted that this development was accompanied by mutual learning processes involving both grid operators and PV installation companies. “Knowledge diffusion” processes are stimulated by a wide range of educational courses aimed at both technical and academic target groups. Due to a perceived lack of specialists in the PV

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(7.69%). Since participants can adopt more than one role within the PV TIS structure, multiple activity selection was possible.

<sup>13</sup> Research (34.38%); education (34.38%); manufacture of components for photovoltaic systems (6.25%); politics (18.75%); supply of components for photovoltaic systems (15.62%); importation of components for photovoltaic systems (19.75%); planning of photovoltaic projects (43.75%); installation of photovoltaic systems (46.88%); after-sales service for photovoltaic systems (18.12%); advocacy or association work (9.38%); and photovoltaic system operator (15.62%). Since participants adopt more than one role in the PV TIS structure, multiple activity selection was possible.

field, experienced players pass on their specialised knowledge in the context of self-organised courses or within the framework of offers from vocational colleges. The weak aspects of the function arise from the fact that the network of actors is regionally shaped and the exchange between groups of actors, such as entrepreneurs and researchers, is quite limited. Project developers and installation companies stated in the interviews that due to a perceived lack of unification of these groups of actors, knowledge exchange processes are rare on a national or international level. This inadequate creation of strategic networks at a global level negatively affects the functions of the intermediate strengths “guidance of search” and “creation of legitimacy”. The strategic orientation of the individual actors, as well as the representation of common interests, is hampered by the perceived non-existence of a common agenda and a development vision. The current provincial and national legislation for decentralised energy production in Argentina is perceived by stakeholders as being very supportive. However, due to incoherence in the Argentinian government’s underlying policy objectives – including energy policy – there is low confidence in the continued existence of the legal framework.

Finally, there are three rather weak system functions where the diffusion of PV systems is specifically complicated by external influencing factors: “market formation”, “resource mobilisation” and “entrepreneurial activities”. The weakness of these functions is clearly related to Argentina’s overall unstable economic situation. Despite the existence of both provincial and national market incentive programmes, the demand for PV systems is inhibited by low electricity prices resulting from government subsidies, high inflation rates, high interest rates, difficult-to-access project finance and low average purchasing power. Although the PV TIS benefits from global price reductions for PV components, Argentina’s historical import dependency, combined with scarce currency reserves and its highly volatile Peso, leads to uncertainties regarding cost and availability of components. These inhibiting factors were intensified by the profoundly negative impact of the Covid-19 pandemic on global supply chains, Argentina’s economic development and scope for entrepreneurial action.

## 5.2 Endogenous and exogenous system strength and weaknesses

In this section, we identify the strengths and weaknesses of the Argentinian PV TIS and examine how these impact specifically on its functional performance. In order to detect the most relevant dynamics, this analysis examines the perceived importance of the specific factors. The degree to which these factors may be shaped by the agency of the PV TIS actors differs from factor to factor. In order to classify the factors on the continuum between endogenous and exogenous origin, we analyse to what degree the factors can be influenced by the PV TIS actors. This provides a deeper understanding of how far the diffusion of PV systems is shaped by the specific Argentinian context. Furthermore, the level of the sphere of influence allows conclusions to be drawn about the extent to which this interaction is monodirectional (external link) or is the result of interdependent dynamics between the PV TIS and the surrounding context (structural couplings).

### 5.2.1 System strengths

Figure 2 provides an overview of how each system strength supports the performance of the seven functions. To begin with, a significant majority of the participants in this investigation identified the existing educational programmes for academics and technicians in the field of renewable energies as an important strength of the PV TIS. With regard to Argentinian universities, the broad range of courses on offer (44 undergraduate, 32 graduate and 9 PhD programmes) is rooted in the existence of long established research groups [70]. In 1978, the “Programa Nacional de Investigaciones en Energía no Convencional”<sup>14</sup> was the starting point for Argentinian research projects in photovoltaics, which developed in 1980 into the now well-known research institute INENCO of the University of Salta [71].

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<sup>14</sup> National Research Programme for Non-Conventional Energy.

A related system strength with a positive impact on the functions “knowledge diffusion” and “resource development” is the existence of technical training courses in the field of renewable energies, backed by the commitment of experienced PV TIS actors. In the year 2016, INET<sup>15</sup> established a multisector commission<sup>16</sup> to develop and define profiles for technical education in the area of renewable energies [72]. Consequently, in the year 2020, 28 courses within INET’s existing infrastructure for different levels of education<sup>17</sup> were offered in 13 of Argentina's 23 provinces. The proactive role played by the TIS actors is particularly noteworthy in light of the fact that the “insufficient availability of professionals with practical experience” was identified as a factor negatively impacting the “market formation” function. The expansion and institutionalisation of the educational portfolio for technical education is a notable example of structural couplings in which system-building actors take advantage of the related educational structures in order to contribute to the diffusion of knowledge.

Furthermore, the results of this research provide interesting insights into the market formation processes. Market formation results from an evolutionary process of the application of a technology in different types of market segments, differing in their sociotechnical configurations and characterised by specific context-dependent selection pressures. As shown in Figure 3, the market segment of rural electrification was perceived by the PV TIS actors to be of particular importance. The “high costs of grid extension” was identified as a major factor giving the decentralised PV system an economic advantage over conventional systems. Furthermore, the rural market segment was decisive for the development of the technology at the beginning of its formative phase [48]. This small, yet important, market niche stimulated the creation of a value chain and the learning processes of early adopters in terms of how to apply the technology. These early experiences were photovoltaic installations in isolated rural areas (off-grid), implemented under the PERMER framework. The main aim of the PERMER project was to guarantee a rudimentary power supply based on renewable energy sources for public institutions and private individuals who lacked access to the Argentinian electricity grid [73,74]. During the PERMER-I project (between 1999 and 2012), a total of 25,711 photovoltaic systems<sup>18</sup> were installed, supporting the formation and capacity building of Argentinian companies in the area of photovoltaic systems [15,16]. Participants in the interviews stated that the different application possibilities in the rural context (energy provision for the local population, for production and as a back-up system for grid instabilities) stimulated the R&D activities of Argentinian companies. These companies are now producing solar panels (Solartec), inverters and battery chargers (QMAX). In 2015, funding for PERMER II was approved and in the year 2019 a US\$ 54 million contract was signed with the aim of installing 120,000 solar kits<sup>19</sup> by 2022 [75].

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<sup>15</sup> Instituto Nacional de Educación Tecnológica (National Institute of Technological Education).

<sup>16</sup> Members of the commission: Instituto Argentino de Normalización y Certificación (IRAM), de la Asociación Argentina de Energía Eléctrica (AAEE), de Luz y Fuerza de la Ciudad Autónoma de Buenos Aires, del Consejo Profesional de Ingeniería Mecánica y Electricista (COPIME).

<sup>17</sup> a) a high school degree with a technical training, specialising in renewable energy: 11 courses in 8 different provinces (Ciudad de Buenos Aires, Buenos Aires, Misiones, Neuquén, Rio Negro and San Juan); b) technical training in renewable energy: 5 courses in 5 different provinces (Catamarca, Mendoza, Neuquén, Santa Cruz and Tucumán); and c) system installer training for the use of solar energy: 12 courses in 2 different provinces (Ciudad de Buenos Aires and Buenos Aires).

<sup>18</sup> 23,456 for households and 2,255 for public buildings.

<sup>19</sup> These kits include: a 30W solar panel, three LED lightbulbs, a 7 amp battery, 2 rechargeable torches, a radio and a cell phone charger.

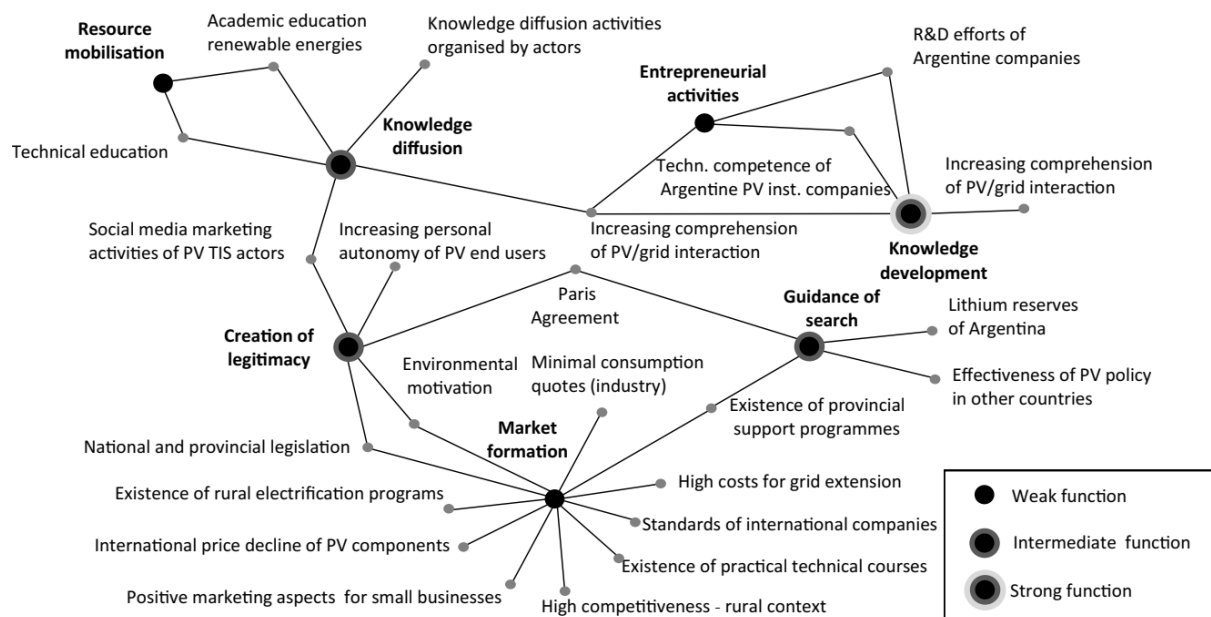


Figure 2: Influence of system strengths on the performance of the functions

In rural areas and small towns, energy cooperatives are playing a strategic role in energy provision [76]. Electricity cooperatives had been established in the 1920s as a means of addressing the lack of access to electricity in small towns and rural areas. At the outset, these used to generate and distribute electricity to their members; following their connection to the National Interconnected System in the 1960s, they only retained responsibility for energy distribution. In the 1990s, some cooperatives in the Buenos Aires and Chubut provinces attempted to regain their role in energy generation by installing wind turbines [77]. Currently, in the early 21<sup>st</sup> century, numerous cooperatives (particularly in the provinces of Buenos Aires, Córdoba and Santa Fe) are still important actors in the energy sector and are developing plans to return to generation activity through implementing renewable energy projects. During the course of this research, numerous examples were found where energy cooperatives were involved in distributed photovoltaic projects. Two of the most important projects are located in the villages of Armstrong (Santa Fe) and Luque (Cordoba). The former started in 2013 as a collaborative initiative when the electric cooperative of Armstrong<sup>20</sup>, the INTI<sup>21</sup> and the UTN<sup>22</sup> formed the project “Proyecto de Redes Inteligentes con Energías Renovables”.<sup>23</sup> From a technical perspective, one of the main aims was to introduce smart metering technology and to gain experience in photovoltaic generation. The project was recognised nationwide for the active participation of the local population, fostered by local workshops where members of the community offered their rooftop spaces for the installation of 50 PV systems. Additionally, a 200 kW<sub>p</sub> PV plant was installed in the industrial area. The energy generated feeds into the local grid and the community benefits from more stable power provision and has grown their experience in the technology. In contrast, the local cooperative in Luque<sup>24</sup> is following a different strategy: it is inviting the local population to make a small investment into the construction of a new PV plant, as a follow-up project to a previously installed 25 kW<sub>p</sub> system. This variation in approach is in line with the perception of Bergek et al. [62], who point out that “... territories often host distinctive cultural communities with specific institutional arrangements that guide cooperation, competition and/or innovation”

<sup>20</sup> Cooperativa de Provisión de Obras y Servicios Públicos Limitada de Armstrong (Cooperative of Armstrong for the Provision of Public Works and Services).

<sup>21</sup> Instituto Nacional de Tecnología Industrial (National Institute of Industrial Technology).

<sup>22</sup> Universidad Tecnológica Nacional (National Technological University).

<sup>23</sup> Smart Grid and Renewable Energy Project.

<sup>24</sup> Cooperativa de Servicios Públicos y Sociales de Luque (Cooperative of Public and Social Services of Luque).

As shown in Figure 2, the existence of “provincial support programmes” has clearly strengthened the “market formation” and “guidance of search” functions. This result is not surprising as, against the backdrop of a lack of national legislation, eight provinces<sup>25</sup> introduced their own regulatory systems in the 2010s for energy exchange between users and electricity distributors. Stimulated by regulatory frameworks for state promotion, mini solar plants have begun to proliferate in small towns, as have domestic photovoltaic installations for self-consumption. The possibility of feeding surplus energy into the low or medium voltage network has created a new market segment for the diffusion of photovoltaic systems. The Santa Fe case stands out as the first to approve a regulation allowing users connected to a distribution network to generate and feed their own energy into the grid (Resolution N° 442/2013). This regulation came into force in 2016 under the incentive programme Prosumidores, which is based on a feed-in tariff aimed at facilitating the repayment of renewable equipment. As a result, by the end of 2019, residents in Santa Fe (including homes, businesses and SMEs<sup>26</sup>) reached 1MW of installed capacity.

The interviewees highlighted that the increasing number of on-grid installations in the pioneer provinces promoted co-evolutionary development processes between installers and grid operators. This strengthened the “knowledge development” and “knowledge diffusion” functions. The mutual development of competencies, the establishment of approval processes and institutional efforts to establish technical norms are examples of how “structural couplings” arise from interdependent development processes between the PV TIS and the complementary infrastructure. In this context, another important contribution to the “increasing comprehension of the interaction between decentralised photovoltaic systems and grid stability” was the IRESUD<sup>27</sup> research project. In 2012, a public-private consortium (comprising the National Atomic Energy Commission (CNEA), the National University of San Martín (UNSAM) and five private companies) was formed to gain technical experience and develop regulations for grid-connected installations of decentralised photovoltaic systems in urban areas [78]. By the end of the project in 2016, 55 PV systems had been installed covering most provinces of the country and involving more than 34 private and public organisations. This stimulated the emergence of new knowledge exchange networks [78,79].

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<sup>25</sup> Santa Fe Res. EPE 442/10/2013, Salta Ley 7824/14 Res. 1315/14, Mendoza Ley 7549/2006 Res. EPRE 019/2015, San Luis Ley IX-0921-2014, Neuquén Ley 9412/2016, Misiones Ley XVI-N°118, Tucumán P.L. 93/ 2016 and Rio Negro Res. EPE /2017.

<sup>26</sup> Small and medium-sized enterprises

<sup>27</sup> Proyecto De Interconexión De Sistemas Fotovoltaicos A La Red Eléctrica En Ambientes Urbanos (Project for the Interconnection of Photovoltaic Systems to the Electricity Grid in Urban Environments).

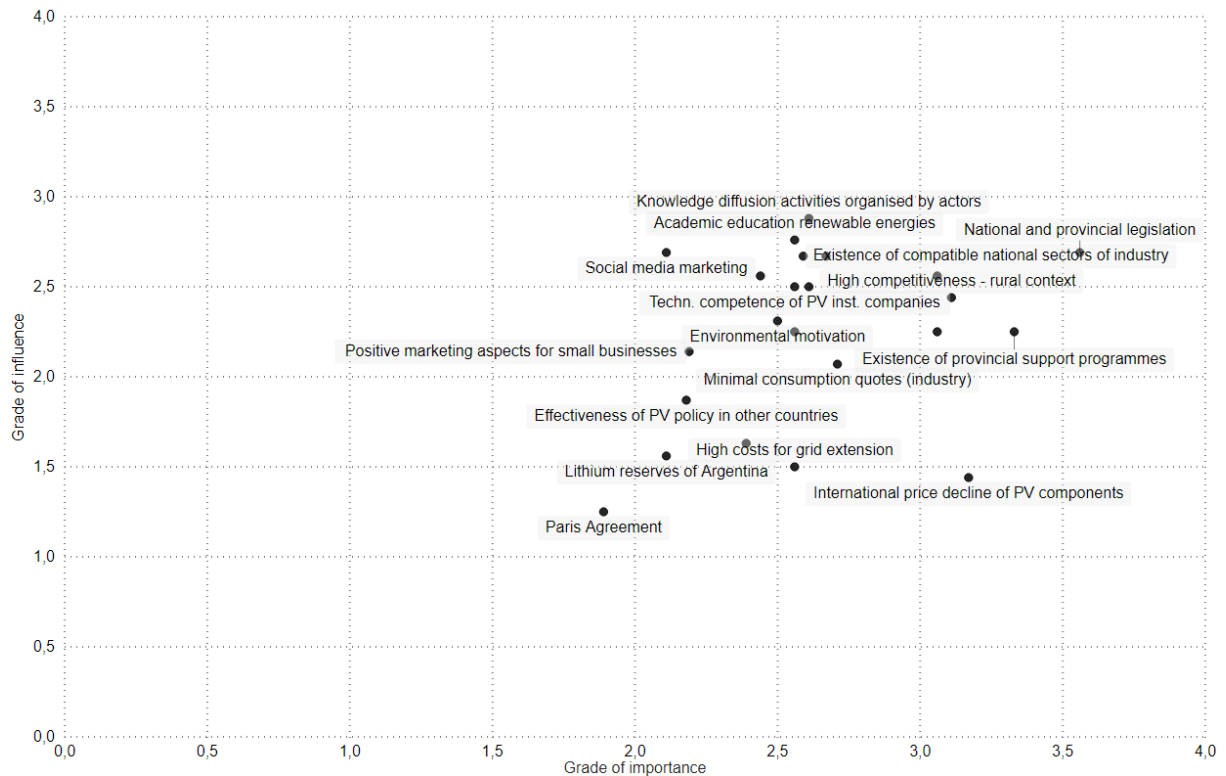


Figure 3: The grade of relevance and structural embeddedness of system strength<sup>28</sup>

A significant milestone identified by the participants in this study was the enactment, in 2017, of Law 27,424 (Regulatory Decree 986 of 2018) for the promotion of distributed generation from renewable sources. This national law establishes the legal and contractual conditions for residential users of the network to generate their own energy for self-consumption and to feed the surplus into the network, creating the “user-generator”. The strengthening of the “market formation” and “creation of legitimacy” functions results from the creation of a unified national legal framework which – for the first time – uniformly regulates the rights and roles of market participants (system installers, grid operators, etc.). As discussed by Coria et al. [80], investments in residential PV systems in Argentina are currently not economically viable based on Net Present Value. The results of this research provide evidence that the environmental awareness of the consumer plays an important role in terms of investment. Moreover, it highlights that the expectation of positive marketing effects is one of the main drivers for SMEs to invest in photovoltaic systems. As such, it can be argued that the cultural shift in parts of Argentinian society towards greater environmental awareness is having a positive impact on the “creation of legitimacy” and “market formation” functions. A further recent market niche resulting from greater global concerns for the environment is the installation of PV systems at sites owned/operated by internationally active companies that have to fulfil internal environmental regulations or the requirements of strategic business partners. Additionally, some interviewees mentioned that another application field has developed as a result of Law 27,191 of 2015. This law mandates that large electricity users (those with an annual average demand greater than 300 kW) must meet 14% (rising to 20% in 2025) of their energy consumption with energy from renewable sources or face fines [81]. To that end, large consumers can choose whether to invest in their own energy generation through decentralised renewable energies, purchase the necessary percentage of renewable energy directly from private generators (from the Renewable Energy Term Market, MATER) or buy the electricity on the wholesale energy market.

<sup>28</sup> Horizontal axis: 0 = very low level of importance / 4 = very high level of importance; vertical axis: 0 = very low level of influence / 4 = very high level of influence.

## 5.2.2 System weaknesses

As shown in Figures 4 and 5, the “market formation”, “resource mobilisation”, “entrepreneurial activities” and “guidance of the search” functions are mainly negatively impacted by factors beyond the influence of the PV TIS actors. In this context, it is interesting to note that some of the important systemic weaknesses are attributed to factors specific to Argentina, which generally affect the diffusion of innovations in the national context.

An exogenous system weakness perceived as being significant by the participants is Argentina’s overall unstable economic context, which negatively influences the “guidance of search”, “entrepreneurial activities” and “market development” functions. In this context, the interplay between three factors was identified as crucial: the substantial decline of the value of the Peso led to higher inflation rates<sup>29</sup>, which in turn resulted in decreasing purchasing power [82]. Between December 2017 (17.723 Argentine Peso/USD) and December 2020 (88.182 Argentine Peso/USD) the Argentine Peso lost a fifth of its value against the US Dollar. However, the revenues from the PV system are paid in Argentine Peso and relate to the relatively stable subsidised electricity price. Moreover, the interviewees outlined that the total investment costs of a PV system are strongly influenced by exchange rate developments because the components are – to a large extent – imported.

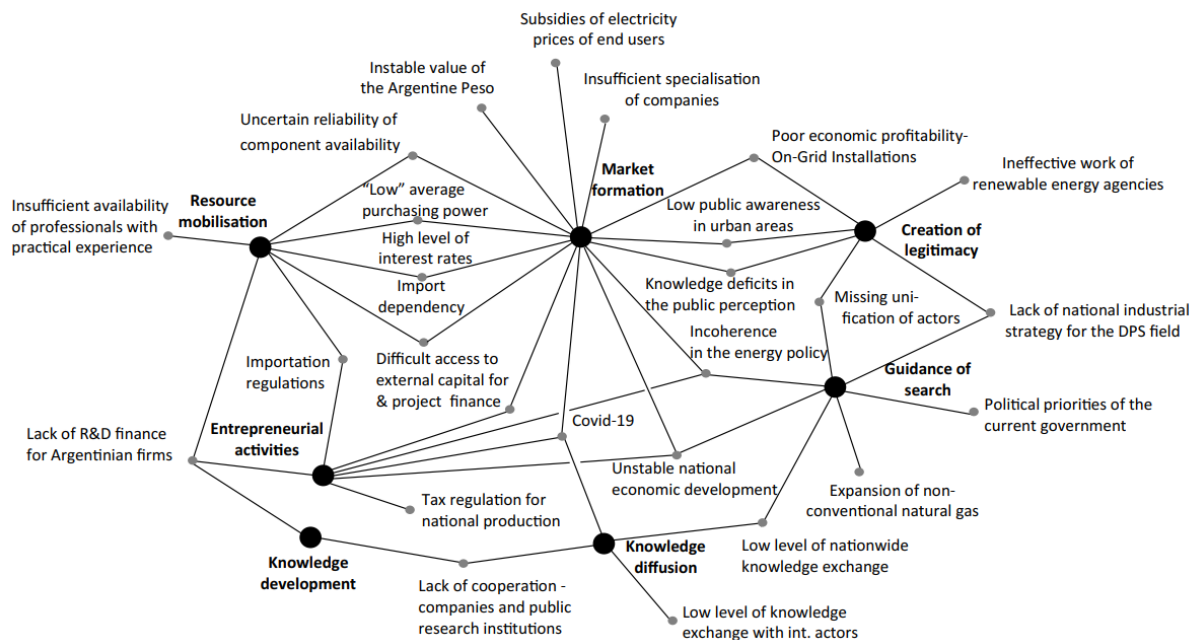


Figure 4: Influence of system weaknesses on the performance of the different functions

The conditions of the Argentinian capital market were identified as another important exogenous factor that negatively impacts on the “entrepreneurial activities” and “market development” functions. High interest rates<sup>30</sup> and difficult-to-access credit were cited as central barriers. The Fund for the Distributed Generation of Renewable Energies (FODIS), as established by Law 27,424 to provide accessible credit, has not yet been implemented. Consequently, corporate investments in R&D measures and project financing for small decentralised PV projects are mostly equity capital-driven, which has negative repercussions on the development dynamics of the Argentinian PV TIS. Moreover, the unstable economic scenario creates investment uncertainties for end-users and entrepreneurs, which limits the performance of the “entrepreneurial activities” and “guidance of

<sup>29</sup> 2017: 25 %; 2018: 48 %; 2019: 54 % (Ministerio de Economía, 2020).

<sup>30</sup> The National Bank’s general interest rate was 38% in 2020 (Gillespie, 2020).

search” functions. As outlined by the OECD [83], the existing macro-economic imbalances have been negatively reinforced by the Covid-19 pandemic.

Another relevant factor that increases uncertainties for users and entrepreneurs is incoherent energy policy as a result of changes in government at provincial and national level. This perceived political instability is a decisive factor that lies outside the sphere of influence of the actors. The low level of confidence in the continuity of the energy policy framework makes it difficult for PV TIS actors to make long-term strategic decisions. The uncertainties associated with the political instability have a negative impact on the “guidance of search”, “market development” and “entrepreneurial activities” functions. A recent case from 2020 is the regulation passed in the province of Santa Fe, which has so far not been incorporated in the national Law 27,424 for distributed generation. Following a change in the provincial government in 2019, the incentives offered under the “Prosumidores” programme – which had shaped the diffusion of PV systems in this province for seven years – were modified (Decree 1098 of 2020), causing disadvantages for existing user-generators and discouraging others from entering the system.

The survey and interview participants alike highlighted the issue of high subsidies for retail electricity in Argentina. Following the 2001 economic crisis, the Argentinian state intervened in the energy market and began subsidising the generation of electricity in order to maintain energy prices at a low level [84]. As a consequence, this policy led to a steadily increasing discrepancy between retail electricity prices and generation costs [85]. Figures published by the Argentinian Energy Institute (IAE) in 2020 show that the average electricity price paid by end customers covered only 54% of the electricity generation costs [86]. However, the national Law 27,424 for distributed generation is based on the net-billing concept, where the profitability of the system is influenced by the share of self-consumption. Therefore, the artificial reduction of the retail electricity price through subsidies has a strong negative impact on the profitability of the PV system and, consequently, on the “market formation” function.

One unanticipated finding was that the “expansion of non-conventional production capacity for gas” was perceived by the actors as one of the least important system weaknesses. Natural gas has historically played a critical role in Argentinian electricity production. It has been supported by the energy policy of the last 30 years, which has promoted the installation of thermal generation capacities. For many years, Argentina’s fossil fuel consumption could be met from national reserves. In the year 2010, after a period of falling natural gas extraction rates, the fossil reserves could no longer meet the national energy demand and Argentina went from being a “Net-Gas-Exporter” to a “Net-Gas-Importer” [87,88]. As a result, in order to regain energy self-sufficiency, the exploitation of unconventional hydrocarbons in the Vaca Muerta basin was advocated by the Argentinian government.

The supply chain for PV components plays an important role in the performance of the “resource mobilisation” and “market formation” functions. A commonly expressed view in the interviews was the positive effect of the international price decline of PV modules. However, the low level of perceived influence can be attributed to the fact that these developments have taken place on an international level: what Binz & Truffer [89] describe as the global level of the TIS. With regard to on-grid installations, the share of national production has so far been limited to the components of metallic structures. In this regard, the PV TIS should benefit from the historically strong metallurgical industry in Argentina. However, against the background of high dependence on international components for PV systems, further entrepreneurial uncertainty arises from import regulations; over the last decade these have been subject to significant modifications due to political change.

Furthermore, the factors shown in Figure 5 illustrate that PV TIS endogenous deficits exist on various dimensions relating to the aggregation of local practices within a global emerging field. The factors “lack of unification of actors”, “lack of national industrial strategy for the decentralised photovoltaic systems field”, “low level of knowledge exchange between actors on a national / international level”

and “lack of cooperation between companies and public research institutions” indicate that actor networks tend to be regional and are characterised by an insufficient heterogeneous constellation of actors. Although an Argentinian Association for Renewable Energies does exist, some interview participants pointed out that they do not identify themselves with the association as they do not feel represented by it. On the one hand, this obstructs the exchange of knowledge at national and international level and the related harmonisation of expectations and perceptions of sectoral problems, which particularly affects the performance of the “guidance of search” function. Another factor pointing to poor coordination in the PV TIS structure is the stakeholders’ perception that the lack of a common national sectoral PV strategy is negatively affecting the advancement of the technology. The associated negative effects on the “guidance of search” function are apparent in the interviewees’ perceptions of the “insufficient specialisation of companies in the supply chain” and “lack of cooperation between companies and public research institutions”.

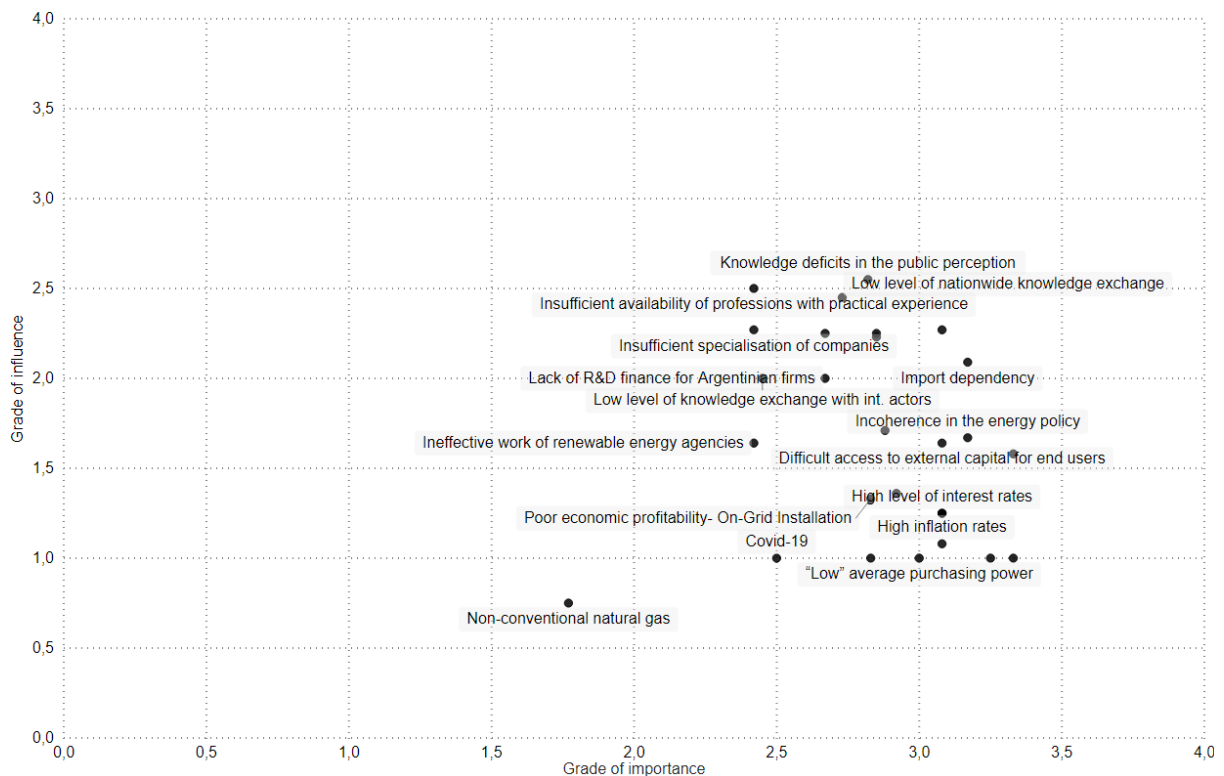


Figure 5: The grade of relevance and structural embeddedness of system weaknesses<sup>31</sup>

The final system weakness relates to a lack of general awareness of the technology among the Argentinian population and the related negative effects on the “creation of legitimacy” function. Due to their low diffusion rate in Argentina, PV systems are not yet part of the population’s everyday reality and, in this context, many of the interview participants remarked that there is generally a lack of knowledge regarding the application and potential of PV systems among the Argentinian population.

## 6 Discussion

This research aimed to provide insights into the development and diffusion of decentralised photovoltaic systems in Argentina using the Technical Innovation System approach. This study aimed to answer the following research question: “How do the functional dynamics and the related endogenous/exogenous system strengths and weaknesses influence the diffusion of decentralised

<sup>31</sup> Horizontal axis: 0 = very low level of importance / 4 = very high level of importance; vertical axis: 0 = very low level of influence / 4 = very high level of influence.

photovoltaic systems in Argentina?”. The main objective was to understand which functions are strong/weak and how endogenous/ exogenous system strengths and weaknesses influence the performance of the different functions.

The results provide evidence of the existence of a variety of market segments in Argentina with significantly different selection environments. The study identified a broad span of application fields which differ widely in their usage context and actor constellation and, therefore, constitute individual market segments. In isolated rural areas, off-grid PV systems provide a wide range of energy services (the off-grid segment) while, in small towns, distributed PV plants contribute to grid stability and security of supply (the on-grid segment). In urban areas, domestic PV systems (although not yet widespread) increasingly appeal to users who want to gain autonomy over their energy supply and reduce their environmental impact.

An interesting finding is that the different market segments identified can be classified within different stages of development of the TIS lifecycle (normally the TIS is classified in only one phase). The off-grid rural segment was decisive for technological development. This small (in terms of installed capacity) but nevertheless important market niche stimulated the formation of a value chain and fuelled the learning process of pioneers in PV technology installation. In terms of the on-grid segment<sup>32</sup>, although the installed capacity is higher the gained experience is lower. This can be attributed to the introduction of the national support programme for distributed generation in April 2019 and the resulting limited number of installations (only 389) by February 2021. Based on the classification of Markard [48], we come to the conclusion that the off-grid rural segment has the longest trajectory and is in a mature phase. The on-grid segment, on the other hand, is still in a formative phase. In this phase there are few actors and entry rates are low, there is a high level of uncertainty, networks are non-existent or incipient, and technology performance is low, with a high degree of variation [48].

While studying the functional performance of the TIS, specifically in the analysis of the qualitative interviews, the authors found it challenging to assess whether a factor was endogenous or exogenous and to what degree it was shaped by the agency of actors or the surrounding context. Based on the idea of structural couplings and external links referring to different degrees of interdependence, the authors of this study decided to empirically determine whether a factor was affected by the actors [62]. This is based on the understanding that factors can be placed on a continuum with endogenous and exogenous at either end and where the degree of influence of the TIS actors determines the proximity to the endogenous endpoint. Thus, the analysis presented in this study contributes to a more nuanced understanding of the interdependencies of the TIS and the context.

Regarding the external links, the authors found a discrepancy with Edsall's [58] landscape factors. We agree with Edsall that the context is important. However, the results of this research show that the ex-ante determination of landscape factors for developing countries is quite vague. For example, the “armed conflict”, “unequal access to education” and “national corruption” factors were not mentioned by the actors interviewed in this research. As every country is highly individual, we are convinced that an inductive research approach is more appropriate for uncovering country-specific factors. The bottom-up methodology used to carry out this research proved appropriate and allowed for the identification of important contextual factors. We consider it to be one of the main strengths of the study.

In this context, the authors also considered the general categories of “geographical context, political context, TIS-TIS context, relevant sectors” as proposed by Bergek et al. [62] as a helpful heuristic for analysing the contextual embeddedness of the TIS. In terms of the political context, the research has

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<sup>32</sup> On-grid installation for private households, business and industry, as well as small PV plants up to 500 kW and 2 MW.

shown that Argentina's political instabilities hamper the institutional alignment processes. The political instabilities result in incoherence in political projects and agreements. This phenomenon is not restricted to the renewable energy sector; it is characteristic of the Argentinian political system. In recent years, changes in government administrations in Argentina have been accompanied by changes in the fundamental strategic direction of the state (market or state, free market policies or protectionism, to name just a couple of examples). The results of this study have shown how this political instability is increasing entrepreneurial and end-user uncertainties and how this, in turn, impacts negatively on various functions of the TIS. Long-term policies that endure over several administrations are needed to provide certainty, clear and reliable regulations, and to encourage the development of the TIS. Another factor hampering the institutional alignment process in Argentina is the insufficiently developed aggregation of local practices by PV TIS actors to a global emerging field. The lack of robust networks at national level not only impacts negatively on internal sectoral dynamics (such as knowledge exchange and coordination of activities) but also lowers the impact (lobbyism) on the institutional context through structural couplings.

In terms of the general category relevant sectors, the interactions with the Argentinian power sector are strongly intertwined with the political context. Although support programmes for decentralised renewable energy exist at both the provincial and national levels, the high levels of subsidisation of electricity retail prices negatively affects the competitive position of decentralised photovoltaic systems. In comparison to the global situation, the possibility to feed excess energy generated from PV systems into the grid in Argentina was only approved at national level relatively recently. Consequently, participants in this study rated interactions with distribution network operators as important. This is a good example of how new institutional frameworks and processes can emerge from structural couplings on the basis of joint competence development. A surprising empirical result is that the "expansion of unconventional gas production" was perceived by the participants as one of the least important system weaknesses. This indicates that PV TIS stakeholders do not consider gas as a competing resource, but rather as a bridge technology towards renewable energies (as it is relatively cleaner than other conventional energy sources).

Regarding the TIS-TIS interaction, positive reinforcing interactions were observed, especially in the off-grid market segment. An example of vertical integration of other TISs are battery systems, which are an integral part of photovoltaic systems in the rural context against a background of fluctuating energy generation. The world's largest deposits of lithium can be found in salt deposits in the desert between Chile, Argentina and Bolivia [1,90]. A study conducted by Obaya et al. [91] demonstrated that the development of battery production in Argentina is still at an early stage due to a lack of capability to produce lithium-ion batteries competitively and the absence of a non-conductive normative framework. Another example in the rural context for the horizontal integration of related TISs is the combination of small wind turbines with photovoltaic systems in the form of hybrid systems that supply several households via a mini grid [92,93]. Furthermore, in the rural context, PV systems are widely used in combination with solar thermal equipment for water heating and cooking, particularly in the North West region (Salta and Jujuy) [90]. There is also evidence of interaction with the electric mobility TIS in the case of the solar car prototype, "Pampa Solar", developed by the School of Engineering at the University of the Centre of Buenos Aires Province (UNICEN), and the development of a "solar bicycle" with associated charging stations by Eco Andina Foundation in the province of Jujuy.

Finally, in terms of TIS development in geographical context structures, we concur with Bergek et al. [62] that "TIS actors, networks and institutions will typically be embedded in structures that pre-exist in a specific territory". In Argentina, pre-existing structures (chambers of commerce, energy cooperatives, state research and technological institutions (e.g., INTI)) act as a canvas on which the PV TIS can develop and expand. Energy cooperatives, for instance, have been key actors<sup>33</sup> in the

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<sup>33</sup>In Argentina, cooperatives are important actors in rural areas and small cities as they are also active in other social services such as internet connectivity, telephone and water provision, and funeral services.

energy system for almost a century. This implies that energy users have a shared history and an acquired experience of energy involvement, which shapes their relationship to energy.

Another important issue highlighted by Bergek et al. [62] is multi-scalarity. On an international scale, global issues affect Argentina's domestic political decisions. The Paris Agreement, for example, prompted new targets for renewable energy in the generation mix. The state of development of the international PV market is also significant: as the cost of the technology falls, imported PV equipment gains a competitive advantage over national production. This, in turn, increases the tendency to rely on imported goods; in a context of fluctuating exchange rates, this has negative impacts. On a national scale, Argentina is a federal country and its provinces retain jurisdiction over energy issues. This has practical implications: for a law to be binding in a province it must be accepted by the provincial chamber but, equally, a province may encourage or discourage a certain technology or activity. On a local scale, some provincial governments are more active than others and take the initiative to promote PV systems through local legislation. Consequently, this affects network formation and the sharing of knowledge on a national scale. Another geographical element to consider is the vast size of the country and the fact that the PV resource is not homogenous. Some areas have greater potential for other renewables such as wind power. The significant expansion of PV technology also affects the degree of unification of the actors. The authors of this article have recognised that the PV sector in Argentina cannot be understood on just one scale; a multi-scale approach is necessary. A multi-scale territorial perspective implies considering the territory as a totality where a variety of strategies, meanings, decisions and actions (taken by social actors located on different temporal and spatial scales) are articulated and implemented. For this reason, particular attention was given to selecting interview candidates encompassing actors from national, provincial and local backgrounds.

Based on the research results, we propose expanding Bergek et al.'s heuristic [62] with the addition of two further general categories: the "macro-economic context" and the "education system". The former is particularly important in the Argentinian scenario as the economy and, in general, the market regulations are highly unstable. This is reflected by high inflation rates, which negatively impact purchasing power, as prices for PV equipment and associated products escalate quickly. Related to this, the fluctuation of the exchange rate also has a strong influence on the cost of PV systems (as equipment is mainly imported) and on the profit margins of implemented projects. The lack of a PV national industry reinforces the dependency on imported technology, creating a "block in" as referred to by Bersalli [94]. In addition, limited access to financing and poor finance conditions deter investment. Regarding the second proposed category, the educational system has a strong influence on the "knowledge development" and "knowledge diffusion" functions. In Argentina, a wide range of academic options are available to qualify a workforce for implementing PV projects. State universities, where high quality education is free, play a major role. The pre-existing infrastructure of INET made it possible to establish a broad selection of technical training courses in a short period of time. Without question, the PV energy experts who pass on their knowledge in these courses play a central role but, without the existing educational materials and institutional infrastructure, the development of a comparable offer would have taken much longer.

The selected research strategy is one of the main strengths of the present study, as it specifically takes the opinions of the actors involved in the sector into account. However, from a self-critical standpoint, this research strategy should also be recognised as the study's main limitation. The key scientific value of qualitative research results depends to a great extent on a heterogeneous and representative sample of interview participants. Therefore, one of the main limitations of the purposive sampling strategy is the risk that a relevant actor group is omitted from the research sample. To avoid this as far as possible, particular attention was paid to selecting interview participants from a wide range of contexts and professions: academia, government, private companies, entrepreneurs and end-users.

## 7 Conclusions

This study analysed the endogenous and exogenous dynamics that currently hinder or support the diffusion of decentralised photovoltaic systems in Argentina. It goes beyond a classic function analysis and adopts a research approach that makes it possible to include the contextual influencing factors in the system analyses within the TIS framework. Within this theoretical field, this study is one of the first attempts to apply an exploratory mixed methods approach to the TIS analysis. The first qualitative research step allowed theory to be used as a guiding heuristic while providing the capability to synthesise expert knowledge in a bottom-up process, and thereby opened the possibility to further develop the referential framework through the discovery of new cause-effect relationships. Moreover, this paper is one of the first attempts to empirically employ [62] the proposed concept of structural couplings and external links to study the contextual embeddedness of the PV TIS. To this end, a subsequent quantitative research approach was used which provided the possibility to empirically determine to what extent a factor can be influenced by the actors, and the significance of the factor for the diffusion of decentralised photovoltaic systems. Based on the results, we propose expanding Bergek et al.'s heuristic [62] with the addition of two further general categories: the “macro-economic context” and the “education system”. This study, therefore, contributes to the growing body of research that aims to develop a deeper understanding of the interdependencies of the TIS and the context.

By applying the TIS framework, this study found that although decentralised photovoltaic systems account for a minor share of the Argentinian electric mix, a span of market segments have emerged that are in different developmental stages due to distinct trajectories. Moreover, the study identified the main system strengths and weaknesses that impact on the diffusion of photovoltaic systems in Argentina. The empirical results indicate that the system strengths relate to both the TIS itself (knowledge development in pilot projects and market formation through provincial and national support programmes) and to contextual relationships (the importance of existing technical educational institutions for the rapid diffusion of knowledge, and the importance of rural areas as “protected spaces” for the application of photovoltaic systems). In terms of the system weaknesses, an interesting finding was that the diffusion dynamics are – to a great extent – hindered by the overall contextual dynamics. The insights gained from this study may help to develop a deeper understanding of the diffusion dynamics of renewable energies in the context of developing countries. The example of Argentina illustrates how problems within a country, such as political instability or macro-economic uncertainties caused by high inflation rates and loss in value of the national currency, hamper the breakthrough of sustainable energy generation technologies. In this respect, the incorporation of the analytical dimensions of the National Innovation framework into the contextual TIS analysis could provide valuable guidance for future research. Additionally, although not explicitly analysed in this research as such, opportunities and threats to the diffusion of photovoltaic systems could be an angle for further studies. Particularly for the purpose of providing relevant findings to decision-makers in the field, it would be beneficial to further develop the idea of system strengths and weaknesses and incorporate them in a SWOT analysis, a well-known concept among practitioners. Opportunities include a widely dispersed population not connected to the grid, as well as the ongoing development of regulations to enable distributed generation. Furthermore, the fact that younger populations are increasingly aware of the risks of climate change implies that they are open to adopting clean technologies. Nevertheless, against the backdrop of economic and political instability, threats include Argentina's dependence on imported equipment and essential components for photovoltaic installation due to an embryonic national industry in the sector.

Further research should be undertaken to investigate development pathways from a centralised to a decentralised power system, and to describe possible strategies and measures. In this respect, the deeper understanding of the interrelationships between different actors (private and public) and how their actions are coordinated (or not) could represent a further line of research. Other studies could focus on the consumers themselves, as the last actors of the value chain, in order to acquire

knowledge about their perceptions and needs. Moreover, it would be of scientific value to further assess the exploratory factors identified in this research through quantitative research with a larger sample size. The Analytic Hierarchy Process (AHP) technique, for example, could provide valuable guidance in this regard, as this method allows elements to be classified in a hierarchy through a process of pairwise comparisons and priorities. By applying the AHP technique, future studies could further analyse the relevance of the specific system strengths and weaknesses.

The analysis in this paper leads to the conclusion that future legislation should demonstrate greater consideration of Argentina's specific underlying micro-economic and macro-economic conditions. Public policy should take into account the diversity of actors participating in the Argentinian energy sector, their interests and resources. In order to become established, the emerging PV TIS in Argentina requires long-term regulations and legal compliance from both state and private actors. Distributed photovoltaic systems in Argentina, as an emerging market, have significant development potentials that could result in greater capabilities and opportunities for growth.

## Appendix A. Interview questionnaire

1. How suitable do you think is the Argentine power grid for the expansion of distributed photovoltaic energy?
2. What are the different market segments and target groups for distributed photovoltaic energy? How would you estimate the stage of market development and the market potential? Which factors create a competitive advantage for distributed photovoltaic energy?
3. How would you characterise the public perception of distributed photovoltaic energy and which arguments dominate the public discourse? What is done to address these arguments?
4. What are your expectations regarding the development and diffusion of distributed photovoltaic energy in Argentina? Do you think that a shared vision exists between the actors working in the area of distributed photovoltaic energy systems?
5. What regulative aspects are hindering and supporting the development of distributed photovoltaic energy in the different market segments and what has to be done to overcome these barriers?
6. How is the overall political context of Argentina impacting the development of the photovoltaic market for distributed-generation and which role does distributed photovoltaic energy play in the energy strategy of the country?
7. Which types of perceived uncertainties influence entrepreneurial activities? To what extent have entrepreneurial activities contributed to the gaining of experiences and lowering of entrepreneurial uncertainties?
8. How do you evaluate the access to resources that are of strategic value for the actors? Which kinds of resources represent a limiting factor for the diffusion of distributed photovoltaic systems?
9. In which knowledge fields regarding the development, diffusion and utilization of distributed photovoltaic energy most progress has been achieved? Which knowledge areas require the most need of improvement?
10. How do you evaluate the knowledge exchange between science, industry and operators of the distributed photovoltaic energy systems? Does knowledge exchange also take place on an international level?
11. Suppose a new company decides to develop and market distributed photovoltaic energy systems in Argentina. What generally accessible resources, structures and regulations this company can draw on? Which areas are still insufficiently developed?
12. How do regional initiatives influence the development of the distributed photovoltaic energy sector?
13. How are international development dynamics of the photovoltaic sector impacting the developments in Argentina?
14. Are there any factors which are important for the development and diffusion of distributed photovoltaic energy which were not mentioned during this interview?
15. What are in your opinion the five most important drivers and barriers for the development and diffusion of distributed photovoltaic energy in Argentina. Please rate the importance of the factor from 1 to 5.

## References

- [1] M.A. Ise, S.C. Carrizo, M. Forget, Challenges of South American energy transition: energy efficiency and distributed generation, in: L.B.T.-T.R. and P. of L.A.E.T. Noura Guimarães (Ed.), Elsevier, 2020: pp. 133–151. doi:<https://doi.org/10.1016/B978-0-12-819521-5.00008-5>.
- [2] J.A. Martinez Buitrago, E. Venancio Camillo, R. Pedace, Solar PV diffusion in Argentina: policy implications for a high penetration scenario until 2030, *Qual. Rev. Eletrônica*. (2016). doi:10.18391/req.v17i2.3078.
- [3] L. Nascimento, M.-J. Kurdziel, H. Fekete, M. Hagemann, G. de Vivero, Decreasing costs of renewables-Implications for Argentina's climate targets, (2020).
- [4] D. Gomel, K.S. Rogge, Mere deployment of renewables or industry formation, too? Exploring the role of advocacy communities for the Argentinean energy policy mix, *Environ. Innov. Soc. Transitions*. (2020). doi:10.1016/j.eist.2020.02.003.
- [5] M.S. Villalba, Hidrocarburos no convencionales en la Argentina del siglo XXI, Universidad Nacional de La Plata, 2020.
- [6] M. Recalde, The different paths for renewable energies in Latin American Countries: enabling environments and the instruments., *Energy Environ.* (2015). <https://doi.org/10.1002/wene.190>.
- [7] L. Clementi, A. Ise, J.L. Berdolini, M. Yuln, S. Villalba, S. Carrizo, El mapa de la transición energética argentina, *An. Geogr. La Univ. Complut.* 39 (2019) 231–254. doi:10.5209/aguc.66938.
- [8] G. Fenés, Un repaso por los problemas que tiene Argentina para atraer inversiones en energías renovables - Energía Estratégica - Información en Movimiento, (2015). <http://www.energiaestrategica.com/las-inversiones-en-energias-renovables-que-no-fueron/> (accessed March 31, 2015).
- [9] H. Mattio, F. Tilca, Recomendaciones para mediciones de velocidad y dirección de viento con fines de generación eléctrica, y medición de potencia eléctrica generada por aerogeneradores, CREE, INENCO, Minist. Planif. Fed. Inversión Pública y Serv. Secr. Energía La Nación. (2009).
- [10] Secretaría de Energía, Energías Renovables: Diagnóstico, barreras y propuestas, (2009).
- [11] H. Rossi Gallegos, R. Righini, Atlas de energía solar de la República Argentina, 2007.
- [12] N. di Sbroiavacca, J. Falzon, CLIMACAP- Climate and Energy Policy reviews for Colombia, Brazil, Argentina, and Mexico, CLIMACAP. (2014).
- [13] S. Budzinski, M.A. Barlatey, Argentina - Biogas, yet another challenge, *Biogas J.* (2014).
- [14] CAMMESA, Informe mensual - Enero 2021, 2021. [https://www.cammesa.com/archcount.nsf/LinkCounter?OpenAgent&X=InformeMensual\\*ENERO\\*2021&L=/linfomen.nsf/WInforme+Mensual/EC1E3B83976B353E0325867F0072099A/\\$File/Informe Mensual\\_2021-01.pdf](https://www.cammesa.com/archcount.nsf/LinkCounter?OpenAgent&X=InformeMensual*ENERO*2021&L=/linfomen.nsf/WInforme+Mensual/EC1E3B83976B353E0325867F0072099A/$File/Informe%20Mensual_2021-01.pdf).
- [15] World Bank, Renewable energy for rural areas, (2015). [http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/2015/03/19/000477144\\_20150319092309/Rendered/PDF/PAD8340PAD0P13010Box385454B00OUO090.pdf](http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/2015/03/19/000477144_20150319092309/Rendered/PDF/PAD8340PAD0P13010Box385454B00OUO090.pdf) (accessed March 30, 2015).

- [16] World Bank Group, Argentina - Renewable Energy in the Rural Market Project (English), Washington, D.C., 2013. <http://documents.worldbank.org/curated/en/341091468212377656/Argentina-Renewable-Energy-in-the-Rural-Market-Project>.
- [17] S. Jacobsson, A. Bergek, Innovation system analyses and sustainability transitions: Contributions and suggestions for research, *Environ. Innov. Soc. Transitions*. (2011). doi:10.1016/j.eist.2011.04.006.
- [18] T. Mäkitie, A.D. Andersen, J. Hanson, H.E. Normann, T.M. Thune, Established sectors expediting clean technology industries? The Norwegian oil and gas sector's influence on offshore wind power, *J. Clean. Prod.* (2018). doi:10.1016/j.jclepro.2017.12.209.
- [19] J. Markard, R. Raven, B. Truffer, Sustainability transitions: An emerging field of research and its prospects, *Res. Policy*. 41 (2012) 955–967. doi:10.1016/j.respol.2012.02.013.
- [20] K.Y. Kebede, T. Mitsufuji, Technological innovation system building for diffusion of renewable energy technology: A case of solar PV systems in Ethiopia, *Technol. Forecast. Soc. Change*. (2017). doi:10.1016/j.techfore.2016.08.018.
- [21] A. van der Loos, H.E. Normann, J. Hanson, M.P. Hekkert, The co-evolution of innovation systems and context: Offshore wind in Norway and the Netherlands, *Renew. Sustain. Energy Rev.* (2021). doi:10.1016/j.rser.2020.110513.
- [22] N. Bento, M. Fontes, The construction of a new technological innovation system in a follower country: Wind energy in Portugal, *Technol. Forecast. Soc. Change*. (2015). doi:10.1016/j.techfore.2015.06.037.
- [23] S. Jacobsson, K. Karltorp, Mechanisms blocking the dynamics of the European offshore wind energy innovation system - Challenges for policy intervention, *Energy Policy*. (2013). doi:10.1016/j.enpol.2013.08.077.
- [24] U. Dewald, B. Truffer, Market formation in technological innovation systems-diffusion of photovoltaic applications in Germany, *Ind. Innov.* (2011). doi:10.1080/13662716.2011.561028.
- [25] V. Vasseur, L.M. Kamp, S.O. Negro, A comparative analysis of Photovoltaic Technological Innovation Systems including international dimensions: The cases of Japan and the Netherlands, in: *J. Clean. Prod.*, 2013. doi:10.1016/j.jclepro.2013.01.017.
- [26] U. Dewald, M. Fromhold-Eisebith, Trajectories of sustainability transitions in scale-transcending innovation systems: The case of photovoltaics, *Environ. Innov. Soc. Transitions*. (2015). doi:10.1016/j.eist.2014.12.004.
- [27] S.O. Negro, M.P. Hekkert, Explaining the success of emerging technologies by innovation system functioning: The case of biomass digestion in Germany, *Technol. Anal. Strateg. Manag.* (2008). doi:10.1080/09537320802141437.
- [28] J. Markard, M. Stadelmann, B. Truffer, Prospective analysis of technological innovation systems: Identifying technological and organizational development options for biogas in Switzerland, *Res. Policy*. (2009). doi:10.1016/j.respol.2009.01.013.
- [29] H. Hellsmark, J. Mossberg, P. Söderholm, J. Frishammar, Innovation system strengths and weaknesses in progressing sustainable technology: The case of Swedish biorefinery development, in: *J. Clean. Prod.*, 2016. doi:10.1016/j.jclepro.2016.04.109.
- [30] T. Nevzorova, E. Karakaya, Explaining the drivers of technological innovation systems: The case of biogas technologies in mature markets, *J. Clean. Prod.* (2020).

doi:10.1016/j.jclepro.2020.120819.

- [31] N. Hacking, P. Pearson, M. Eames, Mapping innovation and diffusion of hydrogen fuel cell technologies: Evidence from the UK's hydrogen fuel cell technological innovation system, 1954–2012, *Int. J. Hydrogen Energy*. (2019). doi:10.1016/j.ijhydene.2019.09.137.
- [32] H. Bach, A. Bergek, Ø. Bjørgum, T. Hansen, A. Kenzhegaliyeva, M. Steen, Implementing maritime battery-electric and hydrogen solutions: A technological innovation systems analysis, *Transp. Res. Part D Transp. Environ.* (2020). doi:10.1016/j.trd.2020.102492.
- [33] K.P. Andreasen, B.K. Sovacool, Hydrogen technological innovation systems in practice: Comparing Danish and American approaches to fuel cell development, *J. Clean. Prod.* (2015). doi:10.1016/j.jclepro.2015.01.056.
- [34] B. Decourt, Weaknesses and drivers for power-to-X diffusion in Europe. Insights from technological innovation system analysis, *Int. J. Hydrogen Energy*. (2019). doi:10.1016/j.ijhydene.2019.05.149.
- [35] A. Kieft, R. Harmsen, M.P. Hekkert, Heat pumps in the existing Dutch housing stock: An assessment of its Technological Innovation System, *Sustain. Energy Technol. Assessments*. (2021). doi:10.1016/j.seta.2021.101064.
- [36] D.J.C. Hawkey, District heating in the UK: A Technological Innovation Systems analysis, *Environ. Innov. Soc. Transitions*. (2012). doi:10.1016/j.eist.2012.10.005.
- [37] H.E. Edsland, Identifying barriers to wind energy diffusion in Colombia: A function analysis of the technological innovation system and the wider context, *Technol. Soc.* (2017). doi:10.1016/j.techsoc.2017.01.002.
- [38] M. Esmailzadeh, S. Noori, H. Nouralizadeh, M.L.A.M. Bogers, Investigating macro factors affecting the technological innovation system (TIS): A case study of Iran's photovoltaic TIS, *Energy Strateg. Rev.* (2020). doi:10.1016/j.esr.2020.100577.
- [39] L.G.S. De Oliveira, S.O. Negro, Contextual structures and interaction dynamics in the Brazilian Biogas Innovation System, *Renew. Sustain. Energy Rev.* (2019). doi:10.1016/j.rser.2019.02.030.
- [40] V.S. Russo, El Proyecto de Energías Renovables en Mercados Rurales (PERMER), *Petrotecnica, Rev. Del Inst. Argentino Petróleo y Gas*. (2009).
- [41] Ministerio de Ambiente y Desarrollo Sustentable, Inventario Nacional de Gases de Efecto Invernadero 2019, 2019. [https://www.argentina.gob.ar/sites/default/files/inventario\\_de\\_gei\\_de\\_2019\\_de\\_la\\_republica\\_argentina.pdf](https://www.argentina.gob.ar/sites/default/files/inventario_de_gei_de_2019_de_la_republica_argentina.pdf).
- [42] L. Clementi, A. Ise, J.L. Berdolini, M. Yuln, S. Villalba, S. Carrizo, El mapa de la transición energética argentina, in: *An. Geogr. La Univ. Complut., XII Congreso de Ingeniería Industrial*, 2019: pp. 20–26.
- [43] P. Schaubé, W. Ortiz, M. Recalde, Status and future dynamics of decentralised renewable energy niche building processes in Argentina, *Energy Res. Soc. Sci.* (2018). doi:10.1016/j.erss.2017.10.037.
- [44] Secretaría de Energía, Generación Distribuida en Argentina. Reporte de avance. Marzo 2021., 2021. [https://www.argentina.gob.ar/sites/default/files/reporte\\_de\\_avance\\_mar\\_2021\\_1.pdf](https://www.argentina.gob.ar/sites/default/files/reporte_de_avance_mar_2021_1.pdf).
- [45] B. Carlsson, R. Stankiewicz, On the nature, function and composition of technological systems, *J. Evol. Econ.* (1991). doi:10.1007/BF01224915.

- [46] R.R. Nelson, S.G. Winter, *An Evolutionary Theory of Change*, 1982.
- [47] A. Schout, D.C. North, *Institutions, Institutional Change and Economic Performance.*, Econ. J. (1991). doi:10.2307/2234910.
- [48] J. Markard, *The life cycle of technological innovation systems*, Technol. Forecast. Soc. Change. (2018). doi:10.1016/j.techfore.2018.07.045.
- [49] J. Markard, H. Worch, *Technological innovation systems and the resource based view - Resources at the firm , network and system level 1 Introduction*, DIME Work. Environmnetal Innov. Ind. Dyn. Entrep. (2009).
- [50] A.J. Wiecek, M.P. Hekkert, *Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars*, Sci. Public Policy. (2012). doi:10.1093/scipol/scr008.
- [51] J. Markard, B. Truffer, *Technological innovation systems and the multi-level perspective: Towards an integrated framework*, Res. Policy. 37 (2008) 596–615.
- [52] T. Jacobsson, S. Jacobsson, *Conceptual confusion - an analysis of the meaning of concepts in technological innovation systems and sociological functionalism*, Technol. Anal. Strateg. Manag. (2014). doi:10.1080/09537325.2014.900171.
- [53] A. Bergek, *Technological innovation systems: a review of recent findings and suggestions for future research*, in: Handb. Sustain. Innov., Edward Elgar Publishing, 2019: pp. 200–218. doi:DOI:
- [54] R.A.A. Suurs, M.P. Hekkert, *Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands*, Technol. Forecast. Soc. Change. (2009). doi:10.1016/j.techfore.2009.03.002.
- [55] R.A.A. Suurs, M.P. Hekkert, S. Kieboom, R.E.H.M. Smits, *Understanding the formative stage of technological innovation system development: The case of natural gas as an automotive fuel*, Energy Policy. (2010). doi:10.1016/j.enpol.2009.09.032.
- [56] R.A.A. Suurs, *Motors of sustainable innovation: Towards a theory on the dynamics of technological innovation systems (PhD thesis)*, 2009.
- [57] M.P. Hekkert, R.A.A. Suurs, S.O. Negro, S. Kuhlmann, R.E.H.M. Smits, *Functions of innovation systems: A new approach for analysing technological change*, Technol. Forecast. Soc. Change. (2007). doi:10.1016/j.techfore.2006.03.002.
- [58] H.E. Edsands, *Technological innovation system and the wider context: A framework for developing countries*, Technol. Soc. (2019). doi:10.1016/j.techsoc.2019.101150.
- [59] A.D. Tigabu, F. Berkhout, P. van Beukering, *Functional evolution and accumulation of technological innovation systems: The case of renewable energy in East Africa*, Sci. Public Policy. 42 (2015) 614–631.
- [60] M. Esmailzadeh, S. Noori, A. Aliahmadi, H. Nouralizadeh, M. Bogers, *A functional analysis of technological innovation systems in developing countries: An evaluation of Iran's photovoltaic innovation system*, Sustain. (2020). doi:10.3390/su12052049.
- [61] J. Markard, M. Hekkert, S. Jacobsson, *The technological innovation systems framework: Response to six criticisms*, in: Environ. Innov. Soc. Transitions, 2015. doi:10.1016/j.eist.2015.07.006.
- [62] A. Bergek, M. Hekkert, S. Jacobsson, J. Markard, B. Sandén, B. Truffer, *Technological innovation systems in contexts: Conceptualizing contextual structures and interaction*

- dynamics, in: Environ. Innov. Soc. Transitions, 2015. doi:10.1016/j.eist.2015.07.003.
- [63] A. Smith, R. Raven, What is protective space? Reconsidering niches in transitions to sustainability, Res. Policy. (2012). doi:10.1016/j.respol.2011.12.012.
  - [64] B.K. Sovacool, B. Turnheim, M. Martiskainen, D. Brown, P. Kivimaa, Guides or gatekeepers? Incumbent-oriented transition intermediaries in a low-carbon era, Energy Res. Soc. Sci. (2020). doi:10.1016/j.erss.2020.101490.
  - [65] J.W. Creswell, V.L. Plano Clark, Designing and Conducting Mixed Methods Research, 2017.
  - [66] D.J. Flinders, InterViews: An introduction to qualitative research interviewing: Steinar Kvale. Thousand Oaks, CA: Sage Publications, 1996, Eval. Program Plann. 20 (1997) 287–288. doi:10.1016/S0149-7189(97)89858-8.
  - [67] Laerd, Purposive sampling, (2015). <http://dissertation.laerd.com/purposive-sampling.php> (accessed June 8, 2015).
  - [68] U. Kuckartz, Qualitative Text Analysis: A Guide to Methods, Practice & Using Software, 2014. doi:10.4135/9781446288719.
  - [69] W.J. Gibson, A. Brown, Working with Qualitative Data, Sage, 2009.
  - [70] Cámara Argentina de Energías Renovables, Carreras y posgrados de energías renovables en Argentina, (2021). <https://www.cader.org.ar/carreras-y-posgrados-de-energias-renovables-en-argentina/> (accessed January 2, 2021).
  - [71] O. Ramírez, M. Fernández, J. Camblong, La energía solar fotovoltaica, aplicaciones de las innovaciones tecnológicas en Argentina, la legislación relacionada y sus perspectivas futuras, 2019.
  - [72] INET, « Comisión Técnica de Energía Eléctrica y Energías Renovables en el INET », (2016) <http://www.inet.edu.ar/index.php/comision-tecnica->.
  - [73] S. Best, Remote access: Expanding energy provision in rural Argentina through public-private partnerships and renewable energy. A case study of the PERMER programme, 2011.
  - [74] Durand, Argentina PERMER: The Argentine Off-grid Electrification Concessionaire EJSDSA, (2012) 0–4.
  - [75] L. Spinelli, Disclosable Restructuring Paper - Argentina Renewable Energy for Rural Areas Project - P133288 (English)., 2020. <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/759081603983964392/disclosable-restructuring-paper-argentina-renewable-energy-for-rural-areas-project-p133288>.
  - [76] L.V. Clementi, G. Jacinto, A.G. Nogar, Generación eléctrica distribuida: nuevas fuentes, actores e interacciones, in: Desarro. Reg. En Sudamérica Investig. y Aportes Multidiscip., A 1a ed., Asociación de Universidades Grupo Montevideo. Editorial de la Universidad Nacional del Sur.(Ediuns, 2019: pp. 243–262.
  - [77] L. Clementi, Energía eólica y territorios en Argentina. Proyectos en el Sur de la Provincia de Buenos Aires entre fines del siglo XX y principios del siglo XXI., Universidad Nacional del Sur. Bahía Blanca. Argentina (PhD thesis), 2018.
  - [78] M.E. Videla, I.H. Eyra, J.C. Durán, MONITOREO PARA SISTEMAS FOTOVOLTAICOS CONECTADOS A LA RED DE DISTRIBUCIÓN ELÉCTRICA DE BAJA TENSIÓN MONITORING OF PHOTOVOLTAIC SYSTEMS CONNECTED TO THE LOW VOLTAGE ELECTRICAL DISTRIBUTION NETWORK, 2018.

- [79] I. Eyra, J.C. Durán, F. Parisi, R. Eyra, M. Álvarez, Proyecto IRESUD: Primeros ejemplos de Energía Solar Fotovoltaica Integrada a la Arquitectura (BIPV) en el país, in: XXXIX Reun. Trab. La Asoc. Argentina Energías Renov. y Medio Ambient. (ASADES)(La Plata, 2016), 2016.
- [80] G. Coria, F. Penizzotto, R. Pringles, Economic analysis of photovoltaic projects: The Argentinian renewable generation policy for residential sectors, *Renew. Energy*. (2019). doi:10.1016/j.renene.2018.08.098.
- [81] Ministerio de Energía y Minería, Resolución 281-E/2017 Régimen del Mercado a Término de Energía Eléctrica de Fuente Renovable, (2017). <https://www.boletinoficial.gob.ar/detalleAviso/primera/169410/20170822> (accessed January 3, 2021).
- [82] M. Llanos, J. Maia, Argentina 2019: Broken Economy, Strengthened Democracy, *GIGA*. 6 (2019). <https://nbn-resolving.org/urn:nbn:de:0168-ssar-65370-7>.
- [83] OECD, OECD Economic Outlook, Volume 2020 Issue 1, 2020. <https://www.oecd.org/economic-outlook/>.
- [84] J. Haselip, C. Potter, Post-neoliberal electricity market 're-reforms' in Argentina: Diverging from market prescriptions?, *Energy Policy*. 38 (2010) 1168–1176. doi:10.1016/j.enpol.2009.11.007.
- [85] C.G. Di Bella, L.D. Norton, J. Ntamatungiro, S. Ogawa, I. Samaké, M. Santoro, Energy Subsidies in Latin America and the Caribbean: Stocktaking and Policy Challenges, (2015).
- [86] Julián Rojo, Informe de Tendencias Energéticas: Diciembre de 2020, Buenos Aires, 2020. <https://www.iae.org.ar/wp-content/uploads/2021/01/Informe-de-tendencias-IAE-Mosconi.-Dic-2020.pdf>.
- [87] M. Vagliasindi, Implementing Energy Subsidy Reforms: Evidence from Developing Countries, World Bank Publications, 2012.
- [88] J.C. Villalonga, Energías Renovables ¿ Por qué debería ser prioritario cumplir el objetivo del 8% al 2016?, 2013. [http://awsassets.wwfar.panda.org/downloads/energias\\_renovables\\_14\\_vf.pdf](http://awsassets.wwfar.panda.org/downloads/energias_renovables_14_vf.pdf).
- [89] C. Binz, B. Truffer, Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts, *Res. Policy*. (2017). doi:10.1016/j.respol.2017.05.012.
- [90] S.C. Carrizo, A. Ise, L. Clementi, S. Villalba, M. Forget, Transición energética en Argentina: Caleidoscopio de proyectos y transformaciones territoriales, in: XXI Jornadas Geogr. La UNLP 9 Al 11 Oct. 2019 Ensenada, Argentina. Construyendo Una Geogr. Crítica y Transform. En Def. La Cienc. y La Univ. Pública, Universidad Nacional de La Plata. Facultad de Humanidades y Ciencias de la ..., 2019.
- [91] M. Obaya, A. López, P. Pasquini, Curb your enthusiasm. Challenges to the development of lithium-based linkages in Argentina, *Resour. Policy*. (2020). doi:10.1016/j.resourpol.2020.101912.
- [92] S. Belmonte, J. Franco, S. Garrido, Experiencias de energías renovables argentina. Una mirada desde el territorio., 1a ed., Salta: Universidad Nacional de Salta. EUNSa, 2017.
- [93] J. Roberts, S. Thibaud, P. Prado, Proyecto De Un Sistema Híbrido De Generación Con Energías Renovables Para Un Establecimiento Rural Aislado, 2015.
- [94] G. Bersalli, El bloqueo tecnológico en el sector eléctrico argentino: Barreras a la difusión de las nuevas energías renovables, 2016.

- [95] Ateera, Cobertura Geográfica de las empresas de transporte de energía eléctricas y de las transportistas independientes nucleadas en ATEERA, 2021.  
<http://www.ateera.org.ar/mapas.php>.