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Status and future dynamics of decentralised renewable energy niche building processes in Argentina

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ABSTRACT

Despite significant natural potential for renewable energy in Argentina and the political intention to generate 8% of electricity from renewable sources by 2017, by 2016 the share was only 1.95%. Although this aggregated picture appears unfavourable, several diverse initiatives promoting the development and application of decentralised renewable energy technologies are in place across the country. The aim of this study is to characterise those initiatives promoting decentralised renewable energy and to assess their potential role in inducing the wider transformation of the Argentinian energy system. To achieve this, we apply conceptualisations for the development of sociotechnical niches and use qualitative research techniques to characterise the sociotechnical dynamics of the decentralised renewable energy sector in Argentina. A niche in an advanced stage of development, in which lessons are systematically aggregated in networks, was identified and examples of generic lessons being used to frame new projects or programmes were also found. In addition to considering the internal niche development processes, we investigate how external factors affect the development of the niche. Finally, we suggest two possible development pathways by which the niche might exert stronger influence on the broader sustainability transformation of the Argentinian power system.

1. Introduction

Over the last ten years, Argentina's fossil fuel-based power system has faced many pressures. The current situation is characterised by a continual increase in electricity demand (3 GWh p.a. between 2005 and 2015, representing 140% over the period), an unreliable power supply, heavy dependence on fossil fuels and the rapid decrease in Argentina's domestic conventional natural gas reserves [1,2]. Fostering the transition towards higher shares of renewable energy in the Argentinian energy system offers a wide range of development prospects for the country. The opportunities arise from actions aimed at reducing dependence on fossil fuels imports, improving the reliability of the power supply, strengthening the existing innovative industrial sectors and ensuring access to reliable power services for around 1.1 million people living in rural areas without access to the national power infrastructure.

Despite significant natural potential for renewable energy and stated political aims to generate 8% of the country's electricity from renewable sources by 2017, the current rate is just 1.95% [3]. Most of the initiatives carried out to date have related to centralised power grids. Although the overall picture seems to be a negative one, different initiatives promoting the development and application of decentralised renewable energy technologies[1] do exist in Argentina (in the private, public and civil society spheres) – and some of these have been in operation for decades. However, it can be hypothesised that this seemingly contradictory picture at a less aggregated level may reflect the struggle faced by emerging sociotechnical niches in renewable energy technologies to stabilise and grow within an environment dominated by firmly established energy regimes based on the use of fossil fuels.

The aim of the study is to characterise the current development status of the decentralised renewable energy sector in Argentina and to assess its potential role in inducing a larger transformation of the Argentinian energy system. To achieve this, we conceptualise the diverse initiatives promoting the development and application of decentralised renewable energy technologies in Argentina as an emerging

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[1] In this study, decentralised power systems are understood as technical configurations where power generation capacities are located close to the served loads. Decentralised power systems can be completely autonomous, i.e. not connected to other power systems (as in the case of so-called off-grid power systems). They can also be interconnected to other and larger power infrastructure [54].

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sociotechnical niche and ask: "What are the internal niche dynamics and the context-related factors that have been hindering or supporting the development of the decentralised renewable energy niche in Argentina?" We apply concepts from Strategic Niche Management (SNM) and the Multi-Level Perspective on sociotechnical transitions (MLP). We use these concepts to analyse the socio-technical configurations and the internal processes by which the presumed niche develops, and to assess how external contextual factors and interactions influence the niche development. Moreover, the study seeks to gain insights into ways in which the niche can further develop and induce the broader deployment of decentralised renewable energy technologies in Argentina. Thereby this article aims to contribute to the growing field of research about energy futures [4].

The article is structured as follows. Section 2 provides a general overview of the current status of the Argentinian power system and the development of renewable energies in the Argentinian context over recent decades. Section 3 sets out the theoretical framework and introduces the concepts of sociotechnical niches and transitions. In Section 4, the methods of data collection and the research strategy are presented. Section 5 presents the results from the analysis of the niche-internal processes which have led to the current diffusion of decentralised renewable energy systems in Argentina and describes the contextual factors that are hindering or supporting the development of the niche. Section 6 discusses the results of our analysis and the implications for future research. Finally, the conclusions are summarised in Section 7.

2. The Argentinian power system and renewable energies

Over recent decades, Argentina has become highly dependent on hydrocarbons. According to the Ministry of Energy and Mines, hydrocarbons accounted for 87% of total primary energy sources in 2015. The electricity sector is highly dependent on the use of fossil fuel. By December 2016, 61% of total installed power generation capacity was from conventional thermal power plants, 32% from large hydro plants, 5% from nuclear plants and 2% from New and Renewable Energy Sources (NRES). The energy demand is distributed relatively evenly between the three main sectors: transport (29%), household (26%) and industry (23%); however, the mix of energy resources consumed by these sectors is quite different. Despite the fact that Argentina has one of the highest proportions of electricity coverage of all the Latin American countries (directly related to its urbanisation rate), 1.1 million people in rural areas nevertheless lack access to grid electricity and rely on conventional energy sources such as firewood, kerosene, batteries or generators [5]. Since mid-2004, the Argentinian energy sector has shown signs of supply problems directly related to the lack of availability of natural gas, which is Argentina's key energy source. The root cause seems to lie in strategies implemented after the liberalisation process in the early 1990s and in public policy up to 2016 concerning energy prices and tariffs. As natural gas plays a critical role in Argentinian electricity production, its lack of availability has resulted in electricity shutdowns, scheduled interruptions to natural gas consumption for industry and an increase in energy imports − all of which have had significant macroeconomic impacts.

In terms of its potential for renewable energies, Argentina is second only to Brazil in the Latin American region [1]. Argentina's energy potential includes huge wind capacity [6,7], favourable conditions for both large and small-scale solar projects [8], hydropower [9] and a significant volume of biofuels [10]. Argentina's wind potential merits a special mention; the average wind speed across 70% of the country is 6 m/s [7]. With wind speeds of between 9 m/s and 12m/s, Patagonia is particularly well suited to harnessing wind power. In the coastal regions and in the region of Buenos Aires, which is the main centre of electricity consumption, average wind speed is also higher than 6.5 m/s [11]. Despite these conditions, as previously mentioned the actual installed renewable capacity in Argentina falls well short of the potential. According to CAMMESA, in August 2016 NRES (predominantly wind and PV) accounted for less than 1% of public power capacity on the wholesale market.

Despite this limited development of renewable energies in the Argentinian power system, Argentina was one of the first countries in Latin America to develop policies and programmes to promote the diversification of the energy matrix. This originated in the mid-1970s and early 1980s, following a global trend in increased energy prices after the first oil crisis. In the power sector, the first regulations came into force with Law 25,019 (adopted in 1998 and covering wind power production). This was replaced by Law 26,190 (in 2006) and subsequently by Law 27,191 (in 2015). In terms of promotional instruments, Laws 25,019 and 26,190 established a scheme of Feed in Premiums (FIPs) for each technology in conjunction with different tax incentives for a 15-year period. Additionally, for the first time in Argentina, Law 26,190 set a target for NRES: 8% of electricity demand should be met by renewable energies by 2016. This regulation also created a fund called Fondo Fiduciario de Energías Renovables [2]. However, none of the instruments introduced by these two regulations were successful. FIPs from Law 26,190 were criticised for two main reasons: they were set at low levels and based on wholesale market prices which were frozen after the 2001 currency devaluation; and they were based on the Argentinian Peso. After years of slow but continuous devaluation of the national currency these FIPs became outdated [1]. The profitability and the incentive to invest in renewables fell, resulting in NRES attracting no investment.

To overcome these problems, in 2009 the government put out its first public tender for the purchase of 1000 MW of renewable energy (under the Program of Generation of Electric Power from Renewable Sources (GENREN)), which consisted of long-term purchase agreements nominated in US dollars, calculated at a fixed price project by project and adopting a Feed in Tariff (FIT) scheme. Despite the high levels of interest initially shown by private actors, most of the capacity contracted by GENREN was not used. Some of the problems faced by this programme related to Argentina's macroeconomic, political and institutional context, rather than to the design of the instruments [1]. These aspects resulted in significantly higher prices for the Argentinian contracts than for similar agreements in the rest of Latin America, as well as a low usage rate (less than 20% by the end of 2015), which may have been due to a lack of funding and low national and international confidence in the development of an Argentinian power sector [1,2,9].

At the end of 2015, the government sanctioned Law 27,191, which replaced Law 26,190 and introduced some important changes. Firstly, the deadline for achieving the 8% target was moved to December 2017 (instead of 2016) and a new target of 20% by 2025 was established. This regulation also modified the definition of NRES for the purposes of the promotional incentives to include wave energy, solar energy and biofuels, and extended the capacity definition of small hydro to 50 MW.

More recently, in mid-2016, the government introduced a new purchase scheme: the Program for the Purchase of Electric Power from Sources of Renewable Energy (RenovAr Program). Although it is too early to evaluate the success of this initiative, preliminary results show that the price per unit of electricity in the concluded contracts was significantly lower than under the GENREN programme and there appears to be significant levels of interest from the private sector in the development of an Argentinian NRES market. By mid-2017, 59 projects had been approved under the RenovAr 1 and 1.5, amounting to 2423 MW of installed capacity (nearly 8371 GWh p.a.). Most of this capacity (71%) will come from wind power and PV will account for 26%, with only 3% coming from small hydro, biomass and biogas. On the downside, the programme is criticised for the lack of national capital and industries involved in the contracts, as well as for its failure to include small projects.

Most of the NRES regulations in Argentina have concentrated on centralised power generation capacity. However, in 1999, under the umbrella of the PAEPRA initiative, the Renewable Energies for Rural

Markets Program (PERMER) was initiated by the Argentinian government. 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 lacking access to the Argentinian electricity grid. The project succeeded in providing more than 100,000 rural residents with access to electricity. In total, 29,980 systems with a capacity of 8.15 MW and an average generation of 19.79 GWh p.a. were installed [12]. The project is designed as a public-private partnership, in which the public sector is responsible for most of the project funding and subsidises the electricity price for the end users, while the operation and maintenance of the systems is financed by private enterprises [13]. Case studies carried out on the PERMER project highlight the positive impacts of electrification on the livelihoods of the beneficiaries [13–15].

A diverse set of initiatives have been promoting the development and implementation of decentralised renewable energy in Argentina. Some of these have resulted in commercial ventures in different technological fields. In recent years, a local small wind turbine industry has developed in Argentina, consisting of 16 manufacturers offering systems with a capacity of between 150 W and 10 kW [16]. In order to support these domestic manufacturers, in 2010 the Argentinian research institute INTI (Instituto Nacional de Tecnología Industrial) initiated a programme consisting of a platform for the exchange of experiences between the manufacturers, combined with scientifically supervised and evaluated testing and certification of the systems (Parque Tecnológico de Cutral-Có) [17]. Other prominent examples of commercial developments in the decentralised renewable energy sector can be found in the field of autonomous off-grid systems [13]. Intermediary organisations, which aim to articulate and represent common interests and challenges faced by the sector within different arenas, have also been established. Some prominent examples are the Argentine Chamber of Renewable Energy, the Argentine Wind Energy Association and the association of renewable energy installers. Moreover, the development of decentralised renewable energy is accompanied by a broad spectrum of interdisciplinary academic research. Examples in the technical field include the University of La Plata, which has developed a small wind turbine, and the National University of San Martin (UNSAM) in cooperation with the National Atomic Energy Commission (CNEA) under the IRESUD project, which is developing regulations to facilitate grid-connected installations of decentralised photovoltaic panels [18,19]. Another focus of national academic research is the sociotechnical user context. Worthy of mention in this respect are the National Agricultural Technology Institute (INTA), which develops and promotes applications of renewable energy technologies in agriculture, and the National University of Quilmes, which is analysing renewable energy initiatives promoting sustainable local development dynamics and social inclusion [20,21].

3. Theoretical framework

Two conceptual frameworks are applied in this study: the Multi-Level Perspective on sociotechnical transitions (MLP) and the Strategic Niche Management approach (SNM). These two frameworks enable the analysis of the current status of the decentralised renewable energy sector in Argentina and the evaluation of its potential role in a larger transition towards a national power system with a high share of renewable energies.

3.1. Multi-Level Perspective on sociotechnical transitions (MLP)

The Multi-Level Perspective builds on theories from evolutionary economics and technology studies. It conceptualises the transition of a sociotechnical system as a process shaped by dynamic interplay on three levels: niches, regimes and landscapes. The regime is a dominant sociotechnical configuration which embodies the mainstream way of providing societal functions (such as the provision of energy, water, food and mobility) and contains its basic logic of functioning [22]. Linkages between interrelated heterogeneous elements lead to the continual reproduction of a dynamic social structure, which has an auto-stabilising effect on the regime and only leaves space for incremental innovation. In contrast, radical innovations challenging the established regime structures arise at the niche level, and these are defined as the “protected spaces that allow the experimentation with the co-evolution of technology, user practices and regulatory structures” [23]. Niches and regimes are embedded in a broader landscape – the macro-level exogenous context – which shapes the overall developments and is difficult for individuals or groups of actors to influence [24]. A sociotechnical transition is understood as a shift from one regime to another, including not only physical changes in infrastructure or organisation, but also leading to a redefinition of norms and values [25]. Consequently, this approach unites bottom-up and top-down dynamics, which interrelate in the different phases of a transition process. On the one hand, through processes of niche-accumulation, radical innovations can break out from the niche to the regime level, “when ongoing processes at the levels of the regime and landscape create a ‘window of opportunity’” [26]. On the other hand, regulation, cognitive and normative rules, sunk-investments in artefacts, stability of existing infrastructure and interdependency between actors and material networks provide stabilisation mechanisms to incumbent regimes and hinder the development of innovative alternatives [23]. Therefore, sociotechnical regimes also serve as selection and retention mechanisms, guaranteeing the stability of sociotechnical configurations − which can lead to path-dependency, i.e. to systemic resistance to change [27].

3.2. Strategic Niche Management (SNM)

The progress of sociotechnical niches is conceptualised as a cyclical pattern of learning and networking in which cognitive rules are consolidated [23]. As shown in Fig. 1, the process can be understood as taking place on two levels: local and global [28]. The local level consists of individual projects, where actors experiment with innovative ways of responding to local problems and demands. A global niche level emerges when the technology is applied in multiple on-the-ground local projects which are linked together by networks and intermediary actors [29]. The development of the global niche implies the comparison and aggregation of lessons learned from individual projects (experiments), which may “gradually become more articulated, specific and stable” [23]. In this way, generic rules emerge that can be applied to the design of projects replicating successfully proven components or practices. The influence of the niche further increases as these cognitive rules become more generic (i.e. applicable to different contexts) and more broadly adopted (i.e. taken up by an increasing number and variety of actors) [30].

The subject matter in these cyclical learning processes is important. The standard literature differentiates between first and second-order learning. First-order learning is “instrumental learning, concerned with the functioning of technologies, not with the assumptions on which their use rests” [32] and is restricted to the accumulation of facts and data [33]. Second-order learning occurs when “conceptions about technology, user demands, and regulation are not tested, but questioned and explored” [34]. Therefore, second-order learning takes a step back and considers all the elements of the ‘bigger picture’ and questions the underlying values and assumptions about the present dominant approaches that fulfil the sociotechnical function [35]. Drawing deeper reflections about the underlying approach enables changes in cognitive frameworks and assumptions, and furthermore helps to develop the underlying values and norms of the new approach [36]. Therefore, “learning processes would contribute more to niche development if they are not only directed at the accumulation of facts and data, i.e. first-order learning, but also enable changes in cognitive frames and assumptions, i.e. second-order learning” [37].

The learning processes are tightly related to the network formation

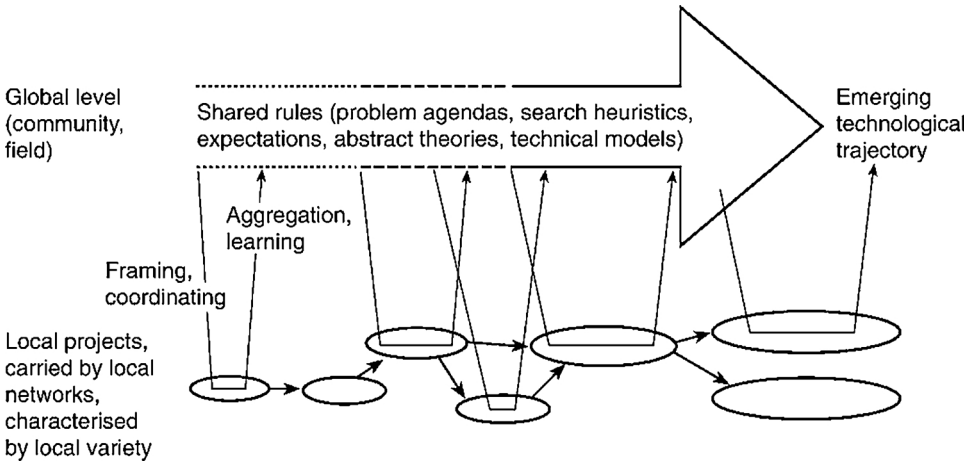

Fig. 1. Niche development process and technical trajectory carried by local projects.
Source: Geels and Raven [31].

of the niche. Previous studies highlight the importance of involving a heterogeneous set of actors to develop the global niche level [38–40]. Furthermore, those studies emphasise that the integration of outsiders and users in these networks can be seen as a source of second-order learning, which "…can lead to changes in the frames of thinking of actors on both the level of the niche and on the regime level" [40]. In the context depicted above it is clear that, in the trajectory of the niche development, learning and networking processes form a reciprocal relationship by uniting the bottom-up and top-down dynamics. Through this interaction of a broad actor network and the resultant aggregation of knowledge, a collective knowledge reservoir which leads to the establishment of dominant cognitive rules and standards is created.

However, learning about a new technology implies significant levels of uncertainty, which can prevent actors from engaging in the experimental settings implied by local projects. In this context, the articulation of expectations is essential for the niche building process. Kemp et al. (1998) point out that these expectations function as a promise for the future and are "…especially powerful if they are shared, credible (supported by facts and tests), specific (with respect to technological, economic and social aspects) and coupled to certain societal problems". When expectations are robust, i.e. shared by many actors, they not only provide guidance for niche-internal processes, but can also attract niche-external interest and support [41]. When the emerging technology is linked to an existing societal problem, these visions can function as a narrative for future development and can help to foster cooperation with niche-external actors [42].

3.3. Conceptualising an Argentinian decentralised renewable energy niche

Based on the theoretical background presented, we propose to conceptualise the diverse set of initiatives that have been instrumental in promoting the development and application of decentralised renewable energy technologies in Argentina as a sociotechnical niche. We view the different actors involved in the sector (e.g. private companies, academia, associations, research institutions) as building blocks in a network nurturing novel ways of providing electrical power through technical configurations where power generation and the served load are physically close to each other. By considering these types of initiatives that advance decentralised renewable energy in Argentina as a sociotechnical niche, the research can be divided into three main areas of focus. The first encompasses the processes by which knowledge gathered from each individual local project (e.g. commercial ventures, research and development projects and rural electrification initiatives) is exchanged, processed and aggregated in order to establish general rules, practices and technical configurations that can be widely applied. The second focus of the research is to identify the articulation of expectations and visions that provide some coherence and guidance among the diversity of actors and activities within the niche community. Finally, the third focus is to distinguish factors external to the niche which have significant effects on the niche's development.

4. Methodology

4.1. Data collection

The data, mostly qualitative, was collected via semi-structured research interviews in 2015 and 2016. This method not only enabled participants to respond to a set of standard questions, but also created the opportunity for the conversations to encompass new ideas during the interviews. An interview guide was used to focus on certain topics and to make it possible to compare the outcomes of the interviews. A questionnaire, consisting of 10–15 open-ended questions (specific to each interviewee), was used as a general outline of the topics to be covered. Most of the interviews took place face-to-face; in special cases only they were conducted by telephone. All the interviews were conducted in Spanish and all were recorded. To effectively and systematically evaluate the information, full transcripts were made of all the interviews.

4.2. Sampling strategy

A purposive sampling strategy, with characteristics of a heterogeneous and discriminative snowball sampling strategy, was used in the research [43]. To ensure a diverse and heterogeneous sample, the selection of participants was purposeful rather than random and, therefore, the results are illustrative rather than representative. The aim was to incorporate views from the diverse range of actors involved in the development of the decentralised renewable energy sector in Argentina. This was addressed in the first place by inviting different types of actors to participate in the study. The initial sample included actors from government agencies, research institutions, non-governmental organisations and equipment suppliers. Further participants were selected based on recommendations made by participants already interviewed, with the aim of ensuring the sample included at least two different organisations for each type of actor. The final sample comprised interviews with experts from 15 organisations, as listed in Table 1.

4.3. Data analysis

Qualitative data analysis is defined "as a search for general statements about relationships and underlying themes" [44]. In this context, theory can be seen as a tool for analysis, as a way of working with data in a particular and guided way [44]. Analysing qualitative data requires active work by the researcher, who should identify dominant broad

Table 1
Overview of the affiliation of the experts who were interviewed for this study.

Type of actor	Name of organisation
Association	Cámara Argentina de Energía Renovable
Association	Asociación Argentina de Energía Eólica
Association	AHK Argentina
Company	ENERSOL
Company	Sustentator
Company	Tecnotrol
Company	Giacabone
Company	Iyara
Ministry	Agencia Provincial de Promoción de Energías Renovables
Ministry	Dirección General de Servicios Públicos – Chubut
NGO	500 rpm
NGO	Ingenieros Sin Fronteras Argentina
Research institute	INTI - Buenos Aires
Research institute	INTI - Centro Patagonia
Research institute	Universidad Nacional de Quilmes

themes. It is based on the creation of a set of codes. Gibson and Brown suggest that concepts deriving from the "top-down" theory can be used to define apriori codes which can function as general analytical categories [44]. In contrast, empirical codes arise out of the exploration of data. In this respect, the application of codes is an iterative process based on the cyclical interaction of apriori and empirical codes. In this study, the ATLAS.ti computer programme was used for the qualitative data analysis to uncover and systematically analyse complex phenomena hidden in the textual data from the transcribed interviews. Before starting the analysis, two groups of apriori codes were developed: one based on the MLP approach and the other based on the SNM perspective. During the analysis, new themes emerged and Table 2 shows the wide range of resulting empirical codes that are interlinked and individually assigned to an apriori code. To validate and ensure reliable results, every phrase from the transcribed interviews was categorised independently by the authors of this study in a double blind analysis.

5. Results

5.1. Characterisation of the Argentinian decentralised renewable energy niche

The interview data indicate that the decentralised renewable energy niche consists of several sub-niches which differ fundamentally in their sociotechnical configurations. Based on the analysis of the data, different application possibilities were identified which could be assigned to four different sub-niches:

Table 2
Coding system for the analysis of the networking and learning processes.

Apriori code		Empirical code
First-order learning	Techno-economic issues	Available technical potential
		Quality
		- Development of standards & certification system
		- Need for technical improvement
		Need for cost reductions
		Viability of decentralised energy systems
	Social & environmental performance	Fields of application
		Final uses of energy
		Impacts on wellbeing
		Suitability of decentralised energy systems
Second-order learning	User level	Actual needs of final users
		Actual technical needs/conditions of users
		Assumptions about financial capacity of users
		Assumptions about awareness of users
		Cultural and social factors influencing technology performance
		Motivations of users
		Questioning of the technology development approach
		Socio-economic & cultural meaning of access to electricity
	Sector Level	Challenges in terms of maintenance, repairs and after-sales service
		Institutionalisation of networks and learning platforms
		Institutionalisation of training formats
		Business models and distribution channels
		Local manufacturing capacities
		Methodologies for programme design & implementation
		R & D infrastructure for the RE sector
		Linking with key actors outside the RE community
	Policy & regulatory framework	At regional level
		- Supportive policies
		- Limitations of regional instruments
		- Lack of coordination
		Political support for decentralised energy options
		- Financing options
		- Regulatory uncertainties (particularly imports)
		- Lack of regulation for grid connection
		- Tariff structures
		Structure of national energy system
		- Questioning the (centralised) structure of power system
		- Centralisation of political decisions on energy
		- Subsidies and regulations of conventional power system
		- The urban-rural gap
		Awareness of RE potentials
		Lack of long-term planning
		Questioning the political economy of the power supply service
		Lessons about the design of state-driven programmes

1) Rural population and public buildings: in Argentina, energy poverty is not only a problem for marginalised groups in society; public institutions in rural areas, such as clinics, schools and police stations, are also affected.
2) Rural production and services: in many cases the cost of grid extension is not financially viable for companies, so off-grid renewable energy systems are a recognised alternative.
3) Backup systems in grid connected regions: as the grid is unreliable and network charges are higher in remote areas, households are beginning to see renewable energy systems as an alternative option. Moreover, as the electrical network in urban areas is unreliable, private households are installing renewable energy systems as a backup solution to ensure a reliable energy source in the event of power cuts.
4) Mining and telecommunication infrastructure: mines and transmission masts are in remote areas and private companies install hydro, solar and wind systems for electricity generation.

5.2. Internal niche processes

5.2.1. Networking and learning

Along the niche development trajectory, learning and networking processes form a reciprocal relationship by integrating bottom-up and top-down dynamics. Through the interaction of a broad actor network and the resultant aggregation of knowledge, a collective knowledge reservoir is created which leads to the establishment of dominant cognitive rules and standards.

To gain deeper insights into these interactions, we developed a matrix (Fig. 2) to illustrate the mutual relationship between the learning and networking processes. The learning topics processed in the niche are presented on the horizontal axis; in this case these are the five topics listed in Table 2, i.e. techno-economic issues, social & environmental performance, user level, sector level and policy & regulatory framework. The vertical axis represents the aggregation level on which the different topics are processed. Here we differentiate between three levels of aggregation: a) 'at project level': lessons on the corresponding topics are mainly processed within single organisations in order to generate generic rules for guiding an organisation's strategies and replications; b) 'within intermediaries': the learning topics are aggregated by organisations that act as intermediaries, collating and contrasting lessons from several single projects, very often in the form of studies focusing on potentials and case studies of single technologies; and c) 'within formal networks': lessons in these topics form part of the discussions within formal networks. Applying these categorisations results in a matrix with fifteen quadrants illustrating the whole spectrum of learning and networking dynamics within the niche, from the learning by single organisations on techno-economic issues (the bottom-left corner) to drawing lessons for policy and regulations from discussions between several stakeholders within formal networks (the top-right corner). Finally, statements from each interviewee are mapped in the matrix; i.e. according to the topics raised and how the topic is processed. In this way, the matrix gives some initial indications about the roles that certain types of actors play in the learning and networking processes.

Around two-thirds of the interviewees reported that discussion of topics relating to policy and the regulatory framework was one of the main activities within the formal networks. A number of issues were identified relating to the underlying approaches and possible structural weaknesses of the dominant regime. Regarding the structure of the national power system, a recurrent theme emerging from the interviews was the critical questioning of the political economy of the power supply service. The main issues were the centralisation of political decisions on energy, the lack of long-term planning, the centralised power grid system and subsidies for conventional energy sources. Over and above these issues, reflections about the repercussions of the configuration of the dominant regime for niche trajectory, such as for access to finance or feed-in regulations, and the elaboration of possible sector development strategies, were identified as activities within the formal networks. Another interesting aspect is that the interviewees use the formal networks as a platform for reflecting on the degree to which the current delivery models are sociotechnically appropriate for decentralised renewable energy. The challenges faced by maintenance and repair services are a recurrent topic in the formal networks. Many interviewees pointed out that this exchange of ideas is particularly important given the geographical expanse of Argentina, which makes it costly for a single actor to provide national after-sales services. Furthermore, institutionalising learning platforms and training formats, cooperating in the development of local manufacturing capacities and R & D infrastructure were identified as dominant topics at sector level within the networks. Interestingly, in some cases the networks are also a platform for self-critical reflections about the decentralised renewable energy technology development approach. Discussions about the actual needs of end users, the socio-economic and cultural meaning of access to electricity and debate about the extent to which the end users' needs

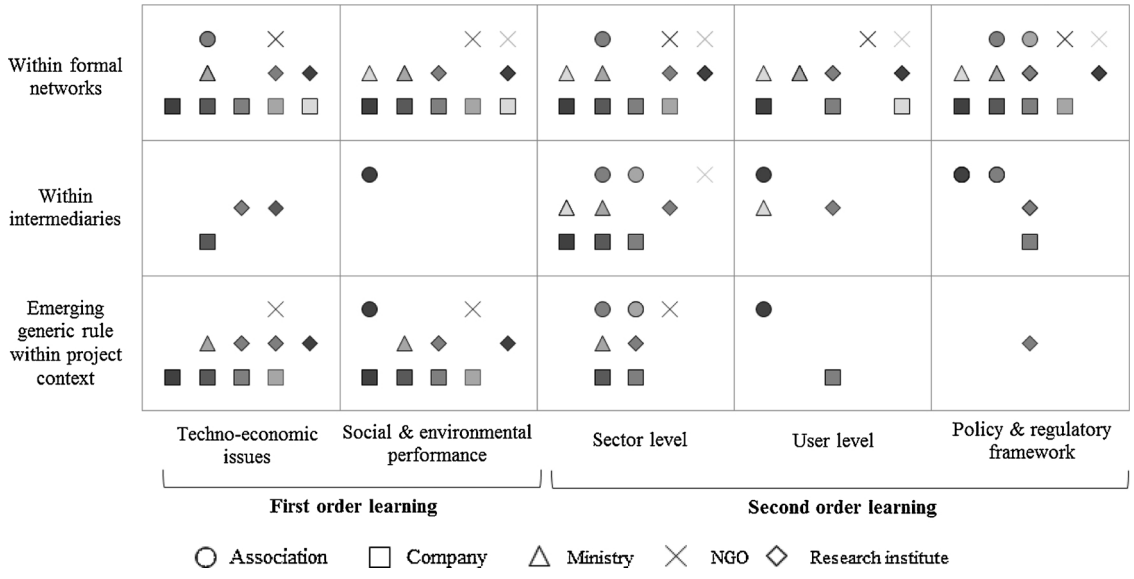

Fig. 2. Overview of niche-internal aggregation processes.
Source: Authors' own data.

are appropriately met in the present configuration were identified as elements of these self-critical reflection processes.

Three main formal networks were identified by the interviewees. One of the most heterogeneous networks is the Argentinian Association of Renewable Energy Installers (Asociación Argentina de Instaladores de Energías Renovables). The association was founded in 2015 and consists of more than 120 installation technicians working in the field of renewable energy systems. The aims of the association are to exchange practical technical knowledge, establish national technical standards and improve the reputation of the profession. The network of manufacturers of small wind turbines is another interesting example. In 2010, to support the domestic manufacture of small wind turbines, the Argentinian research institute INTI initiated a network currently consisting of 14 national companies. As well as sharing experiences, the network aims to support the development of national technical standards and policy for small wind turbines. Furthermore, the members of the network can access a scientific wind turbine certification scheme. The third identified network is the Argentinian Wind Cluster. The "Cluster Eólico Argentino" is supported by the Ministry of Industry and consists of 52 local companies from different industry sectors. The main aim of the network is to support local manufacturers of wind power equipment and thereby strengthen the national market.

Another interesting aspect emerging from the analysis is the role of intermediaries within the development of the niche. Fig. 2 shows that only a few interviewees are in contact with intermediary organisations. This may be attributed to the finding that several heterogeneous formal networks exist in Argentina, guaranteeing the exchange of knowledge between different actors. However, based on the interview material, the association CADER and the INTI institute could be identified as intermediary organisations which facilitate the consolidation and transfer of knowledge.

Surprisingly, several interviewees highlight the significant role played at provincial government level. In contrast to the lack of development at national level, up until 2016 provincial government took the lead in shaping supportive policies for the decentralised renewable energy sector. Over the last 10 years, 16 of the 23 Argentinian provinces have introduced laws to support the development of renewable energy systems. Some provinces have also introduced legislation to enable and regulate the feeding of power from decentralised renewable energy plants into the grid; an instrument commonly referred to as net balance or net metering. This approach has still not been adopted at national level. By applying conceptualisations of sociotechnical niches, it can be concluded that the decentralised renewable energy niche is characterised by a high level of maturity, where the processing and aggregation of lessons is being systematically undertaken and is even used to influence policy at provincial government level.

5.2.2. Expectations and visions

In the final part of the survey, the interviewees were asked a set of questions to understand more about their visions and expectations. Three visions emerged from the analysis of the interview data, based on a broad range of rationales and expectations (Table 3). Together these results provide important insights into the situational perception of the interviewees, from which narratives for future development may result.

The most common and dominant vision amongst the interviewees was that renewable energies will allow Argentina to establish a nationwide comprehensive decentralised power system. A variety of perspectives were expressed which contributed to the rich diversity of this theme. All the 15 interviewees perceived renewable energy from a technical point of view to be a solution for overcoming the centralised power structure of the present dominant regime and for providing electricity to areas which are currently excluded due to the inner regime logic and rules. Furthermore, the decentralised power supply structure is associated by the interviewees with improvements in the reliability of the power supply system. From the interviewees' point of view, the frequent power cuts indicate that the current grid supply is inadequate. Issues related to the interplay between renewable energies and power transmission were also particularly prominent in the interview data. Smart grids are considered important instruments for the integration of renewable energies into the power transmission system. At off-gird level, micro grids were identified as an important instrument for the interconnection of various decentralised renewable energy systems. Another important finding was that the dominant vision was supported by specific expectations about the development of contextual factors in Argentina. In line with global trends, the interviewees anticipate lower investment costs for renewable energies and higher costs for conventional energy sources. Two interviewees anticipate that Argentina will regain access to the international financial markets in the forthcoming years, making it possible to finance the renewable energy transition. 10 out of 15 interviewees were convinced that, in the forthcoming years, the Argentinian government will adopt legislation to promote the expansion of decentralised renewable energy systems. It was assumed that, as a result of these new regulations, it will be possible in future to feed energy from renewable sources into the grid.

Eight interviewees assumed that the development of the renewable energy sector will trigger positive economic impacts for Argentina's economy. Here the most common vision can be described as one in which Argentina becomes a technological leader in the field of renewable energy in Latin America. This vision was connected to the expectation that this will positively influence the socio-economic development of the country. One of the interviewees summarised this issue in a very clear statement: "… renewable energies can be a solution in terms of production and socio-economic development. This will allow for the development of a phenomenal industry which will provide employment, provide development, provide export, support income generation and make savings in terms of the importation of energy". This statement shows that overlapping visions concerning a broad range of areas exist. This is associated with the third vision, which was shared by six of the interviewees. The vision is based on the expectation that the transition towards renewable energies offers an alternative solution to the multiple pressures currently faced by the national energy system.

In general, the visions identified highlight the techno-economic deficiencies of the current Argentinian power system. It is striking that the ecological dimensions of sustainable development (such as climate change concerns or air pollution) seem to be of little relevance among the niche community. Overall, the vision of a future decentralised renewable power system offers a particularly powerful narrative for the future development of the niche; i.e. it is a vision *shared* by nearly all interviewees, it is *specific* (in relation to social, economic, political and

Table 3
Overview of visions.

1. Vision	Renewable energies enable Argentina to establish/transform a nationwide comprehensive decentralised power system and thereby electrify rural areas. *This view was expressed by 15 of the 15 interviewees*
2. Vision	Argentina will be a technological leader in the field of renewable energy in Latin America and this will positively influence the socio-economic development of the country. *This view was expressed by 8 of the 15 interviewees*
3. Vision	The energy transition towards renewable energies will be the solution to the present energy crisis and will allow the country to become self-sufficient in term of energy again. *This view was expressed by 6 of the 15 interviewees*

technological factors), *credible* (supported by an important set of successful projects and business models) and *coupled to a particular societal problem* (i.e. centralised power system, unreliable power supply and lack of access to electricity for the rural population) [22,42].

5.3. Factors influencing the development of the Argentinian decentralised renewable energy niche

5.3.1. Drivers

Regarding the supporting factors, five broad themes emerged from the analysis: the significant natural potential for renewable energy, high national education standards, advanced industrialisation, national research institutes and the structural weaknesses of the dominant power system regime. Notably, the interviewees mainly identified supporting factors that are not unique to the interaction of the regime with the specific niche, but are factors that can be attributed to landscape features in the Argentinian context.

All the interviewees perceive the existence of significant natural potential for diverse renewable energy technologies resulting from geographical conditions as one of the main drivers for the dissemination of renewable energy systems. One of the main drivers is the technical know-how of national companies working in the field of renewable energy. This result is not surprising, as most of the interviewees stated that Argentina historically distinguishes itself by a high level of industrialisation. Likewise, a significant majority (87%) of the interviewees are convinced that Argentina has a generally high level of education and the academic potential to specialise in relevant fields important for renewable energy development. This also ties in with the existence of national technical research institutes, working in cooperation nationally with industry; this was perceived by 14 of the 15 interviewees as an important driver for the development of the renewable sector. Moreover, nearly half the interviewees specifically indicated that, due to the fluctuating development of the national economy over recent decades, the Argentinian industry sector has a highly developed ability to adapt, resulting in strong potential for innovation in the renewable energy sector.

As well as the prominent issues at landscape level, most of the interviewees highlight the structural weaknesses of the incumbent regime as a driver for the studied niche. The argument can be summarised as the inability of the regime to guarantee a reliable energy supply as a universal societal function. The interviewees identify distinct niche supporting factors from this weakness. 80% of the representatives from companies state that the lack of a reliable energy supply in urban areas leads to a rise in demand for decentralised renewable energy systems as a backup solution to power shortages. Another weakness of the regime is its inability to supply 1.1 million Argentinians in rural areas with electricity, due to the high costs of grid extension. Six interviewees argued that, from a systemic point of view, it is cheaper to establish decentralised renewable energy systems to provide electricity to the off-grid population than to extend the national grid. 40% of the interviewees consider the extensive geographical area of the country as a supporting factor for the development of the niche. The absence of the regime in these specific areas results in end users taking on different roles, as they are forced to act in a self-reliant manner to provide their own energy supply. In this context, it is interesting that the company representatives argued that this creates a competitive advantage for decentralised renewable energy systems as, in their point of view, they are more economical than conventional systems.

5.3.2. Barriers

In Argentina, the decentralised renewable energy niche faces barriers due to a combination of technological, geographical, financial, political and social factors related to the regime and landscape levels. The interviewees clearly identified the following regime-related barriers: economic instability, importation regulations, state subsidies of conventional energy sources and limited access to finance for supplying the rural population with electricity. It should be noted that, as well as being seen by the interviewees as a supporting factor, on the landscape level the extensive size of the country is also perceived as a barrier to the development of decentralised renewable energy systems as the maintenance of systems across such a large geographical expanse presents a significant challenge.

According to the interviewees, the general political and economic instability of recent decades has negatively influenced the economic development of the renewable energy sector and the economy as a whole. A commonly expressed view was that this has negative repercussions on the niche development, as the actors associate this instability with inadequate access to finance and difficulties in making long-term entrepreneurial decisions. After the economic crisis in 2001, which paralysed the country's economy, the Argentinian state intervened in the energy market. In order to keep energy prices low, the state subsidises conventional energy sources and electricity generation [45]. This policy has led to a gradual and increasing distortion between energy prices and real energy costs [46]. 4 of the 15 interviewees concluded that this price distortion negatively affects the competitive position of decentralised renewable energy systems in urban areas.

Stringent regulations which, at the time of the interviews, enforced specific import limitations were seen by four interviewees as another major barrier. A common view was that the importation regulations not only significantly increase the system costs of decentralised renewable energy systems, but the bureaucracy also creates barriers that negatively affect the perception of such projects. A recurrent theme in the interviews was the difference in quality and level of technological development between national and international products. Seven interviewees considered imported products to be of higher quality than those manufactured in Argentina. In this context, the interviewees highlighted the difficulties in importing special parts; for example, charge controllers and MPPT trackers. This restriction negatively affects the performance of the renewable energy systems, reducing their techno-economic benefits and significantly slowing down the pace of evolution in the sector.

Specifically concerning the off-grid applications nurtured by the niche, 60% of the interviewees highlight poverty-related issues and a relative absence of state support (such as lack of funding) as the main obstacles. A recurrent theme, expressed by 7 of the 15 interviewees, was that limited access or no access to finance for the rural population is a major barrier. Although state support programmes (such as PERMER) were acknowledged, the respondents consider these to be inadequate and five interviewees were critical about the lack of governmental strategy for providing the rural population with electricity. In this context, the interviewees questioned the long-term sustainability of the current state funded projects as, from their point of view, these projects focus on installations rather than on ensuring long-term operation. One interviewee commented: "There were several failures in programmes like PERMER as windmills were installed which did not work or, more accurately, they did work but only for a while, and when maintenance issues emerged – which is a natural issue for wind turbines – there was no system for providing the required maintenance; therefore, the project failed and in some places distrust emerged, particularly towards small wind energy although not so much towards solar technologies." Additionally, four of the 15 interviewees highlighted the lack of awareness amongst the population about the technical opportunities offered by renewable energies.

6. Discussion

The decentralised renewable energy sector in Argentina features characteristics of a sociotechnical niche in an advanced stage of development. Formal networks are already well established; lessons from individual initiatives are systematically aggregated; global knowledge is used to influence subnational government policies; niche markets for decentralised power systems with a broad span of applications are in

existence. However, the niche faces major challenges for its further expansion, deriving mainly from its interaction with the regime and landscape levels.

On the one hand, niche expansion has been limited by the same institutional, macroeconomic and financial conditions that have caused the low deployment dynamic of the Argentinian renewable energy sector in general. In this respect, the results of this study concur with other recent studies indicating that, despite the enormous potential in Argentina, as of 2016 large-scale renewable energy development had failed to materialise. Our results specifically highlight economic and political instability, in combination with restrictive political regulations (such as the importation of goods and conventional energy subsidies), as the main barriers arising from the dominant sociotechnical regime. On the other hand, and beyond those general challenges faced by the Argentinian energy system as a whole, niche specific barriers that can be assigned to the interaction with the regime and landscape levels were identified. In urban areas, highly subsidised electricity prices and regulations prohibiting electricity from renewable sources being fed into the grid have created comparative economic disadvantages which hinder the growth of the decentralised renewable energy market. The lack of a long-term strategy for the electrification of rural areas was a recurrent topic amongst the interviewees. This issue, in combination with limited access to finance for this population group, represents a major barrier for the development of decentralised renewable energy systems in this sub-niche. On the landscape level, the extensive size of the country was perceived by the majority of the interviewees as not only supporting but also hindering the dissemination of decentralised renewable energy systems. While Argentina's extensive territory has the advantage of providing highly diversified natural potential for renewables, it also creates challenges for the provision of maintenance services for renewable energy installations located across a wide geographical expanse. As the provision of a functioning extended maintenance network is associated with high operational costs, this represents a major challenge for individual (small and medium-sized) enterprises. Therefore, further research should be undertaken to investigate possible solution strategies; such research could examine the role of state institutions and corporate networks in the establishment of an Argentinian maintenance network.

Another important question is whether the decentralised renewable energy niche is sufficiently robust to induce the broader deployment of decentralised renewable energy technologies in Argentina. Based on the insights from the concept of Strategic Niche Management, three arguments support this view:

1) The niche consists of a broad spectrum of sub-niches which differ essentially in their sociotechnical configuration. This diversity of local practices enriches the spectrum of first-order learning processes which, on the global level, extends the range of future development trajectories and thereby strengthens the development prospects of the emerging niche.
2) Moreover, the current study found that the actors shared one unifying vision regarding the future evolution of the global niche, which was substantiated by the existence of specific expectations about the development of the contextual factors in Argentina. The visions represent a counter model to the structural weaknesses of the current sociotechnical regime and, at the same time, form future development narratives which fulfil niche-internal and external functions. They are, therefore, important for the future integration of niche-external actors. The vision of a prospective decentralised power system with high shares of renewable energy is particularly powerful, as it was specific, credible, coupled to identified societal problems and shared by nearly all participants.
3) Furthermore, a variety of heterogeneous formal networks exist which enable the exchange of project-based experiences and stimulate second-order learning aggregation processes. The examples given show that these networks integrate bottom-up and top-down dynamics, leading not only to the creation of a collective knowledge reservoir but also to the establishment of dominant cognitive rules and standards. In some cases, these learning and networking processes have exercised influence and secured the engagement of influential political actors at subnational government levels. In addition, the networks promote critical reflection amongst niche actors; most prominently the critical difficulties in ensuring appropriate national after-sales service and reflections about the policy and regulatory framework in which the niche is embedded.

Further research should be undertaken to investigate development pathways from a centralised to a decentralised power system and describe possible strategy and measures. Moreover, this analysis leads to the conclusion that future legislation should further consider the specific Argentinian underlying micro and macroeconomic conditions. To design effective energy policy, future studies on the current topic should analyse in greater detail the sociotechnical configurations of the different decentralised renewable energy sub-niches.

Most previous studies analysing the development of renewable energy in Argentina were based on secondary information [47,48]. For this reason, 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. From a self-critical standpoint, this research strategy should also be recognised as the main limitation of the paper. 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 snowball sampling strategy is the risk that a relevant actor group is omitted from the research sample. A further limitation, which could be addressed in future research studies, is that the barriers identified by stakeholders are listed but not ranked in order of magnitude. For the development of future policies, it would be interesting to analyse a data set which includes a ranking of these barriers by the actors. This could be undertaken in future studies by the integration of other analytical frameworks, such as Multicriteria Analysis (MCA), to evaluate and categorise those barriers identified by the different stakeholders.

7. Conclusions

This study was designed to investigate the internal niche dynamics and the context-related factors that have been hindering or supporting the development of the contemporary renewable energy niche in Argentina. By applying the MLP and SNM conceptual frameworks, this study found that, although renewable energies currently play a minor role in the Argentinian power system, in several protective spaces a strong and diversified decentralised renewable energy niche has developed. This niche is, however, struggling to stabilise and grow within an environment dominated by a firmly established incumbent regime based on the use of fossil fuels and characterised by a centralised political and regulative structure.

Our findings point to a sociotechnical niche in an advanced stage of development: the niche is already exploring diverse sociotechnical fields of application and supplying commercial products and services. Aggregation of learning is being pursued systematically and (in some cases) transfer to regional state policies has even taken place. Moreover, formal networks are already well-established and these serve to articulate flows of knowledge and discussions within the niche and coordinate advocacy for the sector beyond the niche. However, the further development of the niche is challenged by barriers (pressures) from the regime, as well as from the landscape level. The centralised political and regulatory structure challenges the ability of the niche to bring more influence to bear on the future configuration of the national power system. At the landscape level, the most striking issue derives from the large geographical expanse of Argentina − which makes the provision of adequate technical services for a high number of dispersed renewable energy plants particularly challenging.

The Argentinian case illustrates the importance of considering the multi-level nature of energy policy and politics. Our analysis clearly identified very different types of niche interactions taking place at regional government level in contrast to national government level. This seems to be an expression of the tensions between the current centralised structure of energy politics in the country and the regional struggle for more energy policy autonomy. Moreover these osmotic dynamics between state and national interests seem to be an important issue for future research, as they were highlighted in several recent studies [4,49–51]. While the concept of the incumbent sociotechnical regime is useful for analysing the political context in which the niche is embedded, more differentiated conceptualisations of the regime are needed to understand the multiple interactions with the niche. The interdisciplinary Socio-Political Evaluation of Energy Deployment (SPEED) framework might provide valuable guidance in this respect, as it was developed to facilitate the characterisation of the social and political aspects shaping energy technology deployment in specific contexts [52,53].

Based on our findings, we suggest that the future role of the niche in inducing larger transformations of the national electric power system could proceed along two complementary paths. On the one hand, by expanding and deepening the existing engagement of influential actors at provincial government level, higher pressure could be exerted on the incumbent national regime. On the other hand, efforts should be made to explore the compatibility of some key narratives of the niche's common vision with political agendas at national level. An example of such a common vision is the expectation of a decentralised renewable energy sector that develops into a strong national industry. In this way, promoting the transition to a greater share of renewable energy and a more decentralised national power system would not only be linked to environmental concerns, but also to economic and social issues on national development agendas.

Appendix A. Interview questionnaire

1. Interview questionnaire

1. Introduction - challenges for the current power system and perspectives

1.1 In your opinion, what are the key challenges for the current Argentinian power system? Could these challenges be overcome by long-term developments?

1.2 Do you think that the current configuration of the power system can ensure the power supply in the long term?

1.3 How do you assess the perception of the Argentinian society regarding the overall energy situation?

2. National energy policies

2.1 In your view, what are the main characteristics of the current Argentinian energy policy and what kind of generating capacities were promoted by government actions? What additional energy policy priorities would you include?

2.2 In my background research, I discovered that the Argentinian government subsidises energy prices using different instruments. One instrument is the direct subsidisation of end user prices and the other is the subsidisation of imported natural gas through the state-owned energy company ENARSA (Energia Argentina Sociedad Anónima). How do you evaluate this subsidy policy? What are impacts on the development of the energy mix and how does the policy influence the market opportunities for renewable energies?

3. The renewable energy sector in general

3.1 How do you evaluate the potential of renewable energy in Argentina in comparison to other South American countries? What strengths does Argentina possess which positively influence the development of renewable energy?

3.2 If you had to summarise the development of renewable energy over the last twenty years, what would you highlight as the most important development milestones?

3.3 Despite government legislation (like the 8% goal and funding instruments or the GENREN programme), currently less than 2% of energy demand is met by renewable energy. How do you evaluate the willingness of the government to support renewable energy and, in your opinion, what are the main reasons why the legislation and government initiatives have not led to significant developments in renewable energy?

4. The decentralised renewable energy sector

4.1 In your opinion, what are the different market segments and target groups for the decentralised renewable energy sector? How would you estimate the stage of market development and the potential for decentralised renewable energy systems?

4.2 In your opinion, what are the most important drivers and barriers for the development of the decentralised renewable energy sector?

4.3 How do you evaluate the development of renewable energy in the off-grid and on-grid contexts? Would you say that these developments positively influence each other or should they be seen as two independent development streams? (Are you aware of companies which participate in both on and off-grid projects?)

4.4 What do you see as the political or regulatory barriers to the widespread development of decentralised renewable energy? What are your suggestions for overcoming these barriers and, in your opinion, which political instruments would be important for the promotion of decentralised renewable energy?

4.5 What do you see as the top economic barrier and opportunity for the widespread development of decentralised renewable energy? What are your suggestions to overcome this barrier?

4.6 What are the main technical barriers and opportunities for the Argentinian energy system regarding the integration of decentralised renewable energy?

4.7 Are you part of any network or association and which networks are you aware of? How do you assess the exchange between the different actors working in the field of renewable energy? Which stakeholders do you work with or exchange ideas/information/knowledge with?

4.8 What are your expectations and visions for the development of decentralised renewable energy in the next 10 and 30 years in the on and off-grid contexts and how do you think the energy mix will develop? Do you think that a shared vision exists between actors working in the area of renewable energy?

5. End of the interview

5.1 Could you recommend other people I could interview for my research?

5.2 If you could employ a full-time researcher, what question would you ask him or her to investigate?

5.3 Are there any questions you expected that I did not ask?

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