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The Influence of Context-Specific Factors on the Diffusion Dynamics of Onshore Wind Energy in Argentina

A constellation analysis of the wind energy diffusion dynamics in Argentina

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List of Abbreviations, Units and Symbols

Abbreviations

BCRA	Banco Central de la República Argentina (Central Bank of the Argentine Republic)
BICE	Banco de Inversión y Comercio Exterior (Argentine Bank for Investment and Foreign Trade)
CA	Constellation Analysis
CAMMESA	Compañía Administradora del Mercado Eléctrico Mayorista S.A. (Argentine Wholesale Electricity Market Clearing Company S.A.)
Covid-19	Coronavirus disease 2019
CREE	El Centro Regional de Energía Eólica (Regional Centre for Wind Energy)
DNC	Declared National Component
El	Electricity
EMBI	Emerging Markets Bond Index
ENARSA	Energía Argentina S.A. (Energy Argentina S.A.)
EU	European Union
FIP	feed-in premium
FODER	Fondo para el Desarrollo de Energías Renovables (Trust fund for the development of renewable energies)
GENREN	Programa Generación Renovable (Programme for renewable generation)
GIS	Global Innovation System
IMPSA	Industrias Metalúrgicas Pescarmona Sociedad Anónima (Pescarmona Metallurgical Industries Public Limited Company)
Intern	International
MATER	Mercado a Término de Energía Eléctrica de Fuente Renovable (Electricity Term Market for Renewable Energy Sources)
MLP	Multi-Level Perspective
OWE	Onshore Wind Energy
PPA	Power Purchase Agreement
Pre	Presidency
PROINFA	Programa de Incentivo a Fontes Alternativas de Energia Elétrica (Programme of Incentives for Alternative Electricity Sources)
RenovAr	Programa de abastecimiento de energía eléctrica a partir de fuentes ren-ovables (Programme for the supply of electricity from renewable energy sources)
SADI	Sistema Argentino de Interconexión (The Argentine Interconnection System)
SIP	Sistema Interconectado Patagónico (The Patagonian Interconnection System)
TIS	Technical Innovation System
US	United States
WI	Wuppertal Institut für Klima, Umwelt, Energie gGmbH
YPF	Yacimientos Petrolíferos Fiscales S.A. (Fiscal Oilfields S.A.)

Units and Symbols

$	Dollar
%	Per cent
€	Euro
CO_2	Carbon dioxide
GW	Gigawatt
kW	Kilowatt
kWh	Kilowatt hour
MtnCO2e	Metric tons of carbon dioxide equivalent
MW	Megawatt

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1 Introduction

Promoting the transition towards a higher share of renewable energy in Argentina's power system is expected to open up a diverse spectrum of development opportunities for the country (Schaube et al., 2018). Opportunities derive from initiatives aimed at reducing dependence on imported fossil fuels, improving power supply reliability, achieving the Paris Agreement goals, and strengthening existing and supporting the development of new innovative industrial sectors. In particular, wind energy is playing a central role in the Argentine energy transition. Around 70% of the country's surface is suitable for wind energy, making it one of the areas with the highest onshore wind potential in the world (Fenés, 2015). The potential is particularly high in the region of Patagonia, where wind speeds average between 9 m/s and 12 m/s. Moreover, the conditions for generating wind energy are also favourable along the coast and in Buenos Aires, the main centre for electricity consumption (CADER, 2013), where average wind speeds exceed 6.5 m/s.

Accordingly, Argentina is an intriguing case in the South American context in terms of its wind energy development. The technology was introduced in Argentina in the early 1990s, but its development has been non-linear and prone to disruptions. In 1990, South America saw the establishment of its first wind farm, and in the following years Argentina started developing its own wind sector. Spearheaded by initiatives implemented by energy cooperatives, Argentina evolved into a regional pioneer in wind energy. However, years of stagnation followed the economic crisis of 2001. Over the next 15 years, Argentina concentrated on the development of national wind turbine manufacturers. However, despite ambitious support programmes and targets (in comparison to neighbouring countries such as Chile, Brazil, and Uruguay), very few wind farms were installed during that period. Subsequently, from 2017 onwards, a massive expansion of wind energy took place and Argentina increased its capacity from 27 MW (2010) to 2710 MW (2020). This development was accompanied by ambitious political targets for the expansion of renewable energies. These targets were not achieved, although there has been impressive development in more recent years. The results of previous research indicate that the challenges faced by Argentina's wind sector can be partly attributed to its political instability and recurring macroeconomic crises, which have resulted in a higher level of perceived uncertainty for capital-intensive long-term investments (Barrera et al., 2022a; M. Y. Recalde et al., 2015; Ruggeri & Garrido, 2021). Against this background, this study intends to contribute to a better understanding of the impact of underlying contextual conditions on the trajectory of wind energy in Argentina. By combining a comprehensive literature review with input from experts, the aim of this research is to divide the development trajectory of wind energy in Argentina between 1985 and 2020 into distinct development phases in order to analyse the role of contextual factors on the diffusion dynamics. Thus, this paper is guided by the following research question:

"How have context-specific factors influenced the diffusion of onshore wind energy in Argentina?"

This study is theoretically rooted in sustainability transition research (Grin et al., 2010). In this context, it is interesting to note that the relatively few recent studies that have applied the transition research framework to assess technology diffusion in developing countries have all emphasised the importance of country-specific contextual factors (De Oliveira & Negro, 2019a; Edsand, 2019a; Esmailzadeh, Noori, Aliahmadi, et al., 2020; Tigabu et al., 2015a). The research by De Oliveira and Negro (2019b) highlights the importance of contextual factors for the diffusion of biogas technologies in Brazil and emphasises the role of sectoral regulations and geographically anchored infrastructures for their diffusion. Furthermore, Edsand (2019b) proposes an extended framework for the Technological Innovation System (TIS) framework in the context of developing countries by integrating the landscape level of analysis of the Multi-Level Perspective (MLP) and suggesting an ex-ante categorisation of landscape factors. Esmailzadeh's et al. (2020) study on photovoltaic TIS in Iran also emphasises macroeconomic factors such as government policy and economic conditions as key influencing factors. Regarding the development of wind energy in Argentina, previous literature has tended to focus on individual aspects within specific disciplinary perspectives. Previous research on the diffusion of wind energy in Argentina has mainly focused on analysing the technical potential and development of installed capacity (Genchi et al., 2016; Labriola, 2020a), the role of specific stakeholder groups (e.g. energy cooperatives) or regions (e.g. the province of Buenos Aires) (L. Clementi, 2014, 2018a), as well as the economic and regulatory framework conditions (Barrera et al., 2022b; Giralt, 2011; M. Recalde, 2010, 2011). Therefore, one research gap is a comprehensive study of the different factors influencing the diffusion of wind energy in the Argentine context. First analyses in this direction have been carried out by Clementi et al. (2021a) and Garrido et al. (2016a). While Garrido et al. (2016a) analyses the development of wind energy and its actor structure (1990-2015) from a socio-technical perspective, Clementi et al. (2021a) focuses on the territorial development of wind farms (1990-2020) in the context of changing regulatory frameworks.

Against this background, this study aims to contribute to a deeper understanding of the role of contextual factors in the context of sustainability transition research, and to make an empirical contribution to a holistic understanding of the diffusion of wind energy in Argentina. Therefore, this research seeks to analyse the impact of context-specific framework factors on wind energy development in Argentina by applying a combined MLP-TIS framework. A central component of the MLP-TIS framework is the "focal technical innovation system", which frames the diffusion of new innovations such as wind energy in Argentina as an outcome of a systemic interplay between supportive actors, technologies, networks, and institutions. To examine the influence of contextual conditions on the development of wind power in Argentina in detail, the socio-technical regime (the Argentine energy system) and the landscape factors (macroeconomic developments, etc.) are significant analysis levels. As Argentina is one of the few countries in South America with domestic wind turbine manufacturers, the MLP-TIS framework is complemented by the Global Innovation System (GIS) approach to capture the multi-scale dynamics of technology development. In this research methodology, the theoretical framework is operationalised by applying constellation analysis (CA), which serves as a bridging concept through its visual character to consolidate the interdisciplinary results of the systematic literature review on the one hand and to triangulate and further develop the insights with experts on the other hand. Moreover, this research is one of the first attempts to apply the combined MLP-TIS framework and CA in the context of energy transitions in the

Global South. Thus, this study contributes to the growing body of research that aims to develop a deeper understanding of the contextual embeddedness of new innovations.

This paper is structured as follows. Section 2 provides an overview of the theoretical background and introduces the MLP-TIS framework. Section 3 introduces CA and describes the research strategy. Section 4 provides a comprehensive description of the individual development phases of wind energy and analyses in detail how contextual factors have influenced its development. Section 5 discusses the results and shows how interactions with the socio-technical regime, landscape factors, and the GIS have shaped the diffusion dynamics along the development axis. Finally, the conclusions are presented in section 6.

2 Theoretical framework

The research draws upon Markard & Truffer (2008) who developed an integrated framework of the technical innovation system (TIS) and the multi-level perspective (MLP) from the field of sustainability transition research. These two important complementary theoretical approaches provide a fruitful heuristic to analyse the complex and multi-dimensional nature of the diffusion dynamics of new technologies (e.g., wind energy) and the associated restructuring of the prevailing production and consumption systems (e.g., the Argentine power system) (Markard & Truffer, 2008). The frameworks share common theoretical roots in terms of their fundamental concepts; however, they provide different perspectives on both innovation processes and socio-technical change with complementary features at the analytical level (Markard & Truffer, 2008). This research study adopts the integrated MLP-TIS framework to analyse the influence of contextual factors on the diffusion dynamics of wind energy in Argentina within different phases of its development.

The integrated MLP-TIS framework conceptualises the diffusion of new technologies and the transition of a socio-technical system as a process shaped by the dynamic interplay of four elements: the regime, the TIS, the niche, and the landscape. The regime embodies the dominant way of providing a societal function such as energy supply (A. Smith et al., 2010). Path dependencies between existing infrastructure, normative and cognitive rules, regulation, sunk technology investments, and actor interdependencies act as stabilising mechanisms which serve to facilitate only incremental innovations (Johan & Geels, 2008). Linkages between interconnected heterogeneous entities lead to a constantly self-replicating social structure that impedes the diffusion of radically new technologies through selection and retention mechanisms (Elzen et al., 2002). The development, diffusion, and utilisation of these novel technologies are conceptualised in a TIS as the outcome of the systemic interaction between actors, networks, institutions, and technologies (Jacobsson & Bergek, 2011). In addition to structural elements, innovation dynamics are determined by the performance of emergent system functions, such as knowledge development and diffusion, entrepreneurial activities, guidance of search, market formation, and the creation of legitimacy (Bergek, 2019).

In terms of the TIS, in order to operationalise the theoretical framework for the analysis of the present case, a further distinction is made between the focal TIS and the Global Innovation System (GIS). The GIS is a concept to capture the multi-scalar dynamics of technological development on a global level (e.g., global value chain creation and international competition) (Binz & Truffer, 2017). In contrast, the focal TIS is a concept used to analyse a specific object of study within a defined boundary (Bergek et al., 2015). In the context of this research, the focal TIS is the diffusion processes of onshore wind energy within the geographic boundary of Argentina. Technological niches play an important role in the emergence, growth, and maturity of the focal TIS (Markard & Truffer, 2008). Initially, niches are important testing grounds that make an important contribution to knowledge generation and standardisation. These can further develop into professional application contexts that can lead to breakthroughs in new technology (Johan & Geels, 2008). The broader landscape provides the macrostructural exogenous context over which TIS or regime actors have very little or no influence (Geels & Kemp, 2007). Landscape factors refer to the biophysical environment (e.g., the availability of renewable energy potential in a certain region), slowly evolving developments (e.g., macroeconomics, demography, ideology, geopolitics), and exogenous shocks (e.g., economic crises, drastic accidents, sudden political shifts) (El Bilali, 2019; Geels et al., 2017). The systematic literature review by Bergek (2019) highlighted that the TIS framework needs adaptation and further development in relation to developing and emerging economies, as it does not allow for sufficient consideration of contextual framework factors. In response to this criticism, this research study – with its focus on contextual relationships and the use of constellation analysis (CA) – aims to contribute to the further development of the theoretical framework so it can be more appropriately used outside the European context.

Building on the theoretical background presented, the development of onshore wind energy in Argentina is conceptualised as a focal TIS with diffusion dynamics taking place in a diverse set of socio-technical niches. Given that innovation systems do not evolve in a vacuum but are situated within existing configurations of socio-technical systems, the study of contextual relationships (i.e., the interaction between the focal TIS and the regime and landscape levels) plays a crucial role in developing a deeper understanding of how these aspects have shaped the diffusion of wind energy in Argentina. By incorporating the GIS level of analysis, the embeddedness of onshore wind in the global value chain is considered. In contrast to the regime and landscape levels, which are applied specifically to Argentina's socio-technical energy system in this study, the Global Innovation System (GIS) captures the multi-scale development dynamics inherent to wind energy technology. Figure 1 presents a summary of this framework, operationalised and visualised with the help of constellation analysis (CA).

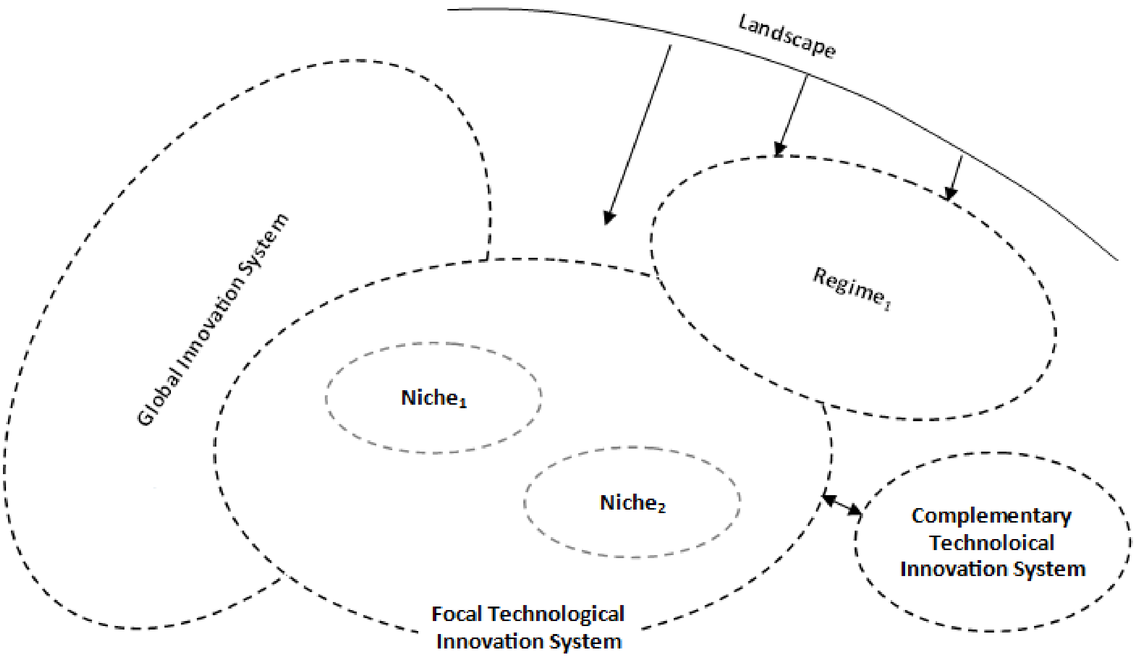

Figure 1: Interaction of the focal TIS with the conceptual elements of the MLP and the GIS.
Source: own illustration, based on Markard & Truffer (2008)

3 Methodology

A mixed-methods research strategy was adopted to empirically explore the diffusion dynamics of wind energy in Argentina and to assess how contextual factors influenced diffusion within the different development phases (Creswell & Plano Clark, 2017). Specifically, a convergent research design was implemented, in which the CA served as a bridging concept to synthesise and triangulate the findings from the literature review and the expert interviews (Creswell & Plano Clark, 2017). Addressing the needs of interdisciplinary research, the CA offers an advanced method for visualising and analysing complex environments (Ohlhorst & Schön, 2015). The CA can be applied for the retrospective investigation of innovation biographies, as well as for the analysis of ongoing innovation diffusion dynamics (Ohlhorst & Schön, 2015). This fruitful concept has been applied in several sustainability and innovation research studies, such as the innovation biography of renewable energies (Bruns et al., 2010; Bruns & Ohlhorst, 2011) and urban sustainable governance strategies (Mahlkow et al., 2016).

The CA is based on the graphical mapping of development processes. The overarching patterns are derived from the bottom-up analysis of individual elements and their relationships (Ohlhorst & Schön, 2015). This process reveals the regularities, principles of order, dynamics, and trends of the overall context. (Schön et al., 2007). A conceptual key point of the CA is the equal consideration of four types of heterogeneous elements: natural elements (e.g., natural resources and environmental media); technical elements (e.g., hardware and power stations); systems of signs (e.g. rules, legislation, and standards); and social actors (e.g. individual people, companies, and associations) (Schafer et al., 2010). Another important focus of the methodology is the relationship between the elements. Statements about relationships between the elements can be made in two ways: by closely or loosely mapping the elements, and by using different line and arrow types (Schön et al., 2007). This typification offers each scientific discipline and each non-scientific participant connecting points for their own perception of reality.

The TIS-MLP framework and the CA share several key features. One of the most important similarities results from the fact that the existence of heterogeneous elements plays a central role in both approaches (Geels, 2011; Schafer et al., 2010). As discussed by Best et al. (2012), this can be explained by the fact that the approaches share common theoretical ground: the actor-network theory. As both approaches classify themselves as mid-range theories, another important point in common comes from the same level of abstraction (Geels, 2011, p. 24; Schön et al., 2004). Both approaches assume that the dominant configuration is embedded within a broad exogenous context that is not under the direct influence of the actors (Geels, 2011; Schafer et al., 2010). Therefore, it can be argued that the landscape level of the MLP and the contextual elements are mutually compatible. One of the key elements of the CA is the identification of overarching orders at the macro level through a continuous iterative bottom-up process based on graphic-visual means. As the overall constellations of the CA represent the structural composition of the most significant elements, parallels can be drawn with the configuration of the socio-technical regime. Within the context of this research, the CA facilitates the synthesis and visualisation of the results of the literature review, the operationalisation of the MLP-TIS framework, the identification and analysis of developmental episodes, and the subsequent triangulation of the results with experts.

To meet the objectives of this study, the CA process was slightly adapted and comprised seven steps: 1) preliminary semi-structured expert interviews (Appendix 8.1. and 8.2.) to obtain an initial understanding of the evolution of the energy sector and the wind energy market in Argentina, 2) systematic literature review and synthesis of relevant events and developments with time classifications, 3) segmentation of the process into individual development phases (Figure 2), 4) visualisation of individual elements and resulting constellations within the individual development phases, 5) description of how the constellation changes from phase to phase (e.g., new relationships and elements) and analysis of the development process, 6) identification of dominant factors that have significantly shaped a phase, 7) iterative verification of the results with experts (Appendix 8.1.), and 8) integration of the experts' perspectives and feedback (Appendix 8.3.).

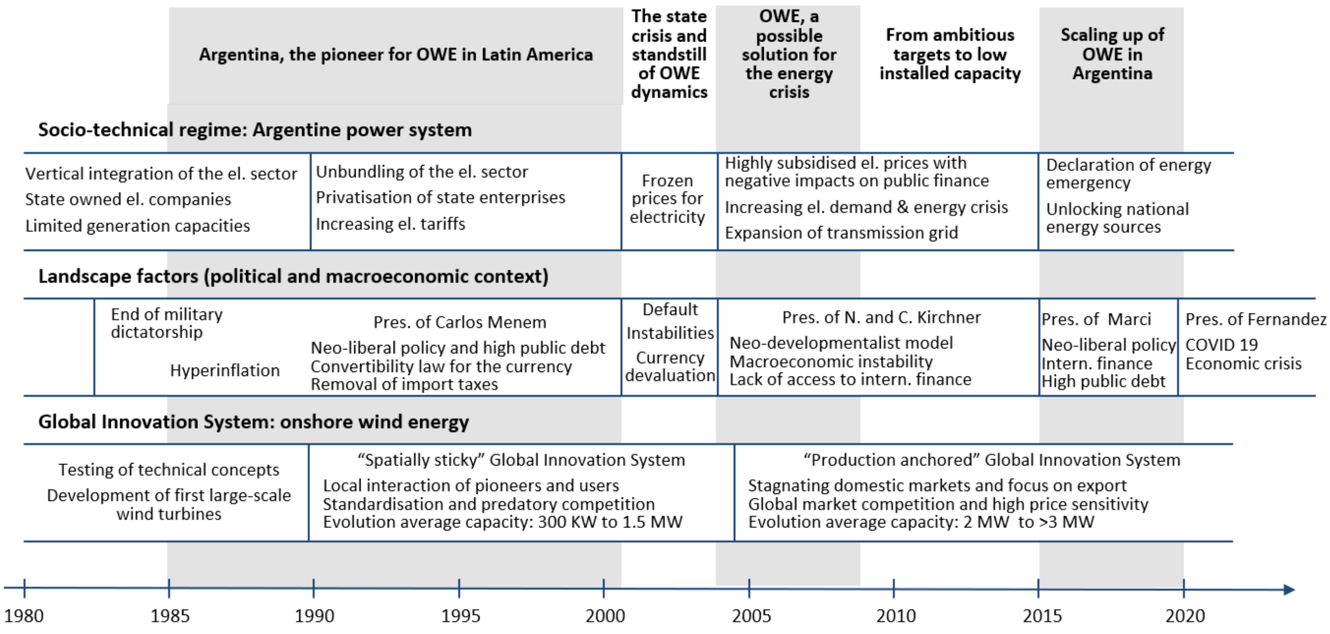

Figure 2: Overview of the development phases of onshore wind energy (OWE) in Argentina
Source: Own illustration

4 Results

4.1 1985-2000: Argentina, the pioneer of onshore wind energy in Latin America

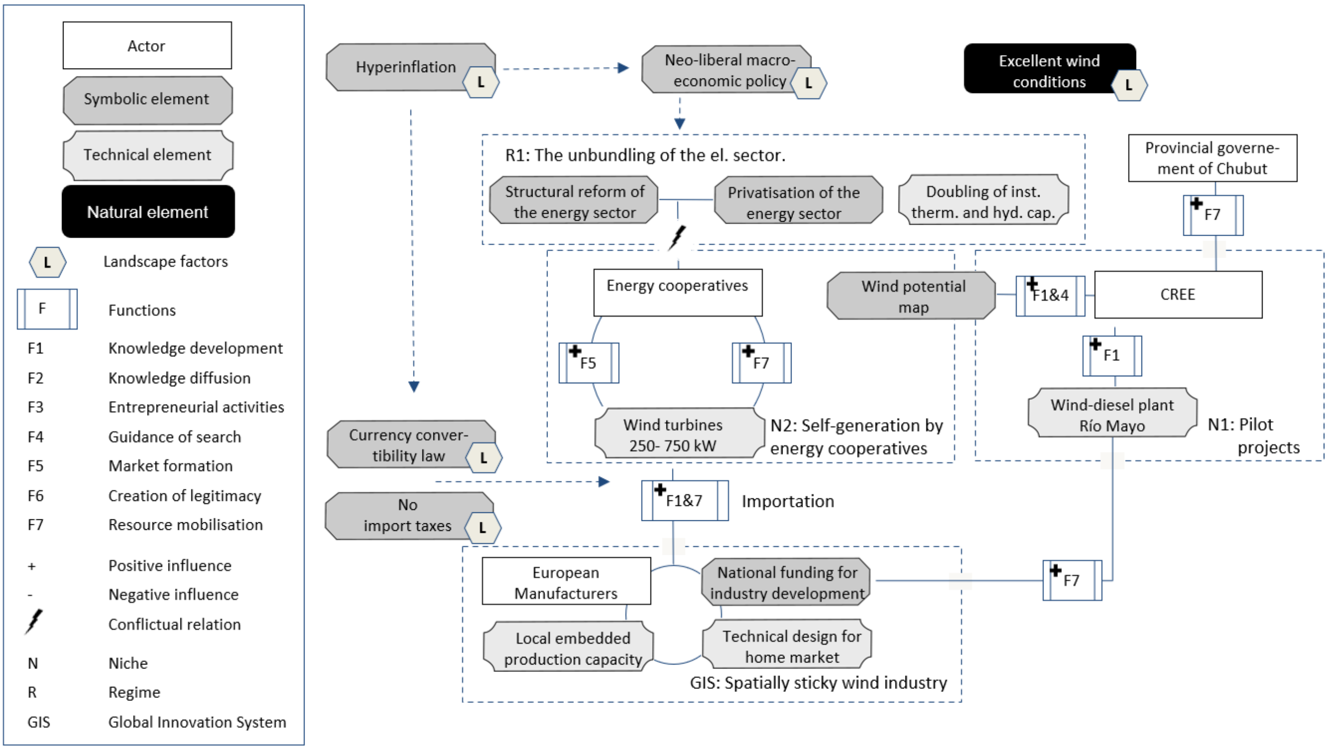

Figure 3: Constellation analysis of the development period between 1985 and 2000
Source: Own illustration

The Province of Chubut as a seedbed for the development of wind energy:

As shown in the results of the CA in Figure 3, in the 1980s and 1990s the development and diffusion of wind energy in Argentina was spearheaded by the province of Chubut and the Argentine energy cooperatives as reflected in Figure 3 by their central role in the constellation analysis (CA). These developments took place during a particular period in Argentine history, as the democratic election of President Raúl Alfonsin in 1983 marked the end of the military dictatorship (M. Y. Recalde et al., 2015). The Regional Centre for Wind Energy (CREE)[1] founded in 1985 in Chubut (Garrido et al., 2016b) initiated the pioneering work in the development of wind energy in Argentina. The creation of the first anemometric observation networks in the province of Chubut and the elaboration of a wind energy potential map of the southern provinces of Argentina endorsed the "knowledge development" and "guidance of search processes" of the emerging focal TIS. An international cooperation between CREE and the Federal Ministry of Education and Research of Germany resulted in a significant milestone in 1990 with the installation of a wind-diesel hybrid system (5 turbines of 30 kW each) in the city of Río Mayo in Chubut: the first large-scale wind energy project in South America (Jones, 2021). Moreover, CREE became known

[1] El Centro Regional de Energía Eólica (Regional Centre for Wind Energy)

internationally for supporting the deployment of small wind turbines for rural electrification (Leary et al., 2019). In 1998, the province of Chubut introduced the first renewable energy legislation in Argentina with Law N°4.389 (Jimeno, 2015). In addition to economic incentives, the use of wind energy and the establishment of its own industry were legally defined as the province's target vision. Up to 2001, the interplay of the aforementioned factors resulted in the installation of 17.46 MW wind capacity, making Chubut (in terms of installed capacity) the leading province in Argentina (Labriola, 2020b). Nevertheless, due to the proportionally low share of installed capacity, wind energy did not play a decisive role in Argentina's energy supply during this phase. Instead, between 1992 and 2000 the development dynamics of the socio-technical regime were characterised by a steady expansion of installed capacity of hydropower (3.7 GW) and thermal power plants (4.5 GW) (CAMMESA, 2023).

Changing landscape conditions create a favourable context for wind energy projects:

In the 1990s, wind energy development at national level was significantly influenced by economic structural reforms in Argentina. Menem's neo-liberal economic policy, oriented towards the "Washington Consensus"[2], created strong pressure as a landscape factor for the transformation of the socio-technical regime. Due to changing market conditions, this opened a window of opportunity for the diffusion of wind energy and the development of a niche spearheaded by energy cooperatives. The starting point for these developments was the hyperinflation and high level of public debt from which Argentina was suffering (Bambaci et al., 2002). To address the hyperinflation of the 1980s, the Convertibility Law was passed in 1991 under the presidency of Carlos Menem (1989-1999). This law included three key measures: pegging the Argentine exchange rate to the US Dollar, guaranteeing a minimum of 100% coverage of the monetary base by freely available gold or foreign exchange reserves, and the guarantee to exchange Argentine currency at any time for US dollars (W. C. Smith, 1991). These measures solved hyperinflation. However, the overvalued Argentine Peso reduced the competitiveness of exports and, in the long term, led to a sharp increase in foreign debt which laid the foundation for the 2001 economic crisis (Starr, 2003). However, the fixed exchange rate of the Argentine currency together with the removal of import taxes on investment goods provided favourable economic and stable landscape conditions for the importation of wind turbine equipment from European companies.

Pioneering role of energy cooperatives incentivised by changes in the socio-technical regime in the context of a spatially sticky GIS:

Furthermore, the structural reforms in the Argentine energy industry resulted in the privatisation of state-owned enterprises, the unbundling of the power sector, and the liberalisation of Argentina's electricity markets (Pollitt, 2008). The increase in electricity procurement costs incentivised energy cooperatives (which play an important role in the provision of energy services, particularly in rural areas) to develop and own their own generation capacities in order to avoid relying exclusively on the electricity provided by distribution companies (L. V. Clementi, 2019). As shown in Figure

[2] The Washington Consensus refers to a series of economic policy reforms recommended by international financial institutions in the 1980s and 1990s with the aim of achieving economic stability and growth in developing countries through market liberalisation, deregulation and further measures (Williamson, 2004).

3, between 1994 and 1998, electricity cooperatives became pioneers in establishing a niche for the diffusion of large-scale wind turbines (Garrido et al., 2016b). This had become possible due to the support of public institutions and foreign companies (mainly of German, Spanish, and Danish origin), which enabled the accumulation of technical know-how, equipment and financial capital (L. V. Clementi, 2019). Consequently, this period saw an increase in OWE to a total capacity of 26.56 MW through the installation of wind turbines from European companies, namely Micon (250 kW and 400 kW), Vestas (750 kW), Gamesa (660 kW), and Bonus (600 kW) (Jones, 2021; Labriola, 2020b). The interaction dynamics between the focal TIS and the GIS are significant in this context. Binz & Truffer (2017) characterise the GIS of wind energy in the 1990s as "spatially sticky", because during this period innovation activity was strongly characterised by locally-based interaction between pioneers and technology users in forerunner countries. To promote the growth of the new industry, subsidy programmes for the exploration of new markets were set up. In terms of the wind energy projects in Argentina, one example is Germany's "Eldorado" programme, which provided funding of up to 70% between 1991 and 1998 for the use of German wind turbine manufacturers (AN-Bonus and Ventis) (Hoppe-Kilpper, 2003). This had a positive effect on the "resource mobilisation" processes of the focal TIS, and field testing in the harsh wind conditions in Argentina contributed to "knowledge development" processes at GIS level.

4.2 2001-2003: Aftermath of the 2001 crisis, stagnation of wind energy development

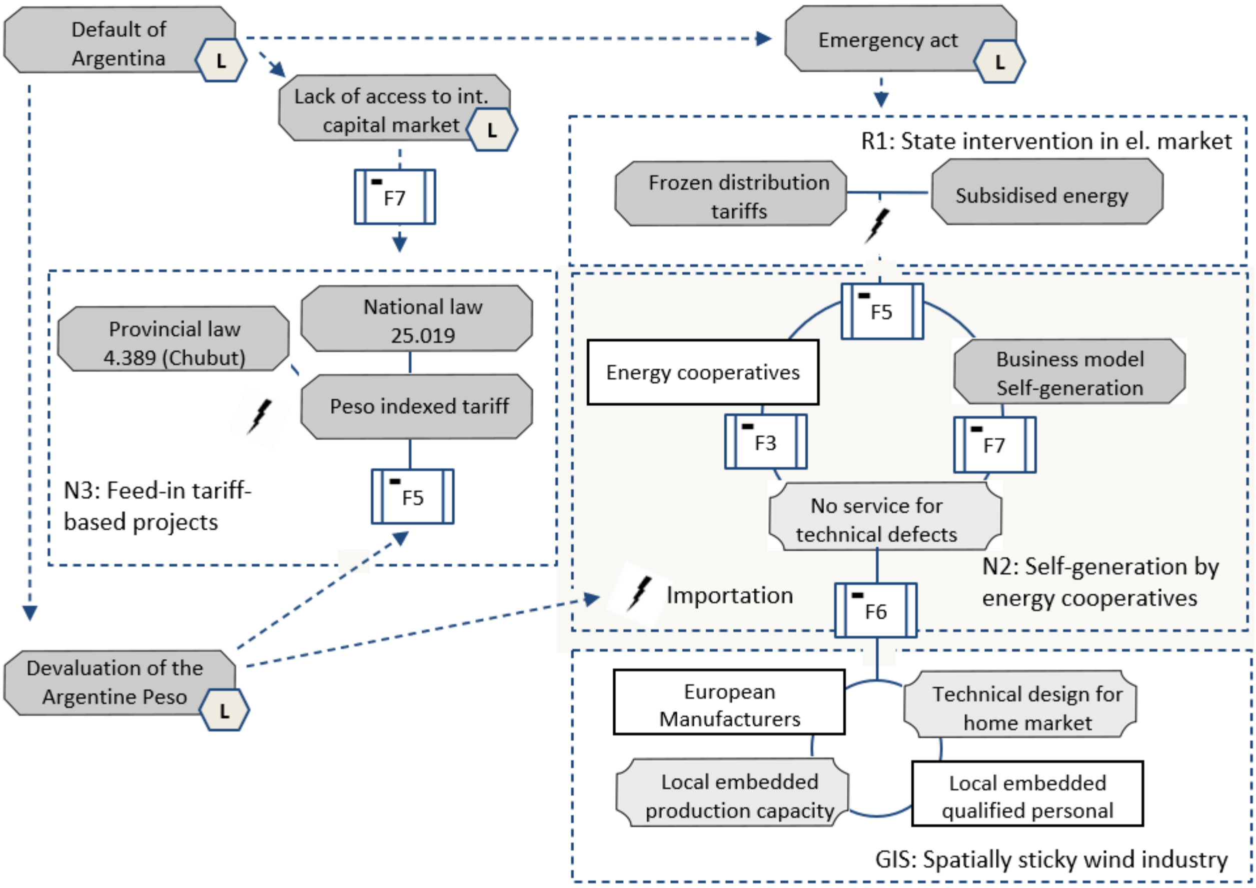

Figure 4: Constellation analysis of the development period between 2001 and 2003
Source: Own illustration

Argentina's role as a pioneer in wind energy in Latin America was disrupted by the economic and political crisis in 2001 which, as an external landscape shock, had massive implications for the socio-technical regime and the evolving focal TIS. In the CA presented above (Figure 4), Argentina's economic default is a key factor with its associated negative implications for existing market segments. This crisis had its origins in domestic contextual factors, such as high levels of public debt, the overvalued Peso, and low competitive advantages, as well as in international issues, such as currency devaluations in other Latin American countries (the Tequila crisis in Mexico in 1994 and Brazil in 1998). Due to the resulting deterioration of macroeconomic data, an "external drain" of foreign capital started at the end of 2000 and fears of a banking crisis fuelled a massive withdrawal of domestic capital. This "internal drain" was addressed through bank account freezes which, in conjunction with a significant decline in living conditions, led to mass protests and uprisings. This crisis culminated in the declaration of the largest default on public debt in global financial history at the end of 2001 (Damill et al., 2015).

In January 2002, to avoid a dramatic increase in electricity prices in the new economic landscape, the government of Argentina authorised the executive to renegotiate all public utility contracts through Article 9 of the Emergency Law (Haselip & Potter, 2010). To ensure stable and affordable electricity prices, the regulated transmission and distribution tariffs were frozen. In addition, the public utility concessions were completely freed from all price adjustment clauses and inflation indexation mechanisms (Di Bella et al., 2015). This had huge consequences for the regime logic. As a result of the widening gap between the adjusted electricity price and the real cost of energy, the economic and financial situation of Argentina's energy companies worsened significantly (Haselip & Potter, 2010; Sbroiavacca & Falzon, 2014). Another effect of the 2001 crisis was that the Argentine Peso was overvalued. The Argentine government was forced to abandon pegging it to the US Dollar to make exports more competitive, which resulted in the Peso losing 70% of its value (Haselip & Potter, 2010).

The impact of the landscape shock (2001/2 crisis) on the development dynamics of the focal TIS:

The results of the CA in Figure 4 show that, on the level of the focal TIS, these macroeconomic measures and the associated interventions in the energy market resulted in long-term negative effects for the development of wind power in Argentina:

- The decline in the Argentine exchange rate (making imports more costly) combined with the state's intervention in energy pricing meant it was no longer attractive for energy cooperatives to build their own wind power generation capacities. This substantially weakened the "entrepreneurial activities" as well as the "market formation" and "resource formation" processes of the focal TIS. As a result, the diffusion dynamics in the formerly successful cooperative niche application context were brought to a standstill. This situation was reinforced by regime dynamics resulting from the significant subsidisation of prices for conventional energy from 2003 onwards (L. V. Clementi, 2019).
- The operation of around half the wind farms from the 1990s was suspended as the procurement of spare parts and qualified personnel for maintenance and operation became considerably more expensive and difficult due to import restrictions and the devaluation of the national currency. This had negative implications for the "creation of legitimacy" function of the focal TIS (L. V. Clementi, 2019; Garrido et al., 2016b). This illustrates a vulnerability in the Argentine focal TIS, which lacks its own capabilities for the downstream activities of "operate and maintain" in the context of a "spatially sticky" GIS (Binz & Truffer, 2017).
- The currency devaluation undermined the first renewable energy legislation that had been introduced at national level (Loy et al., 2007). Law Nº25.019, passed in December 1999, specified that wind turbine operators who fed their electricity into the public grid would receive an additional payment of 0.01 Argentine Peso/kWh for 15 years, as well as tax relief for their investment activities (Helmke, 2009a; LaMarca, 2011). The promotion programme introduced in Chubut Province in 1998, which provided an additional subsidy of 0.005 Argentine pesos/kWh over 10 years, also lost its incentive effect as a result of these macroeconomic changes (Helmke, 2009b). Due to the decoupling of the Argentine Peso from the US Dollar and the macroeconomic uncertainties, project planning for wind energy projects ceased, which, for the next couple of years, prevented niche development dynamics in the application context of large-scale feed-in tariff-based projects. (Jones, 2021).

4.3 2004-2008: Onshore wind energy, a possible solution to the energy crisis

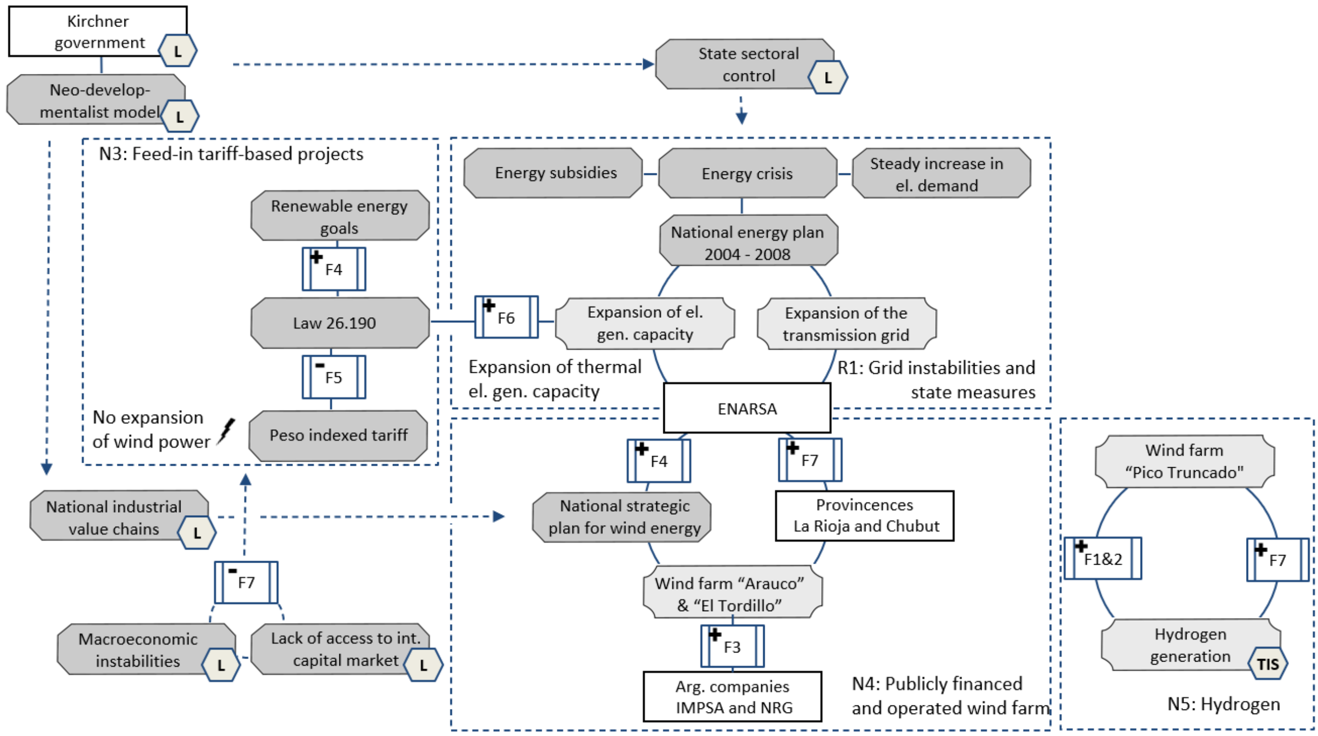

Figure 5: Constellation analysis of the development period between 2004 and 2008
Source: Own illustration

The neo-developmentalist political-economic model as a shaping landscape factor fostering the establishment of a national wind energy value chain:

After around two years of political instability during which the administration of Argentina's presidency changed five times, Néstor Kirchner was inaugurated as the new President of Argentina in May 2003. The state's actions during the period of the Kirchner government (2003-2015) were guided by a new political self-conception, which is referred to in the literature as the neo-developmentalist political-economic model (Féliz, 2012; Ruggeri & Garrido, 2021). To make Argentina's economy more resilient, there was a focus on the enhancement of industrialisation and redistribution processes that intended to promote the development of internal market consumption (Porta et al., 2017). As shown in Figure 5, this economic policy shaped the overall context (the landscape) for the socio-technical regime and the focal TIS. This became evident through the intervention of public authorities in the energy market (sanctioning of prices and tariffs and the implementation of subsidies), deliberate planning of public generation and infrastructure capacities, and the support of national wind energy manufacturers (Furlan, 2014).

Regarding the development of wind energy, the neo-developmentalist politico-economic model was reflected in the "National Strategic Plan for Wind Energy" (Plan estratégico Nacional de Energía Eólica), presented in 2005. Following the aim of increasing electricity generation from wind energy and promoting the development of a national industry for wind turbines, the plan had a positive influence on the "guidance of search" and "creation of legitimacy" processes of the focal TIS, as shown in Figure 5 (Garrido et al., 2016b). In concrete terms, it proposed the development of a national wind energy atlas (under the leadership of CREE) and the installation of 300 MW of generation capacity with a minimum share of 80% of local components by 2012 (Garrido et al., 2016b; IRENA, 2015). To achieve this target, the public energy utility ENARSA together with the respective provincial governments of Chubut founded associations to develop, finance, and operate proprietary wind farms ("El Tordillo" wind park) and La Rioja ("Arauco" wind park) (L. Clementi, 2018b). In terms of the development of the focal TIS, it is worth noting that IMPSA[3] and NRG Patagonia, the only two Latin American manufacturers of wind turbines, developed in Argentina during this period (Pedraza, 2012). In 2003, IMPSA was the first Latin American company to develop a proprietary technical design for a wind turbine and wind generator (UNIPOWER(R)) and, in 2007, it expanded its portfolio by obtaining a licence from the German manufacturer Vensys (Papa & Hobday, 2015). To date, 30 IMPSA wind turbines with a total capacity of 61.5 MW have been installed in Argentina. Against the backdrop of the Brazilian government's support programmes for renewable energy (PROINFA), the company expanded in the areas of hydro and wind to Brazil (Papa & Hobday, 2015). In subsequent years, 289 IMPSA wind turbines (with a total capacity of 1.5 MW) were installed in Brazil. However, due to economic difficulties, IMPSA's Brazilian subsidiary was declared insolvent in 2014 (Bayer, 2018). The second Argentine wind turbine manufacturer is NRG Patagonia. The company's mission is to develop wind turbines that can withstand the particularly strong Patagonian winds (L. Clementi, 2018b). The NRG1500, which they manufactured first, is a 1.5 MW wind turbine which has a triple independent blade pitch system to prevent breakage in extreme Argentine winds (L. Clementi, 2018b). A pilot project was successfully installed at the "El Tordillo" wind farm in 2013 (Labriola, 2020b).

The crisis of the socio-technical regime as a window of opportunity for renewable energy:

From 2004, stimulated by growing exports and subsidised energy prices after years of economic recession, the Argentine economy began to recover (Pollitt, 2008; M. Y. Recalde et al., 2015). However, the resulting increase in electricity demand led to significant problems regarding security of supply in the electricity sector (Pollitt, 2008). In the context of this severe energy crisis, the government under President Néstor Kirchner adopted the National Energy Plan 2004-2008 (Plan Nacional Energético 2004-2008), which was based on five pillars: an increase in taxes on energy exports, the establishment of a public energy utility (ENARSA)[4], measures to promote energy efficiency, the establishment of a public fund for investment in power generation capacities, and a programme for the energy integration of individual regions through investment in high-voltage transmission lines (Helmke, 2009a). By 2015, 5500 km of high-voltage lines had been installed, which were of crucial importance for the subsequent expansion of wind energy (Ruggeri & Garrido, 2021). Moreover, since 2005, the two main grids in Argentina, the SIP[5] and the SADI[6], have been connected by a 500 kV high-tension line (Rolf Posorski et al., 2007). Since the south of Argentina

[3] Industrias Metalúrgicas Pescarmona Sociedad Anónima (Pescarmona Metallurgical Industries Public Limited Company)

[4] Energía Argentina S.A. (state-owned company mainly active in the energy and petrol sectors)

[5] Sistema Interconectado Patagónico (The Patagonian Interconnection System)

[6] Sistema Argentino de Interconexión (The Argentine Interconnection System)

has very high wind potential, this step was important for making it possible to transport electricity to the main points of consumption in the province of Buenos Aires (Helmke, 2009a). This notwithstanding, against the backdrop of insufficient generation capacity, the government also promoted the exploration of additional renewable and conventional domestic energy sources with the objective of increasing Argentina's autonomy. In this way, the energy crisis (socio-technical regime), in combination with the Kirchner government's economic policy (the landscape), created a window of opportunity for the development of renewable energies. At the same time, however, the path dependencies of conventional energy were further consolidated through investment in infrastructure and new regulations. At the level of the socio-technical regime, the stimulation of the expansion of natural gas production through higher purchase prices under the Gas Plus programme, the subsidisation of end user prices for natural gas and, from 2011 onwards, the promotion of shale gas exploration are particularly noteworthy (Gomes & Brandt, 2016).

In 2006, the Argentine government passed a series of laws to promote diversification of the national energy supply: Law Nº26.093 on the regulation and promotion of the sustainable production and use of biofuels; Law Nº26.123 on the promotion of hydrogen; Law Nº26.334 on bioethanol; and Law Nº26.190 on the promotion of renewable energy sources (L. Clementi, 2018b). For the first time (under Law Nº26.190), a national renewable energy target was set: by 2016, 8% of electricity demand was to be met by renewable energy (Guzowski & Recalde, 2010). To ensure the funding of the programme, the government established the Renewable Energy Trust Fund (Fondo Fiduciario de Energías Renovable). However, like Law Nº25.019, this programme failed to have the desired impact on the dynamics of the "large-scale feed-in tariff-based projects" niche. There were three reasons for this. Firstly, the feed-in premium (FIP) fixed under the law was too low to attract investment. Secondly, the maximum subsidy period of 15 years was considered to be too short, and, thirdly (and most relevantly), the FIPs were indexed in Argentine pesos which steadily fell in value from 2008 onwards (Jimeno, 2015; M. Recalde, 2015). Due to the combination of high upfront costs in US dollars and expected reduced revenues from the exchange rate decline, investments in wind energy were exposed to rising uncertainty resulting from the Argentine macroeconomic landscape factors. Consequently, such investments became less attractive. As a result, wind energy did not expand under the scheme established by Law No. 26,190, leading to subsequent support programmes with modified conditions.

Hydrogen generation as a complementary TIS:

One significant milestone independent of the overall national developments described was the inauguration of the Hydrogen-Wind Demo Experimental Plant in Pico Truncado in the province of Santa Cruz in 2005 (Aprea, 2009). Using electricity generated from four Enercon E-40 wind turbines (600 kW each), this was the first such pilot project in Latin America and it remains an important centre for research and development supporting knowledge generation and the diffusion processes of the focal TIS (Belmonte et al., 2017; Bolcich, 2006). The application context of hydrogen production from regenerative sources can be seen as an independent niche. This illustrates how new niches can arise through the interactions between different TIS; in this case, "onshore wind energy" and "hydrogen generation".

4.4 2009-2014: From ambitious targets to low installed capacity

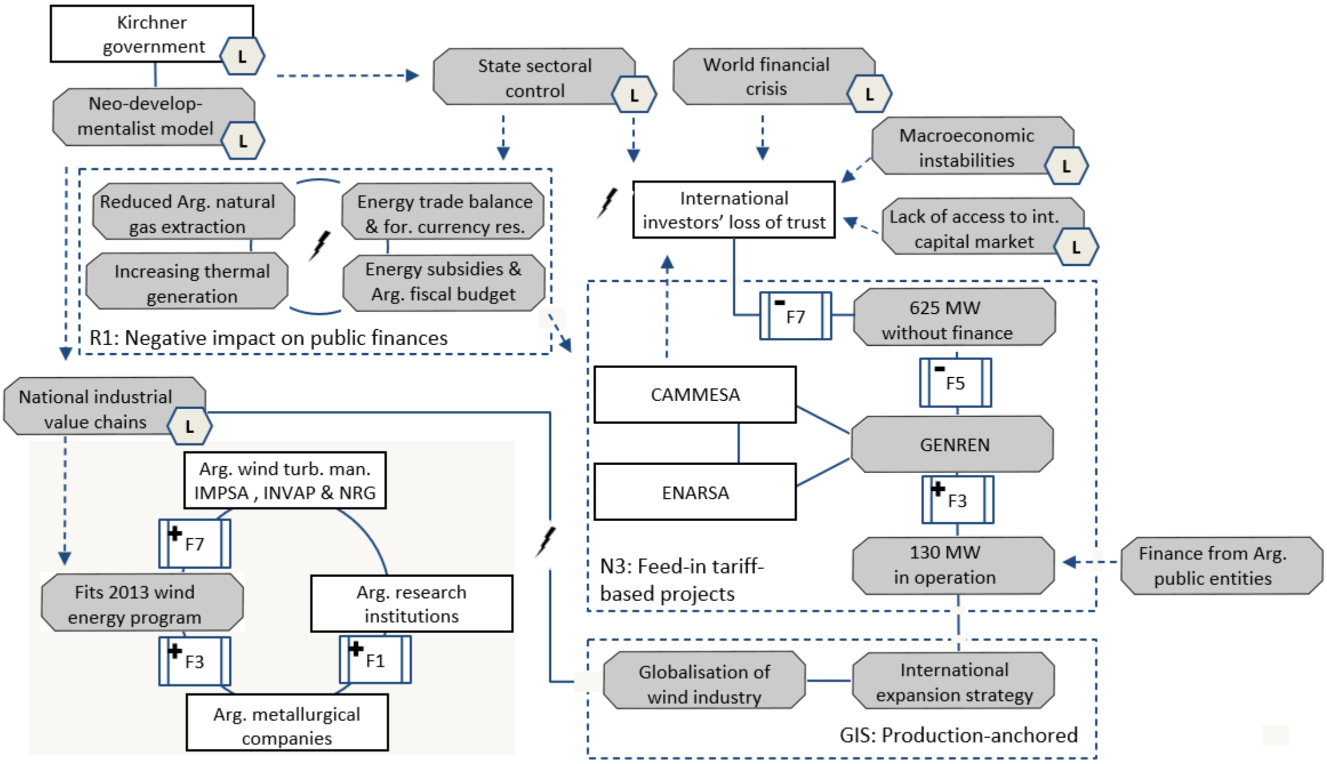

Figure 6: Constellation analysis of the development period between 2009 and 2014
Source: Own illustration

Promotion of an Argentinian wind energy value chain in the context of increasing globalisation of the wind energy industry:

The development of wind energy in Argentina in the early 2010s took place during a period of increasing globalisation of the wind industry (Lacal-Arántegui, 2019). As discussed by Binz & Truffer (2017), onshore wind technology evolved at this time from a "spatially sticky" system in the 1990s to a production-anchored GIS in which wind turbines became a standardised product with price-sensitive global market competition. For many years, the European Union (EU) had been the market with the highest annual rates of newly installed wind power capacity. However, in 2008 China became the market leader, installing between 40% and 50% of the world's capacity in the years that followed (Lacal-Arántegui, 2019). Due to the limited EU market for onshore wind energy and strong dependence on political framework conditions and land use, European manufacturers aimed at achieving economic growth through an international expansion strategy (Lacal-Arántegui, 2019). Consequently, between 2010 and 2015, around 70% of new wind power capacity in Argentina was installed by European manufacturers (Vestas: 83.65 MW, Alstrom: 50 MW, and Enercon: 6.3 MW). Furthermore, in 2007, the German manufacturer Vensys (acquired by the Chinese firm Goldwind in 2008) used licensing to the Argentine company IMPSA to gain access to the Latin American market (Friedrich & Lukas, 2017).

In line with the Kirchner government's neo-developmentalist strategy, an important initiative to strengthen the national wind energy sector was the "Fits 2013 Energy – Development and Production of High Performance Wind Turbines" programme (FITS 2013 ENERGIA – Desarrollo y Fabricación de Aerogeneradores de Alta Potencia), which was launched in 2013 by the National Agency for Scientific and

Technological Promotion (Agencia Nacional de Promoción Científca y Tecnológica). It had positive impacts on the "resource mobilisation", "entrepreneurial activities", and "knowledge development" functions of the focal TIS (Aggio et al., 2018). With the aim of strengthening the different stages of the value chain, six projects totalling 40 million pesos (25 million US dollars at the time of the call for proposals) were promoted in the following areas: production of components for wind turbines, elements for grid connection systems, and the production of wind turbines with a capacity of at least 1 MW (Aggio et al., 2018). This support programme made an important contribution to the further development of technical know-how within various companies. Further information is provided in Annex 8.4. As shown in Table 5, only one project – for the national production of wind turbine towers – was successfully completed within the programme period (Aggio et al., 2018). In terms of industrial policy, the experts interviewed for this study suggested that it would have been more effective to promote Argentina's integration into the global wind energy value chain for areas with comparative advantages, rather than the Kirchner government's strategy of developing a holistic national value chain.

Challenging landscape factors as a barrier to the success of the GENREN programme and the development of the niche for feed-in based projects:

To meet the target of an 8% share of renewable energy (as stipulated in Law 26.190), the GENREN[7] programme was launched in 2009. A key rationale behind the GENREN programme was the growing necessity to reduce fossil energy imports – which exerted increasingly existential pressure on the national fiscal budget and Argentina's foreign currency reserves – through the expansion of renewable generation capacity (Chemes & Bertinat, 2018; Gomes & Brandt, 2016). Until the mid-2000s, Argentina generated substantial surpluses of natural gas and had a positive energy trade balance (by exporting natural gas to Brazil, Chile, and Uruguay) (Gomes & Brandt, 2016). However, the prevailing public policies in the energy sector following the 2001/2002 economic crisis and in the context of increasing energy demand in combination with weak investment incentives led to a sharp decline in domestic gas reserves and production, turning the country into a net importer of gas and hydrocarbons in 2008 and 2011 respectively (Gomes & Brandt, 2016). The expansion of renewable energies was intended to reduce the negative influence exerted by the socio-technical regime on Argentina's overall macroeconomic situation.

Wind energy played a central role in the GENREN programme (M. Recalde, 2015). In contrast to previous funding instruments, the project-specific feed-in tariffs resulting from the tender were fixed under long-term purchase contracts for 15 years in US dollars (M. (Recalde, 2015). A central role was played the public company ENARSA, which was responsible for the tendering process and for commercialisation of the renewable electricity generated. The electricity was sold to CAMMESA[8] as the administrator of the wholesale electricity market (Ruggeri & Garrido, 2021). To secure the transactions, the BICE[9] set up a trust fund that included guarantees of 800 million

[7] Programa Generación Renovable (programme for renewable generation)

[8] Compañía Administradora del Mercado Eléctrico Mayorista S.A. (Argentine Wholesale Electricity Market Clearing Company)

[9] Banco de Inversión y Comercio Exterior (Argentine Bank for Investment and Foreign Trade)

US dollars from the National Treasury to cover the risk of possible shortfalls within CAMMESA and ENARSA (L. Clementi, 2018b). The projects were selected based on the following criteria: tender price, timescales for implementation, and percentage of national production in relation to the total investment (Caruana, 2019). However, during this period, the macroeconomic uncertainty and distrust of government guarantees by the banks and investment funds made it difficult for wind energy project developers to access the international capital market at reasonable interest rates (Ruggeri & Garrido, 2021). Although 754 MW of the 895 MW of total capacity awarded allocated to wind energy, only three projects (with a total installed capacity of around 130 MW) were implemented (Vanesa Clementi et al., 2021b). In this context, the Loma Blanca IV wind energy project with a capacity of 51 MW was the only project which managed to access external finance through the issue of a bond with a Fitch rating of BBB (Isolux Corsán, 2013). The expert interviews carried out in this research study highlighted that, in contrast, the Rawson I and II wind farms were financed by a consortium that included the Argentine bank Banco Macro S.A., public actors such as the Administración Nacional de la Seguridad Social (Argentine national pension system), and the Banco de la Nación Argentina (National Bank of Argentina) (Castro, 2011). The specific national risk premium for investments in renewable energy generation capacities in Argentina becomes apparent through a comparison with the simultaneous tenders for wind energy in Brazil. Under the GENREN programme in 2009, tenders were awarded for Argentine projects with costs of 121 – 134 USD/MWh, while in Brazil tenders for projects with costs of 70–85 USD/MWh were awarded (Bayer, 2018; Schaube et al., 2018). These higher risk premiums result from the challenging contextual conditions at the landscape level, despite the efforts made by the Kirchner government to address these macroeconomic difficulties by introducing a number of economic reforms.

Some of the measures taken actually led to a loss of confidence among traditional international investors (Pollitt, 2008): public debt renegotiation attempts (2006 and 2010), the nationalisation of private pension funds (2008), the rapid pace of monetary creation to finance expansionary fiscal expenditures (after 2009), the abandonment of the stable and competitive real exchange rate strategy by Argentina's central bank (after 2010), the continuous devaluation of Argentina's currency (after 2009), and the increasing fiscal deficit (after 2011) fuelled by energy subsidies and very high inflation rates (Buera & Nicolini, 2019; Damill et al., 2015; Szigeti, 2013). In addition, the investment climate for energy-related commitments was weakened by the growing political involvement in the central market player CAMMESA and the expropriation and nationalisation of the energy company YPF (Yacimientos Petrolíferos Fiscales S.A.) in 2012 (Fernandez Gonzalez et al., 2019; Szigeti, 2013). Moreover, CAMMESA was significantly beholden to the government at the time as it was dependent on state funding due to the energy subsidy policy (Vagliasindi, 2012). This created doubt among national and international investors that the GENREN financial guarantees would be fulfilled by CAMMESA (Garrido et al., 2016b; Vanesa Clementi et al., 2021b). This in turn made it difficult for wind energy projects to access the capital market and had a strong negative impact on the resource mobilisation processes of the focal TIS. Additionally, access to the capital market was complicated by the effects of the global financial crisis in 2009, which was a landscape shock at the global level (Barrera et al., 2022a)

In 2011, the Argentine Secretary of Energy released Resolution 108/2011, which encouraged the “entrepreneurial activities” and “knowledge generation” processes of the focal TIS (Figure 6). The Resolution made it possible to negotiate PPAs between CAMMESA and wind energy projects (Jimeno et al., 2016). Six wind energy projects with a total capacity of 372 MW were selected by the Secretary of Energy for PPA agreements, of which 68 MW were commissioned (L. Clementi, 2018b). One of the projects under Resolution 108/2011 is the wind park Aurauco, which represents a milestone for wind energy development in Argentina (Labriola, 2020b). The project was driven by the province of La Rioja, which took a 75% stake in the wind farm’s operating company (Belmonte et al., 2017). The Arauco wind park, with a total capacity of 50.4 MW, is remarkable because it is the first example of the installation of large-scale wind turbines developed and produced in Argentina by the company IMPSA (Garrido et al., 2016b). Compared to its Latin American neighbours, however, Argentina fell behind in terms of wind power expansion. Between 2009 and 2014, for instance, 440 MW of wind power capacity was installed in Uruguay and 5.6 GW in Brazil (Corrêa et al., 2022; Lucena & Lucena, 2019).

Marginal expansion of renewables and reinforcement of the socio-technical regime development path:

In the expert interviews, respondents stressed that during that period, at the socio-technical regime level, the path dependency on conventional electricity generation grew further. In 2014, a law was passed that enabled and legally regulated the exploration of unconventional gas deposits (Lanardonne & Mazzochi, 2022). Argentina’s shale gas reserves are mainly located in the Vaca Muerta formation in Neuquén province in the west of the country and are one of the largest shale gas deposits in the world (Bravo et al., 2021). The experts pointed out that despite ambitious policy targets in the renewable energy sector, the path dependencies of fossil energy generation increased during this development period in the wake of a 20% increase in electricity demand. This is demonstrated by the fact that around three quarters of the new power plant capacities (in the order of 5 GW) built between 2009 and 2014 are operated using fossil energy sources, with the share of renewable energies only amounting to 1.8% (CAMMESA, 2014).

4.5 2015-2020: Scaling up of wind power in Argentina

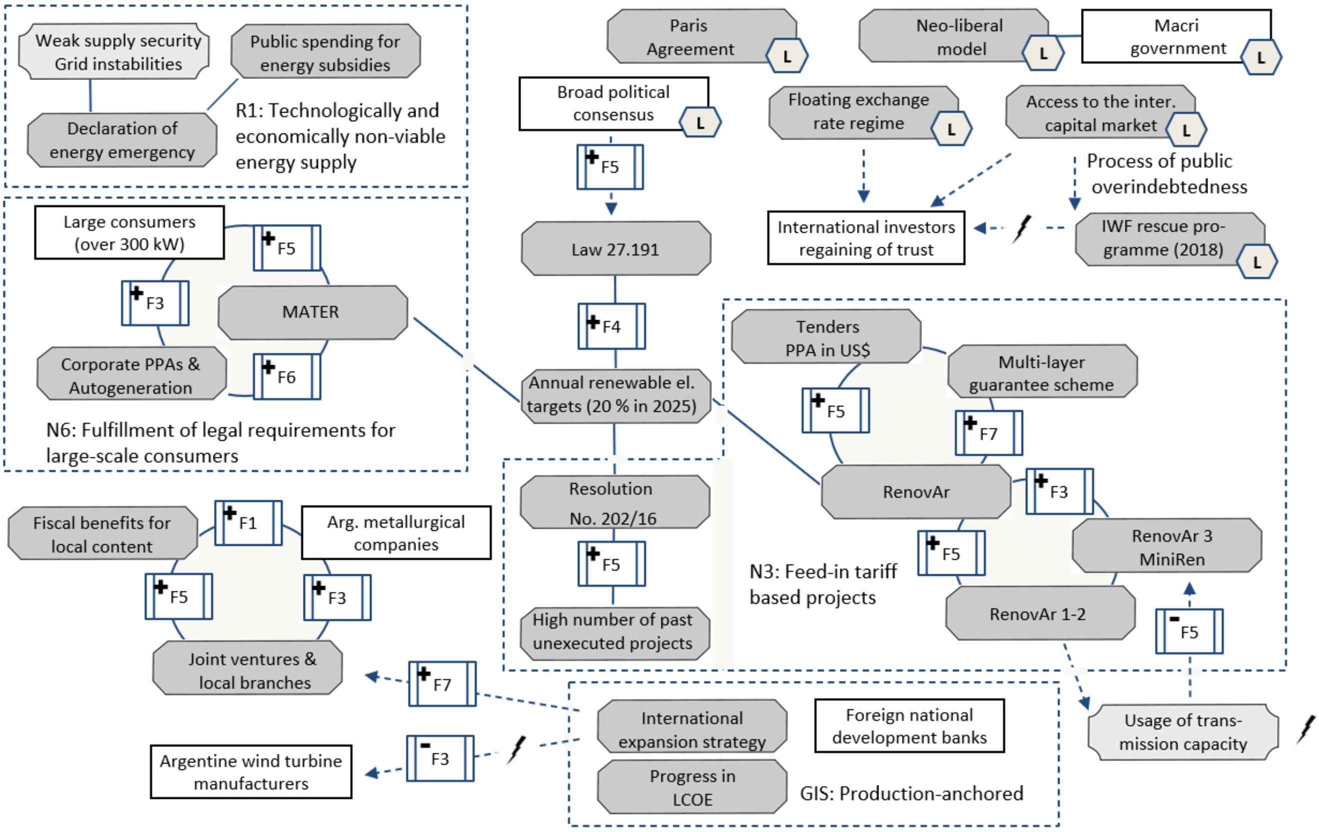

Figure 7: Constellation analysis of the development period between 2015 and 2020
Source: Own illustration

Changes at the landscape level form the basis of new development possibilities for wind energy in Argentina:

Fundamental changes at the landscape level in the political and economic context were a prerequisite for a massive expansion of renewable energy (Figure 8), as the CA analysis above (Figure 7) illustrates. These fundamental transformational changes were initiated at the end of the Kirchner era and at the beginning of Mauricio Macri's government (in office from 2015 to 2019) (Menzies et al., 2019). In contrast to the "neo-developmentalist" model of the Kirchner era, the Macri government's "neo-liberalist" economic policy was characterised by the reduction of energy subsidies, free trade, a dollarisation process in prices and tariffs, capital market deregulation, and the self-perception of the state as a rather passive guarantor within a stable investment climate (Ruggeri & Garrido, 2021). One of the government's first measures was to remove the capital exchange controls and rigid exchange rates that had been in place since 2011 (Barrera et al., 2022a). In addition, Argentina's central bank (BCRA[10]) established the key interest rate adjustment as a central instrument to counteract high inflation rates (Sturzenegger, 2019) In April 2016, Argentina resolved its conflict with the holdout bondholders and regained access to the international capital market (Barrera et al., 2022a). This was crucial for the financing of renewable energy projects and significantly strengthened the "resource mobilisation"

[10] Banco Central de la República Argentina (Central Bank of the Argentine Republic)

processes of the focal TIS. Further relevant contextual factors included the accession to the Paris Climate Change Agreement in 2016 (on the landscape level) and the declaration of the energy emergency (Decree No.134/2015) in 2015 against the background of significant challenges in the reliability of energy supply (on the socio-technical regime level) (Menzies et al., 2019). To incentivise the efficient use of energy and to reduce public spending, one important measure was to reduce the subsidisation of the energy sector at various levels (Gomel & Rogge, 2020). To improve security of supply and diversify the generation matrix, the Argentine government pursued measures to incentivise the construction of new power generation capacity as fast as possible. These measures were based on "Plan 2025", which foresaw an annual increase in electricity demand of 4% and an annual emissions reduction of 11 MtnCO2e (Gomel & Rogge, 2020). A central pillar of this strategy was the rapid expansion of renewable energies (Aggio et al., 2018).

The central energy political components:

Since 2018, Argentina has seen a significant increase in electricity generation from wind energy, as shown in Figure 8. The foundation for this development was laid at the end of 2015 with the passing of Law Nº27.191, which stipulated new targets for the expansion of renewable energies; a share of 8% had to be achieved by 2018 and a target of 20% was set for 2025 (Schaube et al., 2018).[11] Moreover, the law was based on a broad political consensus between the different political factions, which sent an important signal to international investors with a view to shaping an investment climate for long-term investments within an overall context of instability (Rogge et al., 2015). The expansion path of renewable energies described in the law was linked to the expectation that the share of energy imports could be reduced, which would be beneficial for the central bank's foreign currency reserves (Menzies et al., 2019). In addition, the law obliges large consumers (over 300 kW) to comply with the annual national targets for meeting energy demand from renewable energies (Barrera et al., 2022a). In practice, this has been achieved through the MATER[12] market programme, which is, as illustrated in Figure 7, another crucial niche for the development of the focal TIS. Moreover, the law laid the foundation for the creation of a trust fund for the development of renewable energies (FODER[13]) to provide loan guarantees to mitigate the risks of investing in Argentine renewables (Barrera et al., 2022a). Another important element of the law was tax incentives, which included exemption from import duties, accelerated depreciation, the refund of VAT, and incentives for using national products (Pardina & Schiro, 2020). As shown in Figure 8, the cumulative effect of the various measures enabled new wind power projects with a total capacity of 2.5 GW to be installed between 2017 and 2020 (CAMMESA, 2014).

[11] Intermediate targets: 2019: 12 %, 2021: 16 %, 2023: 18 %

[12] Mercado a Término de Energía Eléctrica de Fuente Renovable (Electricity Term Market for Renewable Energy Sources)

[13] Fondo parLa el Desarrollo de Energías Renovables (trust fund for the development of renewable energies)

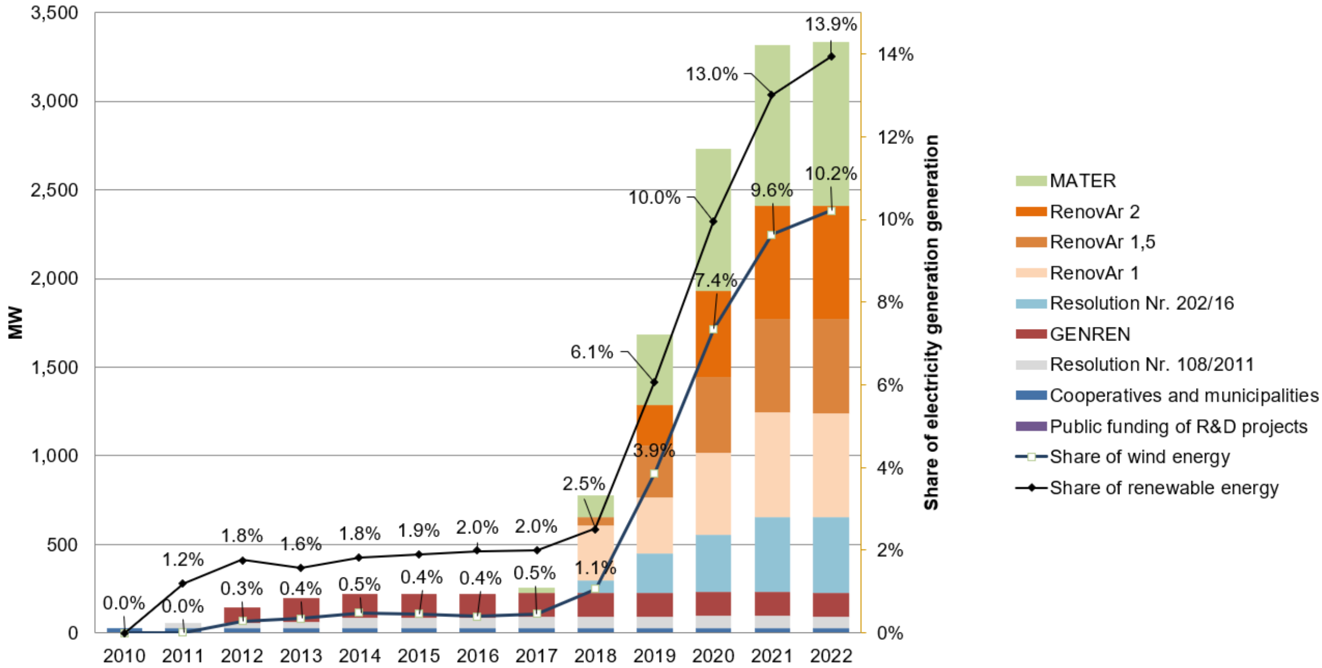

Figure 8: Development of installed capacity and market share
Source: Own illustration based on data from CAMMESA (2023)

The niche for self-generating large power consumers:

With 807 MW of installed capacity by 2020, the fulfilment of legal requirements by large-scale consumers (> 300 kW) developed into one of the most important niches for the diffusion of wind energy. It still remains a key driver in the dissemination of wind energy and, through the incorporation of a broad new actor structure, strengthens the functions of “entrepreneurial activity” and “market formation” within the focal TIS. As part of this regulation, a separate Electricity Term Market for Renewable Energy Sources (MATER) was created, which enables large consumers to select suppliers for renewable energies and negotiate individual PPAs with them (Menzies et al., 2019). In addition, the possibility was introduced for large consumers to invest in their own renewable energy generation capacities by means of a self-consumption model or to buy renewable electricity on the wholesale energy market from projects that had already been built within the framework of promotion programmes (Schaube et al., 2022). The El Llano I–III wind farms (164 MW) are a good example; their electricity is used to power the aluminium smelting plants owned by Aluar Aluminio Argentino S.A.I.C., one of the market leaders in Argentina. In addition, the expert interviews revealed that the MATER market has a special feature in that the broad structure of the off-takers per wind farm results in risk diversification. In the case of MATER, the off-takers are mainly internationally active companies of excellent financial standing, which enables the project developer to access financing. For instance, electricity from the Los Teros I wind farm (123 MW) is purchased under long-term PPAs by Toyota, Coca-Cola, FEMSA, Nestlé, and Profertil (YPF LUZ, 2021). In addition, the expert interviews highlighted the fact that, against the background of restrictive regulations on capital transactions to foreign countries, investments in renewable energies represent an attractive option for internationally active companies to invest part of the profits generated in Argentina and, at the same time, enable them to acquire foreign technologies at the official exchange rate. This is an example of the influence of specific Argentine contextual factors on the diffusion of wind energy.

Table 1: Overview of the results of the RenovAr programme
Source: based on Menzies et al. (2019) and Pardina & Schiro (2020)

	RenovAr 1	RenovAr 1.5	RenovAr 2	RenovAr 3
Tendered capacity (MW)	1,000	600	1,200 (Phase 1) 567.5 (Phase 2)	400
Date of bid submission	05.09.2016	28.10.2016	19.10.2017	30.05.2019
Country risk for Argentina JP Morgan EMBI+	4.50	4.48	3.60	9.14
Technology specific values for wind energy:				
Tendered capacity (MW)	600	400	550 (Phase 1) 275 (Phase 2)	350 (with solar)
Received capacity (MW)	3,468	1,561	3,811	155
Contracted capacity (MW)	707.4	765.4	665.8 (Phase 1) 327.6 (Phase 2)	128.7
Required capacity of a project (min & max) (MW)	1-100	1-100	1-100	0.5-10
Maximum Reserve price (USD/MWh)	82.00	59.39	56.25	60.00
Average price (USD/MWh)	59.40	53.30	41.23 (Phase 1) 40.27 (Phase 2)	58.04

First significant development of the FITS niche through the RenovAr programme and renegotiation of former unimplemented projects:

To exploit the unused potential of a high number of unexecuted projects from previous funding programmes, the Ministry of Energy and Mines published Resolution No. 202/16. The renegotiation of contract conditions already concluded accelerated the expansion of wind energy generation capacity and, as shown in Figure 8, resulted in the installation of 426 MW of wind energy capacity (L. Clementi, 2018b). An interesting case is the Malaspina I project, which was originally developed by the Argentine wind turbine manufacturer IMPSA and thus had the potential to positively stimulate national wind turbine production. However, due to a debt restructuring process within IMPSA, the project had to be sold to the French company Total Eren. Financed by the German KfW IPEX-Bank and the Dutch entrepreneurial development bank, 14 type 3.6M114 wind turbines from the German company Senvion were commissioned in 2020 (KfW IPEX-Bank, 2019).

The RenovAr[14] programme plays a central role in mapping the CA (see Figure 7). It provided the decisive impulse for the development of wind energy in Argentina in the context of the “large-scale feed-in tariff-based projects” niche. As shown in Table 1, most of the total awarded capacity was allocated to wind power projects; this reflects the enormous potential of wind energy in Argentina (Ruggeri & Garrido, 2021). Up to the end of 2022, wind parks with a total capacity of 1.8 GW were installed within a very short timeframe under the RenovAr programme. The programme comprises two key elements: (1) a public tender procedure to select the most suitable projects, and (2) a power purchase agreement for the individual projects (Pardina & Schiro, 2020). The award procedure was conducted on the basis of two selection criteria: (1) the

[14] Programa de abastecimiento de energía eléctrica a partir de fuentes renovables (Programme for the supply of electricity from renewable energy sources)

projects with the lowest bid prices were awarded the contracts, and (2) in the case of equal bid prices, the higher share of Declared National Component (DNC) was the decisive factor (Barrera et al., 2022a). The foundation for the success of the RenovAr programme was based on an in-depth understanding by the legislator of the selection mechanisms resulting from Argentine-specific macroeconomic and political contextual conditions. Thus, the RenovAr programme managed, on the one hand, to reduce the financial risk for investors and, on the other hand, to foster a rapid[15], cost-effective, and plannable expansion of renewable energy generation capacity through the following conditions:

- Risk of payment default: In addition to the Power Purchase Agreement (PPA) designed to create trust for a twenty-year ongoing investment in the context of historic economic and political instability, a three-level safety net of payment and solvency guarantees was established to protect the successful bidders' revenue streams against financial risks such as non-payment by the off-taker (Pardina & Schiro, 2020). The first level of security is the FODER trust fund. If CAMMESA is unable to fulfil its payments of revenue from electricity generation over a period of months for liquidity reasons, these payments will be covered by the FODER trust fund. If the FODER trust fund is unable to cover its liabilities at any time, the Ministry of Energy (and thus the Argentine state) is responsible for the liabilities as a second security layer. Payment guarantees from the World Bank offer an optional third security layer, which would come into play if the Argentine state were unable to fulfil its obligations (Menzies et al., 2019). During the first three tender rounds (RenovAr 1, 1.5 and 2), Argentina was in a phase of macroeconomic stability with access to the international capital market (Barrera et al., 2022a), which was decisive for the success of the RenovAr programme.
- Exchange rate risk: To eliminate exchange rate risks for investors, a 20-year PPA with CAMMESA was established with pricing denominated in US dollars.

The enormous potential of wind energy in Argentina is reflected in the dominance of this technology within the RenovAr programme. As shown in Table 1, in the first three rounds, on average five times the amount of the tendered capacity was offered. Furthermore, awards were made to projects with a total capacity of 641 MW above the tender target. Specifying regional power limits within the tendering process ensured that the wind turbines installed under the RenovAr programme are geographically distributed across different provinces in the windy regions of Argentina. However, about half the capacity was built in the province of Buenos Aires which is, together with the city of Buenos Aires, the region with the highest demand for electricity in Argentina. One political intention behind the regional targets was to distribute investment in renewable energies as evenly as possible across different provinces to ensure the political support of these provinces (Pardina & Schiro, 2020).

[15] To achieve the targets set in Law Nº27.191 and to accelerate the expansion of renewable energies, a number of measures were implemented under the RenovAr programme: 1) A technology-specific maximum project duration was specified for the respective tender rounds. For wind energy, this ranged from 730 to 900 days. When the project was awarded, an individual project plan with an integrated penalty for a delayed start was then contractually agreed; 2) Within the price formula for calculating the Adjusted Offered Price (AOP), preference was given to projects that constructed the wind turbine before the end of the maximum installation period; and 3) The rate of the feed-in tariff is indexed. The "annual adjustment factor" of 1.7 % is designed to replicate the US inflation rate, while the "incentive factor", which decreased from 1.2% in 2017 to 0.8% in 2038, is aimed to incentivise rapid installation and commissioning (Pardina & Schiro, 2020).

Table 2: Installed capacity and market shares of wind energy in Argentina in 2020

	Installed capacity [MW]	Market share [%]
Argentina	**64.5**	**2.4%**
IMPSA	61.5	2.3%
NRG Patagonia	3.0	0.1%
China	**209.8**	**7.7%**
Envison	149.8	5.5%
Goldwind	60.0	2.2%
Europe	**2,313.8**	**85.4%**
Vestas	1,532.9	56.6%
Acciona (Nordex)	349.0	12.9%
Nordex	196.3	7.2%
Siemens-Gamesa	99.8	3.7%
Senvion	50.4	1.9%
Alstrom	50.0	1.8%
Enercon	33.9	1.3%
Wobben	1.2	0.0%
Micon	0.3	0.0%
USA	**122.6**	**4.5%**
General Electric	122.6	4.5%
Total	**2,710.6**	**100.0%**

The interaction with the GIS:

Another interesting aspect of the RenovAr programme is the interaction between the focal TIS and the GIS, as illustrated in Figure 7. The RenovAr programme focused on the rapid and cost-effective expansion of renewable energies using international financing. However, these target dimensions limited the participation of existing national wind turbine manufacturers as these companies were not competitive with the international market players of the GIS (in terms of both short-term production capacity and cost) (Caruana, 2019). As a result of these developments, all RenovAr projects were built by global wind turbine manufacturers and the market share of Argentine manufacturers decreased to 2.4% in 2020, as shown in Table 2. However, collaborations developed between international wind turbine manufacturers and Argentine suppliers. This is also reflected in the increase in the average share of declared domestic parts in wind energy in the tender rounds, which rose from 11% (RenovAr 1) to 35% (RenovAr 2) (Caruana, 2019). This increase is largely attributable to changes in the RenovAr 2 tender conditions: 1) The tax exemptions for wind turbine imports were abolished and aligned with Mercosur regulations (Gomel & Rogge, 2020); 2) To encourage manufacturers to use a higher share of national components, the penalties for not reaching the declared CND share in the tender were reduced (Gomel & Rogge, 2020); 3) Within the RenovAr programme, project-specific tax benefits were granted for a CND share of 30% or more; and 4) Wind turbines that were at least 35% domestically-produced were assessed as 100% Argentine (Ruggeri & Garrido, 2021). In this context it is worth noting that the two manufacturers with the largest market shares, Vestas and Nordex (see Table 2), started to invest in local production capacity during this development period (Álvarez, 2018; NORDEX, 2019). An illustrative example is the assembly line for nacelles and hubs, with an annual capacity of up to 500 MW, which was built in 2019 by Nordex in cooperation with the Argentine company “Fábrica Argentina de Aviones” (NORDEX, 2019). To further increase local value creation and take advantage of tax benefits, the Nordex Group set up three local production facilities for concrete towers via subcontractors. In addition, the experts interviewed in this study highlighted that the increase in Chinese investment and financing of renewable energy projects in Argentina has resulted in a much stronger presence of Chinese companies in recent years, accounting for 7.7% of the market by 2020 (Table 2). In the Argentine wind energy sector, Chinese companies not only had a high share in RenovAr tenders (19%), but also acquired the Loma Blanca I, II and III wind farms (each with a capacity of 50 MW), Loma Blanca VI (with a capacity of 100 MW) and the Miramar I wind farm (with a capacity of 96 MW) through merger and acquisitions activity (Rubio & Jáuregui, 2022). In order to support the national value chain, the experts pointed out that a small-scale RenovAr tender based on actual national production capacities, in which the share of national value added was the central award criterion, could have had a positive impact on the development of the national value chain.

Slowdown of high wind energy diffusion dynamics due to external context conditions:

One important observation from the data in Table 1 is that the price per kWh decreased between bidding rounds 1, 1.5 and 2. The decrease indicates that confidence in the programme and the tender mechanism increased after the first successful round (Barrera et al., 2022a). Furthermore, it is interesting to note that, compared to the GENREN tender (121–134 US$/MWh), prices more than halved. On a global level, this can be partly explained by cost reduction dynamics resulting from the interplay of techno-economic variables responsible for cost reductions of individual components: learning effects, economies of scale, improvements in the supply chain, and increased international competition (Elia et al., 2020). Another decisive factor is the assumed lower project financing costs; this reduction resulted from Argentina's access to the international capital market, a phase of economic stability between 2015 and 2018, and the three-level safety net of payment and solvency guarantees of the RenovAr programme. However, a direct comparison with bidding results for wind energy in neighbouring countries indicates the continued existence of a risk premium for investments in Argentina: the average in Peru in 2016 was 38 USD/MWh and in Chile in 2017 it was 32 USD/MWh (De Fonseca et al., 2019). Furthermore, as shown in Table 1, it is surprising that the tender prices increased again in round 3. This can be explained by the interplay of two factors:

- As a result of the projects awarded in the RenovAr 1, 1.5 and 2 tender rounds, the calculated transport capacity of SADI became saturated (Ruggeri & Garrido, 2021). Consequently, the RenovAr 3 tender round (also known as MiniRen), stipulated that wind parks must be connected at the 13.2 kV/33 kV/66 kV grid level (Labriola, 2020b). As the average capacity of a wind power project only amounted to around 13 MW, the project entry costs were given a higher weighting. The experts interviewed for this research study universally pointed out that the lack of available transmission capacity is one of the biggest contextual barriers to the further expansion of wind energy in Argentina (Gutiérrez, 2019). In addition, the experts indicated that the government's ability to finance these necessary infrastructure projects is constrained. This is further complicated by the issue that the exploitation of unconventional gas deposits is also associated with high development costs for infrastructure.

- In 2018, the short window of opportunity for project finance for wind energy narrowed once again. This underlines the relevance of the political and macroeconomic environment for the diffusion of wind energy in Argentina. From 2018 onwards, capital costs started to rise again due to an emerging economic crisis and the largest rescue package in the history of the IWF, resulting from the “debt-led growth strategy” of the Macri government (Barrera et al., 2022a; Pardina & Schiro, 2020). The increase in country risk (EMBI between 2017 and 2019) shown in Table 1 is an indicator of the risk perceived by the financial market in relation to the country’s macroeconomic performance. The financial arrangements devised at the project development stage had to be reassessed in this context. As a result, many RenovAr 2 projects that had been awarded or had signed a PPA did not reach the financial closure required for their implementation (Nanda Singh, 2019).

Moreover, experts interviewed for this research study were critical of the fact that the non-implementation of some of the wind power projects was partially attributable to certain project developers proposing artificially low bid prices in the last bidding rounds, which meant it was ultimately not economically viable to implement these projects. In addition, the Argentine central bank had to restrict access to the foreign exchange market to stabilise the Argentine Peso following several devaluations after 2018. The lack of US Dollar reserves led to a depreciation of the Argentine Peso, which increased the financial risks for projects. Limited access to the foreign exchange market made it difficult for renewable energy projects to meet their payments to foreign suppliers or to repay loans in foreign currency (Calvetti et al., 2021). Despite solutions introduced by the central bank in 2019, foreign exchange restrictions affected the ability to structure new long-term financing on reasonable terms (Calvetti et al., 2021). Consequently, the pace of implementation of wind energy projects slowed rapidly in comparison with the previous tender rounds. These effects were reinforced by the impacts of the Covid-19 pandemic.

In addition, the experts noted that since 2018 the diffusion dynamics have been negatively affected by a decline in confidence in the fulfilment of government commitments. Firstly, the incentives promised by law in 2015, such as the early VAT refund, were not implemented by the administration until 2019. Due to the devalued Argentine Peso, as well as considerable interim financing costs, this resulted in economic damage to wind energy projects already in operation (Nanda Singh, 2019). Secondly, when the new government of Alberto Fernández took office at the end of 2019, the future direction and development of renewable energies in the country became unclear and uncertain. The experts pointed out that there were contradictions between rhetorical promises and actual government action, despite Alberto Fernández voicing initial support for renewable energy. The energy policy mainly relied on conventional energy sources such as gas and oil, especially through the promotion of the Vaca Muerta project (Analytica, 2021). This is reflected in limited progress in the development of wind energy and in the failure to meet the legally set targets for the development of renewable energy. Conversely, the experts noted that the private MATER programme is still generating market momentum for the diffusion of wind energy in Argentina. To address the challenges related to the lack of transmission capacity, the MATER framework was revised in 2023. There is the possibility of private investment in the expansion of the transmission network and for the additional capacity to be used as priority feed-in capacity for associated MATER projects.

5 Discussion

This research aimed to provide insights into the contextual embeddedness of the diffusion dynamics of onshore wind energy in Argentina using a combined MLP/TIS framework complemented by the GIS concept and the CA. The purpose of this study was to answer the research question: "How have context-specific factors influenced the diffusion of onshore wind energy in Argentina?"

The results provide evidence of the emergence of a variety of socio-technical niches throughout the five development phases of the focal TIS: pilot projects, self-generation by energy cooperatives, feed-in tariff-based projects, publicly financed and operated wind farms, generation of hydrogen, and self-generation of large-scale users. Throughout the trajectory of the focal TIS, the niches are characterised by different application contexts and key actor groups. The starting point of the development was the pilot project of a wind-diesel hybrid system in the city of Rio Mayo in 1990, which was the first wind farm in South America. While energy cooperatives were a formative actor, especially for the first development phase during the 1990s, publicly financed and operated wind farms enabled Argentine wind turbine manufacturers to position themselves as market actors. In addition, hydrogen production using wind energy, a key factor for the global energy transition, has been researched in Pico Truncado since 2005. However, with no catalyst for further progress, progress has largely stagnated. Feed-in tariff-based programmes led to strong expansion of wind energy in Argentina under the RenovAr programme. The rapid development from 2015 onwards was also driven by the obligation of large customers to meet legal targets regarding the share of renewable energy in their electricity mix, which continues to be a driver for the installation of new wind farms.

Previous studies that applied the Sustainability Transition Research frameworks in the context of the Global South have emphasised the importance of contextual frameworks (De Oliveira & Negro, 2019; Edsand, 2019; Esmailzadeh et al., 2020; Tigabu et al., 2015). The results of this research have undermined these findings and demonstrated that the CA is an appropriate method to investigate the contextual embeddedness of new innovations. This study has also demonstrated how the contextual landscape factors in particular have had a determining influence on the clustering of the development phases. A comparison with the trajectory of wind energy in today's mature markets, such as Germany and Denmark, shows that landscape factors in those countries (although also impacting the diffusion dynamics) mostly occurred in the form of narrative shaping events such as the oil price crisis, the reactor accident in Fukushima, and the Paris Agreement (Geels et al., 2017). In contrast, in the case of Argentina, mutually-influencing systemic instabilities are decisive, and these also act as general contextual factors for the innovation dynamics of other technologies. In this regard, the results of the analysis underline the importance of contextual landscape factors for the diffusion of new innovations in developing countries, as also emphasised by Edsand (2019b). However, the research has shown that the landscape factors are highly influenced by the respective country's development history. The ex-ante categorisation of relevant landscape factors (Economic Growth, Environmental Awareness, Climate Change, Armed Conflicts, Corruption and Inequality, Unequal Access to Higher Education), in the context of developing countries as proposed by Edsand (2019b) could not be confirmed in this study. Rather, the research results emphasise the importance of an open, bottom-up approach for capturing country-specific factors. The following broader patterns that have shaped the different phases of wind energy development in Argentina in the period between 1985 and 2000 can be derived from the research results:

- **The discontinuities of the macro-political orientation**

A key contextual factor influencing the country's economic dynamics, and consequently the development of wind energy, are changes in the country's economic policies. Over the last three decades, changes in government in Argentina have often been accompanied by far-reaching changes in economic policy premises (e.g., free or fixed exchange rate, privatisation and nationalisation, free trade policy or protectionism). These economic policy discontinuities have had a negative impact on the expansion dynamics of wind energy among market actors as they are the source of increased perceived uncertainty and are in tension with the requirements of long-term investments in wind farms or local value chains. Furthermore, these discontinuities have led to distortions in the development of the wind energy sector in Argentina. The neo-developmentalist approach of the Kirchner government promoted the development of national value chains in the wind energy sector, while Maurico Macri's more neo-liberalist approach was very successful in focusing on the rapid and cost-efficient development of wind power. However, national wind turbine manufacturers were unable to participate in this development in the face of global competition.

- **Two poles of development dynamics: the emergence of a national value chain and the evolving Global Innovation System**

Another formative pattern is the interaction between the partly politically supported development trends towards the creation of a national value chain and an increasingly globalised wind energy industry. The analysis of the multi-scale dynamics of the focal TIS with the GIS provides additional relevant insights. After a phase of technical concept testing, the wind energy industry developed in certain leading markets such as Denmark, Germany, and the USA in the 1990s. The development phase described in the literature as "partially sticky" was characterised by the development of production capacities and technical know-how as a result of reciprocal processes located locally in the leading markets (Binz & Truffer, 2017). During the 1990s, contextual factors, such as the parity of the Argentine Peso with the US Dollar and trade tariff policies, favoured the import logic of wind turbines. These tendencies were reinforced by industrial policy support programmes, such as the German "Eldorado" programme, which aimed to strengthen the global competitive position of national manufacturers. On the one hand, this enabled the rapid construction of wind energy capacity for projects undertaken by Argentine wind cooperatives and strengthened knowledge generation processes at the GIS level through the testing of wind turbines under Argentine environmental conditions. On the other hand, the effects of Argentina's economic crisis in 2001 showed that the high dependency on external technical know-how and spare parts (resulting from the import logic) was not conducive to the diffusion dynamics of wind energy in Argentina in the long-term, as non-functioning wind farms temporarily damaged the legitimacy of the technology. Another relevant issue is the evolution of Argentine wind turbine manufacturers in the context of the GIS. It is noteworthy that Argentina's neo-developmentalist economic policy in the 2000s led to the development of technology by national wind turbine manufacturers that was successfully implemented at a number of wind farms. During the same period, on an international level, the wind industry developed into a “production-anchored GIS”, in which (due mostly to stagnating domestic markets) established wind turbine manufacturers tried to expand into new markets and wind turbines developed into a standardised price-sensitive product exposed to global competition. Established GIS manufacturers dominated the ramp-up of wind energy in Argentina from 2015 onwards, as high production capacities necessary to meet installation schedules and low prices were decisive in the tender logic before the CND share, meaning that Argentine manufacturers could not benefit from this development. However, tax incentives relating to the CND rate led to global companies such as VESTAS and Nordex establishing assembly production facilities in Argentina and creating joint ventures to manufacture wind turbine towers.

- **The macroeconomic instabilities**

One of the most significant influencing patterns is Argentina’s macroeconomic development, which has been volatile and heavily shaped by the government’s economic policies. During the 1990s, pegging the Argentine Pisa to the US Dollar supported the import logic of wind power systems, while the devaluation of the Argentine Peso in the 2000s meant that support programmes for renewable energies with fixed feed-in tariffs in Argentine pesos could not provide the desired incentive to make them economically attractive. For the financing of wind power projects in particular, a further decisive contextual influencing factor is Argentina’s access to the international capital market. Argentina’s leading role in wind energy in Latin America was interrupted by the economic and political crisis in 2001, which led to a massive outflow of foreign capital and made access to the international capital market very difficult until an agreement was reached with the remaining creditors in 2015. Additionally, the confidence of international investors was weakened by government intervention in the energy sector, as well as by Argentina’s monetary and fiscal policies. This meant that the majority of the wind power projects under the GENREN programme were not implemented due to a lack of project financing. The agreement with the remaining creditors in 2015, together with the momentum resulting from the Macri government’s policies, facilitated Argentina’s access to the international financial market. In combination with the multi-level guarantee safety net of the RenovAr programme, this created the basic conditions for the success of the first tender rounds of the RenovAr programme. Subsequently, Argentina’s growing national debt, culminating in an IMF rescue programme, coincided with an economic crisis; this led to increased capital costs for wind energy projects in later RenovAr bidding rounds, which had a negative impact on project realisation rates.

- **Dysfunctionalities of the power system as a window of opportunity for wind energy**

Another shaping contextual influence for the trajectory of wind energy stems from the interaction with the socio-technical regime. It is interesting to highlight that the increased cost of electricity as a consequence of the unbundling and privatisation processes of the energy sector led energy cooperatives to invest in their own power generation capacities, especially during the initial phase in the 1990s, making Argentina a pioneer in South America in the field of wind power until 2001. In addition, numerous crises in the Argentine energy system from the

2000s onwards opened a window of opportunity for renewable energies. Renewable energies were increasingly perceived at the political level as part of the solution to diversify the energy matrix. The aim was to meet the challenges of insufficient power generation capacity, declining national natural gas extraction rates, and rising energy imports with negative effects on scarce foreign currency reserves.

- **The effects of fossil path dependency and energy subsidies on wind energy diffusion:**

The diffusion of wind energy in Argentina was also constrained by interactions with the regime level throughout the different development phases. Illustrative examples include the impact of frozen energy prices in the wake of the Emergency Act on the activities of energy cooperatives, the indebtedness of CAMMESA resulting from subsidy policies with negative effects on risk assessments for projects under the GENREN programme, and the saturated transmission system capacity after the first RenovAr bidding rounds. One of the distinctive features of Argentina's energy sector is the diversity of national energy sources. In addition to a high potential for renewable energy, the country has an extensive deposit of fossil energy sources, which have significantly shaped the development path of the Argentinian energy system. From the end of the 1990s, natural gas became the most important energy source in the energy supply. The strong path dependencies resulting from this development path have been further intensified by the development of non-conventional gas in recent years. Due to the country's limited resources, investment, subsidisation and regulatory decisions influence both the development of renewable energies and the use of conventional resources. If Argentina succeeds in substantially increasing the share of renewable energies, it could once again be in a position to export natural gas, which plays an important role worldwide as a bridging technology in the context of the energy transition.

In the scope of this research, the CA was demonstrated to be an adequate method to: 1) operationalise the MLP/TIS framework, 2) consolidate the findings resulting from the preliminary interviews and the literature review process regarding the development of wind energy and specific contextual influencing factors, 3) divide the diffusion process into different phases depending on changes in the constellations, and 4) validate the resulting phase constellations through interviews with experts. In the context of this research the CA has proven to be particularly appropriate for visualising complex relationships and making them accessible to different stakeholders as well as integrating their perspectives without major access barriers. However, a significant challenge for this research study arose from the purposive sampling strategy of experts, which carries the risk of potentially excluding other valuable perspectives on the development of wind energy in Argentina. In order to address this challenge, a broad spectrum of experts was selected. More critically, it should be noted that in some cases it was challenging to clearly attribute the factors influencing the policy developments to the landscape level or the regime level.

Further research should be undertaken to investigate how future energy policy frameworks in Argentina should be designed to achieve the greater resilience of renewable energies in relation to the country's recurrent political and economic instabilities. In this context, it would be interesting to examine how to reduce the influence of Argentina's macroeconomic situation on access to project finance for wind farms, e.g., through financing instruments in the context of global climate change policies. Further development of the theoretical framework would benefit from comparative analysis of how the nature and operation of landscape factors differ, for example in the Global North and South. In addition, it would be worthwhile to examine the ways in which unstable regimes can have an impact at the landscape level, although independently of each other. The effects observed in this study, such as those resulting from the impact of high energy subsidies and import dependency on the economic capacity of the state, suggest such relations. Another interesting field of research would be an analysis of the interrelationship between the TIS of wind power and hydrogen. Argentina has enormous wind power potentials and experience in both technologies. Against the background of the global challenges of energy transformation, it would be relevant to investigate the necessary framework conditions for the co-evolutionary diffusion of both technologies in the Argentine context.

6 Conclusion

This study has provided an overview of the distinct development phases of onshore wind energy in Argentina since 1990, with the aim of identifying how exogenous dynamics have hindered or supported the diffusion of the novel technology. Beyond the empirical results, this research contributes to the development of the research field on a theoretical level in two ways. Throughout the research journey of this study, the integrated MLP-TIS framework has proven particularly valuable in analysing the influence of contextual factors on the diffusion dynamics of wind turbines in Argentina at different stages of development. The CA served as a valuable method for structuring interdisciplinary findings from the literature review processes and facilitating the triangulation and further development of the insights with experts through coherent visualisations.

In the case of Argentina, contextual factors have unlocked opportunities for the development of wind energy, e.g., wind energy as a response to the national energy crisis and as a business model for reducing excessive electricity procurement costs for energy cooperatives. In addition, the exceptionally strong development of wind energy during the 1990s in Chubut province demonstrates how political federal structures can have positive impacts in early stages of technology diffusion. However, the Argentine case also illustrates how structural problems within a country, such as institutional instability and macroeconomic uncertainties caused by high inflation and strong exchange rate fluctuations, can severely hamper the breakthrough of wind energy. Access to international project finance and the cost of capital, influenced by Argentina's risk premiums and macroeconomic situation, have been critical to the development of wind energy in Argentina. Illustrative examples in this context are the effects of the economic and debt crises of 2001 and 2018. Both brought the previous diffusion dynamics to a standstill for several years, as wind energy projects struggled to obtain financing.

Furthermore, the structural challenges of the Argentine power system shaped the development of wind energy. Wind energy was seen as a solution to the lack of generation capacity and the reduction of energy imports, which were having a destructive effect on the country's finances. The discontinuities in the fundamental political-economic strategic orientation of the country due to changes in government were another key influencing factor. The Kirchner government supported the development of national wind turbine manufacturers through research programmes and the financing of wind farm projects. The Mauricio Macri government succeeded in the impressive rapid expansion of wind power. However, due to the focus on low prices and short installation periods, globally-active wind turbine manufacturers dominated. Notwithstanding the prevailing challenges, the 2015-2020 expansion period undoubtedly resulted in an impressive development of wind energy. During this period, the share of wind energy in the generation matrix increased from 0.5% to 7.4%, and wind energy became a central pillar for the diversification of the energy matrix. At the same time, the rapid expansion of generation capacity led to the almost total saturation of transmission capacity, which is clearly a limiting factor for current diffusion dynamics.

With its focus on context-specific factors, the empirical insights gained from this research help to develop a deeper understanding of the diffusion dynamics of wind energy in the Global South and underline how comprehending the interconnected and multi-faceted interplay of various contextual framework factors is particularly relevant for a country-specific understanding of transformation processes. In this regard, the CA has proven to be a valuable method for subdividing the development of wind energy into different phases and identifying diverse types of focal TIS-context interactions. In addition, through its visual nature as a bridging concept, the CA enabled the results of the literature review to be combined and triangulated with expert opinions.

7 Bibliography

Aggio, C., Verre, V., & Gatto, F. (2018). *Innovación y marcos regulatorios en energías renovables: el caso de la energía eólica en la Argentina*. CIECTI. https://www.ciecti.org.ar/dt14-innovacion-y-marcos-regulatorios-en-energias-renovables-el-caso-de-la-energia-eolica-en-la-argentina/

Álvarez, I. R. (2018). *Vestas strengthens presence in Argentina with new assembly facility, delivering local content and creating jobs*. https://www.vestas.com/en/media/company-news/2018/vestas-strengthens-presence-in-argentina-with-new-assem-c2963432

Analytica, O. (2021). Argentina energy doubts mount as Vaca Muerta stalls. *Emerald Expert Briefings*, *oxan-db*.

Aprea, J. L. (2009). Hydrogen energy demonstration plant in Patagonia: Description and safety issues. *International Journal of Hydrogen Energy*, *34*(10), 4684–4691. https://doi.org/10.1016/J.IJHYDENE.2008.08.044

Bambaci, J., Saront, T., & Tommasi, M. (2002). The political economy of economic reforms in Argentina. *The Journal of Policy Reform*, *5*(2), 75–88.

Barrera, M. A., Sabbatella, I., & Serrani, E. (2022a). Macroeconomic barriers to energy transition in peripheral countries: The case of Argentina. *Energy Policy*, *168*, 113117. https://doi.org/10.1016/J.ENPOL.2022.113117

Barrera, M. A., Sabbatella, I., & Serrani, E. (2022b). Macroeconomic barriers to energy transition in peripheral countries: The case of Argentina. *Energy Policy*, *168*, 113117. https://doi.org/10.1016/J.ENPOL.2022.113117

Bayer, B. (2018). Experience with auctions for wind power in Brazil. *Renewable and Sustainable Energy Reviews*, *81*, 2644–2658.

Belmonte, S., Franco, J., & Garrido, S. (2017). *Experiencias de energias renovables argentina. Una mirada desde el territorio.* (1a ed.). Salta: Universidad Nacional de Salta. EUNSa.

Bergek, A. (2019). Technological innovation systems: a review of recent findings and suggestions for future research. In *Handbook of Sustainable Innovation* (pp. 200–218). Edward Elgar Publishing. https://doi.org/10.4337/9781788112574

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., & Truffer, B. (2015). Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions*. https://doi.org/10.1016/j.eist.2015.07.003

Best, B., Prantner, M., & Augenstein, K. (2012). The concept of regime and „flat ontologies ": empirical potential and methodological implications. *Proceedings of the 3rd International Conference on Sustainability Transitions*, 87–109.

Binz, C., & Truffer, B. (2017). Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. *Research Policy*. https://doi.org/10.1016/j.respol.2017.05.012

Bolcich, J. C. (2006). Wind industrialization and province of Santa Cruz contribution to the improvement of global environment through hydrogen use as a fuel. *Expanding Hydrogen: Proceedings of the 16th World Hydrogen Energy Conference. Lyon, France, June 13-16*, *6*, 6.

Bravo, V., Di Sbroiavacca, N., & Di Sbroiavacca, N. (2021). Shale Oil and Shale Gas in Argentina. State of Situation and Prospective. *Oil and Natural Gas Economy in Argentina: The Case of Fracking*, 281–300.

Bruns, E., & Ohlhorst, D. (2011). Wind Power Generation in Germany--a transdisciplinary view on the innovation biography. *Journal of Transdisciplinary Environmental Studies*, *10*(1).

Bruns, E., Ohlhorst, D., Wenzel, B., & Köppel, J. (2010). *Erneuerbare Energien in Deutschland–Eine Biographie des Innovationsgeschehens*. Universitätsverlag der TU Berlin.

Buera, F., & Nicolini, J. P. (2019). *The Monetary and Fiscal History of Argentina, 1960–2017*.

CADER. (2013). + *Renovables 2012 / 2013. 4*.

Calvetti, D., Isaac, R., Mandará, H., Redes, E., & Echeverría, R. (2021). *Energías Renovablesen Argentina: Desafíos y Oportunidades en el contexto de la transición energética global*.

CAMMESA. (2014). *Informe anual 2013 - Mercado Eléctrico Mayorista*. http://www.cammesa.com/archcount.nsf/LinkCounter?OpenAgent&X=InformeAnual*2013*Vanual13.zip&L=/linfoanu.nsf/WInforme+Anual/BFF8619E1BFA201603257CC50048291E/$File/Vanual13.zip

CAMMESA. (2023). *Estadísticas anuales 2005 - 2022*.

Caruana, M. E. C. (2019). Renewable energy in Argentina as an energy and industrial policy strategy. *Problemas Del Desarrollo*. https://doi.org/10.22201/iiec.20078951e.2019.197.64625

Castro, M. G. (2011, November 1). Energías renovables: inversiones por US$ 950 millones. *LA NACION*.

Chemes, J., & Bertinat, P. (2018). *Políticas públicas en el sector de energías renovables en el período 2003-2018*.

Clementi, L. (2014). De molinos y Quijotes. Energía eólica y cooperativismo en el sur bonaerense. *Revista de Geografia*, *15*(7000).

Clementi, L. (2018a). *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*.

Clementi, L. (2018b). *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).

Clementi, L. V. (2019). *Tribulaciones de la primera generación eólica argentina: un análisis a partir de los parques de Mayor Buratovich y Centenario en el sur Bonaerense*.

Corrêa, K. C., Uriona-Maldonado, M., & Vaz, C. R. (2022). The evolution, consolidation and future challenges of wind energy in Uruguay. *Energy Policy*, *161*, 112758. https://doi.org/10.1016/J.ENPOL.2021.112758

Creswell, J. W., & Plano Clark, V. L. (2017). Designing and Conducting Mixed Methods Research. In *SAGE Publications, Inc*.

Damill, M., Frenkel, R., & Rapetti, M. (2015). Macroeconomic Policy in Argentina During 2002–2013. *Comparative Economic Studies*, *57*(3), 369–400. https://doi.org/10.1057/ces.2015.3

De Fonseca, L. G., Parikh, M., & Manghani, R. (2019). Evolución futura de costos de las energías renovables y almacenamiento en América Latina. *Banco Interam. Desarro*.

De Oliveira, L. G. S., & Negro, S. O. (2019). Contextual structures and interaction dynamics in the Brazilian Biogas Innovation System. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2019.02.030

Di Bella, C. G., Norton, L. D., Ntamatungiro, J., Ogawa, S., Samaké, I., & Santoro, M. (2015). *Energy Subsidies in Latin America and the Caribbean: Stocktaking and Policy Challenges*.

Edsand, H. E. (2019). Technological innovation system and the wider context: A framework for developing countries. *Technology in Society*. https://doi.org/10.1016/j.techsoc.2019.101150

El Bilali, H. (2019). The Multi-Level Perspective in Research on Sustainability Transitions in Agriculture and Food Systems: A Systematic Review. In *Agriculture* (Vol. 9, Issue 4). https://doi.org/10.3390/agriculture9040074

Elia, A., Taylor, M., Ó Gallachóir, B., & Rogan, F. (2020). Wind turbine cost reduction: A detailed bottom-up analysis of innovation drivers. *Energy Policy*, *147*, 111912. https://doi.org/10.1016/J.ENPOL.2020.111912

Elzen, B., Geels, F. W., & Hofman, P. S. (2002). *Sociotechnical Scenarios (STSc): Development and evaluation of a new methodology to explore transitions towards a sustainable energy supply*. University of Twente.

Esmailzadeh, M., Noori, S., Nouralizadeh, H., & Bogers, M. L. A. M. (2020). Investigating macro factors affecting the technological innovation system (TIS): A case study of Iran's photovoltaic TIS. *Energy Strategy Reviews*. https://doi.org/10.1016/j.esr.2020.100577

Féliz, M. (2012). Neo-developmentalism: Beyond neoliberalism? Capitalist crisis and Argentina's development since the 1990s. *Historical Materialism*, *20*(2), 105–123.

Fenés, G. (2015). *Un repaso por los problemas que tiene Argentina para atraer inversiones en energías renovables - Energía Estratégica - Información en*

Movimiento. http://www.energiaestrategica.com/las-inversiones-en-energias-renovables-que-no-fueron/

Fernandez Gonzalez, R., Arce Farina, M. E., & Garza Gil, M. D. (2019). Resolving conflict between parties and consequences for foreign direct investment: the Repsol-YPF case in Argentina. *Sustainability*, *11*(21), 6012.

Friedrich, K., & Lukas, M. (2017). *State-of-the-Art and New Technologies of Direct Drive Wind Turbines BT - Towards 100% Renewable Energy* (T. S. Uyar, Ed.; pp. 33–50). Springer International Publishing.

Furlan, A. (2014). *La crisis del sistema eléctrico en la Argentina de la posconvertibilidad: El caso de la articulación geoeconómica crítica de la costa atlántica bonaerense*. Tesis doctoral. Universidad Nacional de la Plata.

Garrido, S., Lalouf, A., & Santos, G. (2016a). Energía eólica de alta potencia en Argentina. Análisis socio-técnico de su trayectoria (1990-2015). *XI Jornadas Latinoamericanas de Estudios Sociales de La Ciencia y La Tecnología - ESOCITE*.

Garrido, S., Lalouf, A., & Santos, G. (2016b). Energía eólica de alta potencia en Argentina. Análisis socio-técnico de su trayectoria (1990-2015). *XI Jornadas Latinoamericanas de Estudios Sociales de La Ciencia y La Tecnología - ESOCITE*.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. In *Environmental Innovation and Societal Transitions* (Vol. 1, Issue 1, pp. 24–40). https://doi.org/10.1016/j.eist.2011.02.002

Geels, F. W., & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society*. https://doi.org/10.1016/j.techsoc.2007.08.009

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule*, *1*(3), 463–479. https://doi.org/10.1016/J.JOULE.2017.09.018

Genchi, S. A., Vitale, A. J., Piccolo, M. C., & Perillo, G. M. E. (2016). Wind energy potential assessment and techno-economic performance of wind turbines in coastal sites of Buenos Aires province, Argentina. *International Journal of Green Energy*, *13*(4). https://doi.org/10.1080/15435075.2014.952426

Giralt, C. (2011). Energía eólica en Argentina : un análisis económico del derecho. *Letras Verdes, Revista Latinoamericana de Estudios Socioambientales*. https://doi.org/10.17141/letrasverdes.9.2011.904

Gomel, D., & Rogge, K. S. (2020). Mere deployment of renewables or industry formation, too? Exploring the role of advocacy communities for the Argentinean energy policy mix. *Environmental Innovation and Societal Transitions*. https://doi.org/10.1016/j.eist.2020.02.003

Gomes, I., & Brandt, R. (2016). *Unconventional Gas in Argentina: Will it become a game changer?* Oxford Institute for Energy Studies.

Grin, J., Rotmans, J., Schot, J., Geels, F., & Loorbach, D. (2010). Transitions to sustainable development : new directions in the study of long term transformative change. *New York*, *31*. https://doi.org/10.4324/9780203856598

Gutiérrez, H. A. V. (2019). Una visión general de las tendencias de Argentina hacia las energías renovables. *IEEE Latin America Transactions*, *17*(10), 1625–1636.

Guzowski, C., & Recalde, M. (2010). Latin American electricity markets and renewable energy sources: The Argentinean and Chilean cases. *International Journal of Hydrogen Energy*, *35*(11), 5813–5817. https://doi.org/10.1016/j.ijhydene.2010.02.094

Haselip, J., & Potter, C. (2010). Post-neoliberal electricity market 're-reforms' in Argentina: Diverging from market prescriptions? *Energy Policy*, *38*(2), 1168–1176. https://doi.org/10.1016/j.enpol.2009.11.007

Helmke, A. C. (2009a). Windenergie in Brasilien. In *Windenergie in Südamerika*. Springer.

Helmke, A. C. (2009b). Windenergie in Brasilien. In *Windenergie in Südamerika*. Springer.

Hoppe-Kilpper, M. (2003). *Entwicklung der Windenergietechnik in Deutschland und der Einfluss staatlicher Förderpolitik-Technikentwicklung in den 90er Jahren zwischen Markt und Forschungsförderung*.

IRENA. (2015). *Renewable Energy Policy Brief: Argentina*.

Isolux Corsán. (2013). *Activity Report: Annual Report 2012*.

Jacobsson, S., & Bergek, A. (2011). Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions*. https://doi.org/10.1016/j.eist.2011.04.006

Jimeno, M. (2015). *Explaining divergent energy paths: electricity policy in Argentina and Uruguay*.

Jimeno, M., Knaack, J., Grundner, C., Mayer, J., & Brückmann, R. (2016). Enabling PV in Argentina. *Berlin: German Solar Association–BSW-Solar*.

Johan, S., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554.

Jones, R. D. (2021). Un acercamiento al potencial eólico de la Patagonia. *Ciencia e Investigación, Tomo 71*(1), 42–50.

KfW IPEX-Bank. (2019). *Total Eren, KfW IPEX-Bank and FMO achieve financial closing for 50.4 MW wind project in southern Argentina*. Press Release. https://www.kfw-ipex-bank.de/Presse/News/Pressemitteilungsdetails_508544-2.html

Labriola, C. (2020a). Wind Energy in Argentina: Actuality and Prospects. In *The Age of Wind Energy* (pp. 147–173). Springer.

Labriola, C. (2020b). Wind Energy in Argentina: Actuality and Prospects. In *The Age of Wind Energy* (pp. 147–173). Springer.

Lacal-Arántegui, R. (2019). Globalization in the wind energy industry: contribution and economic impact of European companies. *Renewable Energy*, *134*, 612–628. https://doi.org/10.1016/J.RENENE.2018.10.087

LaMarca, K. (2011). Renewable Energy Initiatives: A Look at Argentina and Law 26,190. *Law & Bus. Rev. Am.*, *17*, 583.

Lanardonne, T., & Mazzochi, J. C. (2022). *Energy Transition in Argentina: Past, Present and Future - From Fossil Fuels to Low Carbon Energy Transition: New Regulatory Trends in Latin America* (G. Wood & J. F. Neira-Castro, Eds.; pp. 119–136). Springer International Publishing. https://doi.org/10.1007/978-3-031-00299-1_7

Leary, J., Schaube, P., & Clementi, L. (2019). Rural electrification with household wind systems in remote high wind regions. *Energy for Sustainable Development*. https://doi.org/10.1016/j.esd.2019.07.008

Loy, D., Fütterer, H., Jüttemann, P., & Reiche, D. (2007). Energiepolitische Rahmenbedingungen für Strommärkte und erneuerbare Energien 23 Länderanalysen. In *Kapitel Karibik, Deutsche Gesellschaft fuer Technische Zusammenarbeit (GTZ) GmbH*.

Lucena, J. de A. Y., & Lucena, K. Â. A. (2019). Wind energy in Brazil: an overview and perspectives under the triple bottom line. *Clean Energy*, *3*(2), 69–84. https://doi.org/10.1093/ce/zkz001

Mahlkow, N., Lakes, T., Donner, J., Köppel, J., & Schreurs, M. (2016). Developing storylines for urban climate governance by using Constellation Analysis — insights from a case study in Berlin, Germany. *Urban Climate*, *17*, 266–283. https://doi.org/10.1016/j.uclim.2016.02.006

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*. https://doi.org/10.1016/j.respol.2008.01.004

Menzies, C., Marquardt, M., & Spieler, N. (2019). Auctions for the support of renewable energy in Argentina. *Report of the EU-Funded AURES II Project*.

Nanda Singh. (2019). *Bono electrónico: se definió el procedimiento para que proyectos renovables soliciten su certificado fiscal anticipado ante AFIP*.

NORDEX. (2019). *Nordex Group and FAdeA celebrate official opening of a wind turbines production plant in Córdoba, Argentina*. https://www.nordex-online.com/en/2019/06/nordex-group-and-fadea-celebrate-official-opening-of-a-wind-turbines-production-plant-in-cordoba-argentina/%0A

Ohlhorst, D., & Schön, S. (2015). Constellation analysis as a means of interdisciplinary innovation research-theory formation from the bottom up. *Historical Social Research*, *40*(3), 258–278. https://doi.org/10.12759/hsr.40.2015.3.258-278

Papa, J., & Hobday, M. (2015). Building-up technological capabilities to overcome economic adversity: the case of a latecomer firm in Argentina. *GLOBELICS 2015*.

Pardina, M. A. R., & Schiro, J. (2020). *The Argentinian experience of designing and implementing renewable energy auctions*.

Pedraza, J. M. (2012). The current and future role of renewable energy sources for the production of electricity in Latin America and the Caribbean. *International Journal of Energy, Environment and Economics*, *20*(5), 415.

Pollitt, M. (2008). Electricity reform in Argentina: Lessons for developing countries. *Energy Economics*, *30*(4), 1536–1567.

Porta, F., Santarcángelo, J., & Schteingart, D. (2017). Un proyecto político con objetivos económicos. Los límites de la estrategia kirchnerista. *Los Años Del Kirchnerismo. La Disputa Hegemónica Tras La Crisis Del Orden Neoliberal*, 99–143.

Recalde, M. (2010). Wind power in Argentina: Policy instruments and economic feasibility. *International Journal of Hydrogen Energy*, *35*(11). https://doi.org/10.1016/j.ijhydene.2009.12.114

Recalde, M. (2011). Energy policy and energy market performance: The Argentinean case. *Energy Policy*, *39*(6), 3860–3868. https://doi.org/10.1016/j.enpol.2011.04.022

Recalde, M. (2015). The different paths for renewable energies in Latin American Countries: enabling environments and the instruments. *Energy and Environment*.

Recalde, M. Y., Bouille, D. H., & Girardin, L. O. (2015). Limitations for renewable energy development in Argentina. *Problemas Del Desarrollo*, *46*(183), 89–115.

Rogge, K., Friedrichsen, N., & Schlomann, B. (2015). *Regime analysis of the German electricity system*.

Rolf Posorski, Wasielke, A., & Meyer, T.-P. (2007). *Energy-policy Framework Conditions for Electricity Markets and Renewable Energies*.

Rubio, T. G., & Jáuregui, J. G. (2022). Chinese overseas finance in renewable energy in Argentina and Brazil: implications for the energy transition. *Journal of Current Chinese Affairs*, *51*(1), 137–164.

Ruggeri, E., & Garrido, S. (2021). More renewable power, same old problems? Scope and limitations of renewable energy programs in Argentina. *Energy Research & Social Science*, *79*, 102161. https://doi.org/10.1016/j.erss.2021.102161

Sbroiavacca, N. di, & Falzon, J. (2014). CLIMACAP- Climate and Energy Policy reviews for Colombia, Brazil, Argentina, and Mexico. *CLIMACAP*.

Schafer, M., Ohlhorst, D., Schon, S., & Kruse, S. (2010). Science for the future: challenges and methods for transdisciplinary sustainability research. *African Journal of Science, Technology, Innovation and Development*, *2*(1), 114–137.

Schaube, P., Ise, A., & Clementi, L. (2022). Distributed photovoltaic generation in Argentina: An analysis based on the technical innovation system framework. *Technology in Society*, *68*, 101839. https://doi.org/10.1016/J.TECHSOC.2021.101839

Schaube, P., Ortiz, W., & Recalde, M. (2018). Status and future dynamics of decentralised renewable energy niche building processes in Argentina. *Energy Research and Social Science*, *35*. https://doi.org/10.1016/j.erss.2017.10.037

Schön, S., Kruse, S., Meister, M., & Nölting, B. (2007). *Handbuch Konstellationsanalyse: Ein interdisziplinäres Brückenkonzept für die Nachhaltigkeits-, Technik- und Innovationsforschung*. Oekom Verlag.

Schön, S., Nölting, B., & Meister, M. (2004). Konstellationsanalyse. Ein interdisziplinäres Brückenkonzept für die Technik-, Nachhaltigkeits-und Innovationsforschung. *Zentrum Tecnikund Gesellschaft. Technische Universität Berlin. Berlin: Juni.*

Smith, A., Voß, J. P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. In *Research Policy* (Vol. 39, Issue 4, pp. 435–448). https://doi.org/10.1016/j.respol.2010.01.023

Smith, W. C. (1991). State, Market and Neoliberalism in Post-Transition Argentina: The Menem Experiment. *Journal of Interamerican Studies and World Affairs*, *33*(4), 45–82. https://doi.org/10.2307/165879

Starr, P. K. (2003). Argentina: Anatomy of a crisis foretold. *Current History*, *102*(661), 65.

Sturzenegger, F. (2019). Macri's Macro: The Elusive Road to Stability and Growth. *Brookings Papers on Economic Activity*, *2019*(2), 339–436.

Szigeti, P. L. (2013). *Cambios regulatorios para incentivar la generación de electricidad a partir de fuentes renovables*. Universidad Nacional de Cuyo. Facultad de Ingeniería.

Tigabu, A. D., Berkhout, F., & van Beukering, P. (2015). The diffusion of a renewable energy technology and innovation system functioning: Comparing bio-digestion in Kenya and Rwanda. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2013.09.019

Vagliasindi, M. (2012). *Implementing Energy Subsidy Reforms: Evidence from Developing Countries*. World Bank Publications.

Vanesa Clementi, L., Cecilia Carrizo, S., & Paula Jacito, G. (2021a). GENEALOGÍA EÓLICA ARGENTINA (1990-2020). *Finisterra: Revista Portuguesa de Geografia*, *55*(116).

Vanesa Clementi, L., Cecilia Carrizo, S., & Paula Jacito, G. (2021b). GENEALOGÍA EÓLICA ARGENTINA (1990-2020). *Finisterra: Revista Portuguesa de Geografia*, *55*(116).

Williamson, J. (2004). The strange history of the Washington consensus. *Journal of Post Keynesian Economics*, *27*(2).

YPF LUZ. (2021). *Energy where it should be: Sustainability Report 2020*.

8 Appendix

8.1 Interviewed experts

Table 3: Overview of the affiliation of the experts and stakeholders interviewed for this study

Research step	Name of the institution or independent expert	Classification
Preliminary	CONICET	Research
Preliminary	Facultad de Ingeniería de la Universidad Nacional del Comahue	Research
Preliminary	AHK Argentina	Association
Preliminary	Esteban van Dam	Independent expert
Validation	YPF Luz	Company
Validation	Fundación Bariloche	Research
Validation	Instituto Argentino de la Energía "General Mosconi"	Association
Validation	Mario Francisco Iacona	Independent expert

8.2 Interview guide for preliminary interviews

- How would you evaluate the development dynamics of the Argentine power system over the last decades? What factors have fostered the development path?
- How have these development dynamics in the electricity sector impacted the development of large-scale wind energy in Argentina?
- What have been the different market segments and target groups for large-scale wind energy?
- How suitable do you think the Argentine power grid is for the expansion of wind power?
- What uncertainties have influenced entrepreneurial activities in the wind energy sector?
- What role has the national industry played?
- How would you evaluate the access to resources that are of strategic value for the actors? What kind of resources have represented a limiting factor for the development of the wind energy sector?
- How would you characterise the public perception of wind energy and what arguments dominate the public discourse?
- How have regional initiatives and international development dynamics influenced the development of the wind energy sector in Argentina?
- In your opinion, what were the five most important barriers to the development of wind energy in Argentina?
- What are your expectations regarding the development and diffusion of large-scale wind energy systems in Argentina?

8.3 Validation process

Table 4: Interview guide for the validation questions and experts' remarks

Number of remarks		Interview questions: Do you think anything should be modified regarding the classification of the development phase?	Do the elements represent the most important influencing factors? Should elements be added or deleted?	Do you think anything should be modified regarding the relationship between the elements?
1985 - 2000	Visualisation of the CA		1	
	Analytical insights		4	
2001 - 2003	Visualisation of the CA			
	Analytical insights		1	
2004 - 2008	Visualisation of the CA			
	Analytical insights		2	
2009-2014	Visualisation of the CA		3	4
	Analytical insights		3	4
2015 - 2020	Visualisation of the CA			1
	Analytical insights	1	13	2

8.4 "Fits 2013 Energy" programme

Table 5: Projects and outcomes* of the "Fits 2013 Energy" programme
Source: based on the report of Aggio et al. (2018)

Project	Results*[16]	Private and public partners
1. Development of a 1.5 MW variable speed wind turbine with gearbox, suitable for Class II winds in Argentina.	The project encountered regulatory difficulties that prevented the testing of the prototype wind turbine that had been developed.	NRG Patagonia S.A. Universidad Nacional de la Patagonia San Juan Bosco
2. Development of a comprehensive repair and maintenance service for large wind turbines, with the capacity to manufacture the necessary spare parts for such purposes.	The project was still in the development phase in 2017 but with the expectation of fully achieving the expected results.	Centro de Maquinado Metalúrgico S.R.L. INTI
3. Setting up a technology platform to enable the development and domestic production of blades for high-power wind turbines. This includes the design of two prototypes for a testbed and three more prototypes to be tested in the field.	The technical design of 40 metre-long blades was engineered, and a prototype of a small blade version was manufactured. The funding was not sufficient to manufacture prototypes for field tests.	INVAP S.E. ITP Argentina S.A. Universidad Nacional de La Plata Municipalidad de Cutral Co
4. Development, prototyping, and serial manufacturing of large-scale parts for high power wind turbines.	Although the production of components was achieved during 2017, the planned significant cost reduction was not achieved as a production centre in the Río Santiago shipyard could not be built.	Ente Administrador Astilleros Río Santiago Metalúrgica Calviño S.A Universidad Nacional de La Plata Ministerio de Producción de la Provincia de Buenos Aires
5. Development of the metallurgical company Sica into a national, stable, and competitive supplier of wind	The project objectives were achieved, and the company's facilities were expanded to	Sica Metalúrgica Argentina S.A. INTI

[16] These are the project results at the end of the official project duration in 2017 based on the report by Aggio et al. (2018)

Project	Results*[16]	Private and public partners
turbine towers. The development of R&D projects was supported with the aim of establishing a model factory for wind turbine towers.	produce towers under better qualitative and logistical conditions.	
6. The aim was the production of a prototype of the Unipower wind turbine (patented by IMPSA) with improvements that represent significant technological advances. In addition, the construction of a test bed for prototype testing and to qualify highly specialised personnel was planned.	The project ended with the construction and inauguration of IMPSA's production facility in Godoy Cruz, which manufactured components for its proprietary wind turbines during 2017. However, further activities in the wind energy division were negatively affected by the company's economic difficulties.	Industrias Metalúrgicas Pescarmona S.A.I.C.yF. Ministerio de Infraestructura y Energía de la Provincia de Mendoza EMESA

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