Investigaciones Regionales – Journal of Regional Research
https://doi.org/10.38191/iirr-jorr.25.007

Accepted Article

Functional analysis of technological innovation systems as an approach for smart specialization: the case of solar energy in Arequipa - Peru

Arturo Alatrista-Corrales, Maritza Chirinos-Marroquín**, Jackeline Lucía Campos-Vera***, Maribel Jessica Chullunquia-Pari****, Angel Jeancarlo Coaquira Flores*****, Cecilia Arace Escobar-Huisa*******

Received: 22 November 2023
Accepted: 29 April 2025

Abstract:

This study proposes the application of the methodological framework for functional analysis of technological innovation systems in the context of the implementation of a regional smart specialization strategy. The case focuses on the solar energy industry in the Arequipa region - Peru. For this purpose, interviews, surveys and workshops were conducted with more than 70 stakeholders. The results allowed for the formulation of specific initiatives based on the identification of certain blocking mechanisms. The proposed approach can contribute to the development of innovation policies with regional scope, especially in territories with low scientific-technological infrastructure.

Keywords: Solar energy; technological innovation systems (TIS); regional development.
JEL Classification: O32; Q42; R58.

Análisis funcional de sistemas de innovación tecnológica como enfoque para la especialización inteligente: el caso de la energía solar en Arequipa - Perú

Resumen:

Este estudio propone la aplicación del marco metodológico de análisis funcional de sistemas tecnológicos de innovación en el contexto de la implementación de una estrategia regional de especialización inteligente. El caso se centra en la industria de la energía solar en la región de Arequipa - Perú. Para esto se realizaron entrevistas, encuestas y talleres con más de 70 actores. Los resultados permitieron plantear iniciativas específicas a partir de identificación de ciertos mecanismos de bloqueo. El enfoque propuesto, puede contribuir al desarrollo de políticas de innovación, con alcance regional, especialmente en territorios de baja infraestructura científico-tecnológica.

Palabras clave: Energía solar; sistemas de innovación tecnológica; desarrollo tecnológico.
Clasificación JEL: O32; Q42; R58.

[*] Universidad La Salle, Arequipa, Perú. aalatrista@ulasalle.edu.pe
[**] Universidad La Salle, Arequipa, Perú. mchirinos@ulasalle.edu.pe
[***] Universidad La Salle, Arequipa, Perú. jcamposv@ulasalle.edu.pe
[****] Universidad La Salle, Arequipa, Perú. mchullunquiap@ulasalle.edu.pe
[*****] Universidad La Salle, Arequipa, Perú. acoaquira@ulasalle.edu.pe
[******] Universidad La Salle, Arequipa, Perú. cescobarh@ulasalle.edu.pe
Corresponding author: aalatrista@ulasalle.edu.pe

1. Introduction

In modern societies, economic development and well-being are sustained by the constant creation and destruction of knowledge (UNIDO, 2005). "Technological learning" promotes productivity and higher wages, leading companies to shift from labor-intensive activities to more technological sectors; this promotes diversified and sophisticated industrial production, driving faster economic growth even in low—and middle-income countries (UNIDO, 2009).

In recent years, innovation has become central to the policy agenda (Chandra, 2006). Several approaches have been explored to achieve successful initiatives (Navarro et al., 2016); however, it is recognized that not just one type but a set of policies will better consider specific social, political, and technological factors that affect innovation promotion (Tödtling & Trippl, 2005; Bergek et al., 2015).

The territorial approach has emerged as a prominent strategy in several countries worldwide to foster innovation and economic development in specific regions (Eklinder & Åge, 2017). An essential component of this approach is smart specialization, which is based on understanding each territory's unique resources and capabilities, enabling greater efficiency and effectiveness in promoting innovation and growth (Foray, 2015). This approach has recently been adopted in Peru and other Latin American countries (Barroeta et al., 2017).

The Arequipa region, located in southern Peru, features diverse geography from mountainous terrain to fertile valleys, flanked by the Andes Mountains and the Pacific Ocean. Its strategic location is a vital link for trade and commerce, with access to major ports along the Pacific coast. Its economy is primarily driven by extractive industries such as mining, agriculture, and fishing. Non-traditional sectors like agriculture, agro-industry, manufacturing, steel, metallurgy, and chemicals have grown significantly since 2002. Arequipa contributes 5.4% to the national GDP, making it the second most important region after Lima. Mineral extraction, including copper, lead, zinc, molybdenum, and gold, is the region's primary activity, accounting for 27% of the national production (Agenda Innovación Arequipa, 2019).

With the support of the national program for the development of regional capacities for the promotion of innovation, and led by the academic sector, during 2018 and 2022, studies were implemented to develop an innovation strategy based on the concept of smart specialization. The identified areas of specialization are linked to the mining and manufacturing industry, agribusiness, tourism, information technologies, and environmental technologies. While the innovation ecosystem has strengths supported by its diverse resources, favorable conditions, cultural heritage, and strategic location, challenges such as business informality, centralized decision-making, a deficiency in innovation culture, institutional trust issues, and limitations of infrastructure represent obstacles that must be addressed for sustainable growth (COPASA, 2022).

In the area of specialization related to environmental technologies, the use of renewable energy, including solar, stands out strongly. This fact is supported by internal factors, like the high potential for non-conventional renewable energies, including the region's outstanding solar radiation index (greater than 6.5 kWh/m2.day), and the fact that Arequipa concentrates the largest Peruvian market for solar technologies (COPASA, 2023). External factors are related to the imperative need to massively scale up renewable energy technologies, which could contribute to the global goal of decarbonizing the economy in the coming decades (Jacobsson et al., 2017; Guerrero et al., 2016; Jaiswal et al., 2022).

However, as is the case of different regions located in Latin American countries, constraints in scientific and technological infrastructure, institutional underdevelopment, and deficient centralized policies negatively impact the capacity to foster innovation (Sagasti, 2011; Navarro et al., 2016). In addition, innovation promotion is also hindered by specific factors like political instability, low levels of empowerment of regional actors, and limited regional capacities for policymaking (Alatrista, 2022). This context raises the question of Identifying adequate initiatives that could contribute to a successful innovation strategy based on regional specialization.

This study deals with this question using the analytical framework of technological innovation systems (Bergek et al., 2008). This framework was applied to the solar energy sector, but considering a territorial-regional specialization perspective, in this case, in the region of Arequipa-Peru. The study aims to examine the mechanisms that either limit or promote the "regional" technological innovation system and how, from this perspective, strategies can be identified to contribute to smart specialization strategies. This approach may suggest a positive convergence between the smart specialization approach and the TIS analysis, which may help regions increase the probability of success when they select and implement regional innovation initiatives.

The work is structured as follows: in chapter 1, we make the introduction considering the background of the region's innovation system. In chapter 2, we introduce a conceptual framework to frame the study in the state of the art of TIS and smart specialization strategies. In chapter 3 we show the methodology emphasizing the functional analysis of TIS In Chapter 4, we show the results, starting with an analysis of the context that leads to the formation of the TIS of solar energy in Arequipa. Findings and corresponding analysis are then shown regarding each of the TIS functions, also considering the relevant actors, networks and institutions for each of the functions; we then identify blocking mechanisms and suggest strategies to foster TIS development. Finally, in chapter 5 we note our conclusions.

2. Analytical framework

Innovation policy has been a relevant topic of analysis in recent decades (Edler & Fagerberg, 2017), not only in industrialized but also in catching-up countries (Jacobsson & Bergek, 2006; UNIDO, 2005). Academics have highlighted the need to find mechanisms to promote innovation and technological change, even considering related perspectives such as technological policy (Nelson, 1995) or industrial policy (Jacobsson, 1986). This includes a series of initiatives whose approaches evolved from R&D financing, addressing market failures, to innovation systems (Edler & Fagerberg, 2017; Jacobsson et al., 2017). Although not simultaneously and with certain particularities, this evolution process has also occurred in less industrialized countries (Sagasti, 2011; Alatrista & Coaquira, 2023).

Innovation systems (IS) have emerged as a highly flexible approach to assessing both industrial and technological evolution (Carlsson, 2006; Edquist, 2006). Various approaches have been identified throughout the literature, some based on territory, others on sectors, and some on specific technologies (Nelson, 1993; Malerba, 2004; Bergek et al., 2015). These approaches have evolved, leading to a growing emphasis on territorial dimensions, like regional innovation systems (Camagni & Capello, 2013; Foray, 2015).

In recent years, territorial approaches have gained considerable relevance by focusing on the regional sphere as a crucial platform for resource aggregation (Hauser et al., 2007). In a way, these approaches provide valuable insights into the interpretation of concepts such as the "concentration factor" or "critical mass" in an industrial district (Marshall & Groenewegen, 2013) and the concept of clusters (Porter, 1998). It is important to note that although a regional innovation system (RIS) can overlap with a cluster, an RIS can host multiple clusters and industries (Eklinder & Åge, 2017).

Given the geographical complexity of innovation, it is essential to identify specific patterns aligned with the territory to design effective policies (Camagni & Capello, 2013; Arza & López, 2021). Research and Innovation Strategies for Smart Specialization (RIS 3) emphasize the use of local resources (Foray, 2015) and prioritize the interconnection of relevant regional economic sectors to achieve sustainable development (Romão & Neuts, 2017). Furthermore, they underscore regional diversity and a region's capacity to implement innovation policies aligned with its unique characteristics and economic transformation objectives (Wibisono, 2022). According to Foray et al. (2012), the RIS3 implementation process requires, among other activities, an analysis of the regional context, identifying priorities (entrepreneurial discovery process rooted in the territory), and implementing a combination of policy initiatives.

Implementing smart specialization strategies requires multilevel governance (Carayannis & Grigoroudis, 2016), and a high level of institutional capabilities (Lazzeretti et al., 2022). This would make the process a challenging task that becomes greater in contexts of weak governance, communication gaps, and limited inter-institutional coordination (Trippl et al., 2019). At the same time, the implementation of successful policy initiatives may be prevented by low preconditions or propensity for innovation (Tödtling & Trippl, 2005; Marques & Morgan, 2018). These limitations may be present in numerous regions in developing nations that often concentrate their foreign trade in labor-intensive sectors, which hinders their technical capabilities (Bo & Liu, 2023) and their capacity to transition to more specialized sectors (Alshamsi et al., 2018). They may have limited funding for research and development activities (UNIDO, 2005; Vovchenko et al., 2016) and restricted access to relevant information which undermines their ability to promote and implement innovative practices (Kokt & Makumbe, 2020; Chandra, 2006). On the other hand, many of these regions are located in contexts of institutional underdevelopment, deficient policy (Sagasti, 2011; Navarro et al., 2016; Ferreira & Botero, 2020; Zapata & González, 2021), and low political empowerment in local territories that negatively impact their capacity for implementing and sustaining consistently regional policy initiatives for innovation (Alatrista, 2022).

Although the selection of innovation policies that are most appropriate for a certain region is of key interest, there is no ideal procedure that fits all (Tödtling & Trippl, 2005). Some authors have focused on classifying different innovation policy initiatives regarding their focus (Navarro et al., 2016; McCann & Ortega, 2013; Edler & Fagerberg, 2017). Foray, et al. (2012) proposed a classification model for the typology of European regions and proposed a set of policies that could best fit each typology. Alatrista (2022) used this approach to evaluate its relevance in regions of Latin America.

In order to select appropriate initiatives, the methodological framework of technological innovation systems can be relevant. Technological innovation systems (TIS) focus on the generation, diffusion, and utilization of specific technologies; regardless of geographical boundaries, they can encompass multiple industrial sectors (Carlsson & Stankiewicz, 1991). In contrast to traditional neoclassical economic approaches, which tend to emphasize market mechanisms and individual incentives as drivers of innovation (Jacobsson et al., 2017), these systems acknowledge that innovation is a complex process that involves not only technological advancements but also social, economic, and institutional factors (Bergek et al., 2015). Furthermore, they emphasize the need for policies, infrastructure, and supportive institutions that facilitate collaboration and the exchange of knowledge related to specific technologies (Wang, 2023).

Bergek et al. (2008) developed a scheme for analyzing TIS that helps to identify key policy issues and set policy goals. The analysis focuses on identifying obstacles associated with the development of seven functions responsible for the system's compelling performance. These functions include "Knowledge development and diffusion [F1], Influence on the direction of search [F2], Entrepreneurial experimentation [F3], Market formation [F4], Legitimation [F5], Resource mobilization [F6], and Development of positive externalities [F7]." The functional analysis also involves recognizing structural components of the TIS, comprising (a) key actors such as companies, universities, public bodies, or influential organizations; (b) networks, both formal and informal, such as consortiums of technological platforms, public-private partnerships, and academic research groups; and (c) relevant institutions that influence norms and laws. Many authors have made contributions in order to get a further understanding of the mechanisms of TIS formation and evolution (Suurs, 2009; Hekkert et al., 2007). The TIS analysis has been applied to many technological sectors, including renewable energy (Hekkert & Negro, 2009).

Most studies related to TISs and their functions have reached findings that could be perceived as conclusive within the context of developed countries; however, extrapolating these results to emerging nations would not be totally correct due to the significant technological gaps and other inherent factors that would complicate its application (Esmailzadeh et al., 2020; Edsand, 2019). Despite this argument, some authors have applied the TIS analysis for policy formulation in developing nations, even applied to renewable energy (Fernández & Watson, 2022; Esmailzadeh et al., 2020).

Although numerous studies concentrate on the technology focus for defining the scope of TIS analysis, further contributions have suggested the importance of including space as a relevant factor that affects knowledge creation among networks (Binz et al., 2014). These contributions suggest that TIS analysis may consider smaller-scale study areas than the national level, such as regional and local levels. For example, Rohe and Chlebna (2021) examined wind energy TIS in the Ondenburger Land and Uckermark regions in Germany. These regions share a similar technological trajectory but differ in terms of demographic, socio-economic development, and other elements of the TIS. These distinctions affect the configuration of specific institutional actors, which ultimately significantly impact legitimacy (Rohe & Chlebna, 2021).

3. Methodology

With the purpose of identifying adequate initiatives that could contribute with a successfully innovation strategy based on regional specialization, we examined the context of solar energy as an area of specialization in the Arequipa region. Based on official documentation and other previous local studies, we conducted a context analysis of the implementation process of the regional innovation strategy based on the concept of smart specialization. We specifically analyzed the identification of renewable and solar energy as an area of regional specialization.

Subsequently, a functional analysis of the solar energy innovation technological system was conducted, employing the methodology recommended by Bergek et al. (2008). For the functional analysis, we collected data on actors, networks, and institutions, then identified and selected key indicators to contextualize the seven functions of the technological innovation system. The chosen indicators encompassed the following:

Table 1.
Indicators used for the functional analysis of the technological innovation system

Function	Function Description	Indicator	Authors
Knowledge development and diffusion	Increase in the knowledge base of a TIS and exchange of knowledge between all the elements that make up the system (Ulmanen & Bergek, 2021). Likewise, this function is fundamental because it focuses on the knowledge base of the TIS, globally, and the performance of the local TIS from its knowledge base (Bergek et al., 2008)	Number and size of R&D projects. Number of academic programs. Number of research centers. Number of patents. Academic events.	(Bergek et al., 2008)
		R&D on the needs of the industry. R&D projects. Workshops, conferences.	(Hekkert et al., 2011; Huang et al., 2016; Markard & Truffer, 2008)
Influence on the direction of search	This function is the result of combining both the pressures and incentives that determine the entry of organizations and companies into a TIS (Bergek et al., 2008).	Visions. Clear forecasts. Expectations about how the technology will develop.	(Bergek et al., 2008; Hekkert et al., 2011)
		Transparency of specific objectives. Regulations determined by government and industry / Policy objectives.	(Hekkert et al., 2011)
		Support the goals with specific programs and policies. Incentives.	(Bergek et al., 2008; Hekkert et al., 2007)

TABLE 1. CONT.
Indicators used for the functional analysis of the technological innovation system

Function	Function Description	Indicator	Authors
		Beliefs in growth potential Incentives from factor/product prices, e.g. taxes and prices in the energy sector. The extent of regulatory pressures, e.g. regulations on minimum level of adoption ("green" electricity certificates, etc.) and tax regimes. The articulation of interest by leading customers.	(Bergek et al., 2008)
Entrepreneurial experimentation	It is considered one of the main sources of uncertainty reduction to the extent that it involves an analysis of new technologies and applications (Bergek et al., 2008).	The presence of a sufficient number of industrial actors in the innovation system / Providing sufficient innovation from industrial actors.	(Hekkert et al., 2011)
		Actors developing entrepreneurial activities.	(Esmailzadeh et al., 2020).
		The rate of entry of new entrants, entrepreneurs.	(Bergek et al., 2008)
		Number of new entrants, including diversifying established firms. Number of different types of applications. The breadth of technologies used and the character of the complementary technologies employed.	(Bergek et al., 2008)
Market formation	This function is based on the opening and development of a space in which products can be exchanged in a semi (structured) way between buyers and suppliers (Ulmanen & Bergek, 2021). It should be noted that authors such as Hekkert and Negro (2008) establish that new technologies, such as sustainable ones, usually encounter difficulties in competing with existing technologies; in that sense, the generation of protected spaces for new technologies is necessary.	Number, size and type of markets formed / actors' strategies, the role of standards (1). Customer groups, the role of standards, and lead users.	(Bergek et al., 2008; Bergek et al., 2005).
		Estimated amount of energy that can be covered with renewable energy / The existence of support policies for the local industry.	(Esmailzadeh et al., 2020)

Table 1. cont.
Indicators used for the functional analysis of the technological innovation system

Function	Function Description	Indicator	Authors
Legitimation	The present function is based on compliance with relevant institutions and social acceptance (Ulmanen & Bergek, 2021).	Attitudes towards technology among different stakeholders. Rise and growth of interest groups. Political debate and the media.	(Bergek et al., 2008)
		Quantity and quality of alliances or pressure groups.	(Hekkert et al., 2011)
		Supportive comments on the use of new technologies in the media, social networks. Scientific and industrial meetings. Resistance to change and use of new technologies.	(Esmailzadeh et al., 2020)
Resource mobilization	It involves the acquisition of resources of diverse nature by the system for innovation; Within the resources we find: labor, materials, among others (Ulmanen & Bergek, 2021).	Volume of capital and venture capital. Volume and quality of human resources. Volume and quality of complementary assets.	(Bergek et al., 2008)
		The amount of access to these resources for stakeholders.	(Hekkert et al., 2011)
		The use of international financial resources, including international donations and loans.	(Edsand, 2019)
		Use of human resources resident abroad.	(Esmailzadeh et al., 2020)
		Increasing volume of capital. Increasing volume of initial and risk capital. Changing volume and quality of human resources (e.g. number of university degrees). Changes in complementary assets.	(Bergek et al., 2008)
Development of positive externalities	The generation of profits at the system level, which will be available to all actors in the system, even for those who did not contribute to its construction (Ulmanen & Bergek, 2021).	Strength of political power of TIS actors. Activities aiming at uncertainty resolution. Existence or development of specialized intermediates and/or a pooled labour market. Information and knowledge flows.	(Bergek et al., 2008)

Note: Evaluation was made during the first half of 2023.
Source: author´s elaboration.

Based on previously mentioned indicators, the seven functions of the technological innovation system were examined, adopting a spatial or territorial focus centered on the Arequipa region in Peru.

Secondary data were obtained from official documents and databases covering renewable energy projects in Arequipa between 2018 and 2023. The data was complemented with primary data collected through 25 structured surveys, 10 in-depth interviews with experts conducted in April 2023, and 3 participatory workshops, from April 25 to May 11, which engaged over 70 stakeholders from academia, industry, and government. We examined sectoral barriers, innovation impacts, and collaboration dynamics, in order to provide an understanding about the solar energy ecosystem. The instrument is provided in Annex 1.

4. Results

4.1. Analysis of the context: solar energy as a specialization area for the Arequipa Region

Efforts to strengthen regional innovation systems under intelligent specialization (RIS3) began in 2017 with the "Arequipa Innovation Agenda," supported by the National Council of Science and Technology. This initiative aimed to develop a regional innovation strategy, integrating competitiveness studies and identifying solar energy as a specialization niche, particularly in mining and industrial processes (Agenda Innovación Arequipa, 2019). In 2019, the Ministry of Production's "PROINNOVATE" program expanded these efforts, defining six areas of specialization, including renewable energy, advanced manufacturing, and agro-tech (COPASA, 2022).

In 2022, three pilot projects were implemented to strengthen these areas. One focused on renewable energy, emphasizing solar technologies, and involved key stakeholders from local governments, academic institutions, and private companies. This collaboration led to the creation of a roadmap prioritizing photovoltaic solar energy and green hydrogen development due to competitive energy costs. Additionally, barriers to sectoral growth were identified, offering insights for future strategies (Innova Arequipa, 2023a; Innova Arequipa, 2023c).

4.2. Analysis of TIS functions

4.2.1. Function 1: Knowledge development and dissemination

This section explores renewable energy knowledge production in Peru, focusing on academic research, educational programs, and funded projects. Over 700 theses were reviewed from national repositories like ALICIA – CONCYTEC (CONCYTEC, 2023), with 78% from undergraduate studies and 22% from postgraduate levels (18% master's, 4% doctoral). Topics largely centered on photovoltaic technology applied to agriculture, construction, and industry. Arequipa contributed 20% of this production—25% in doctoral theses—despite its smaller population compared to Lima. However, only 20% of the theses showed technological innovation, the rest applying existing technologies to specific sectors.

Regarding educational programs, 12 Peruvian universities offer renewable energy studies, including four undergraduate programs, twelve master's, and three doctoral programs (Innova Arequipa, 2023a). Arequipa hosts two research centers but received minimal national funding—participating in just one of eight emblematic doctoral programs supported by $14 million each. This underscores an imbalance in funding despite the region's strong knowledge base in renewable energy.

Financially, 46 solar research projects funded by the National Scientific Research Program were analyzed, with most concentrated in Lima despite Peru's highest solar radiation levels in the southern coast (SENAMHI, 2003). Over half targeted fishing industry applications, yet only 20% aimed at developing new products or processes. Experts attribute this to limited collaboration among universities and stakeholders, hindering transitions from technological to commercial readiness levels (TRL to CRL).

At the national level, events like the APES solar symposium, established in 1986, promote knowledge sharing but have limited impact on advancing technological innovation (Innova Arequipa, 2023c).

4.2.2. Function 2: Direction of search

Peru's renewable energy framework promotes electricity generation through laws such as Supreme Decree No. 012-2011-EM, which facilitates long-term contracts and incentives for renewable projects.

Other laws, like the Climate Change Framework Law (No. 30754-2018) and National Energy Policy (No. 064-2010-EM), align with these goals by setting guidelines for sustainable development. However, regional policies in Arequipa remain limited due to centralized decision-making, with regional governments lacking authority to call renewable energy auctions (Mitma, 2023; Alatrista, 2022).

Currently, Peru has an installed solar capacity of 300 MW, primarily photovoltaic, with Arequipa hosting the largest number of projects, including the San Martín solar plant with 300 MW capacity set for operation by 2025 (Zurita, 2023; Energías Renovables, 2023). Yet, reliance on imported technology and lack of local supplier engagement hinder innovation ecosystems. Green hydrogen, a nascent sector, shows promise, with pilot projects in southern Peru and roadmaps developed by regional and binational mining clusters. However, the lack of regulatory frameworks and mature platforms, as seen in Chile, limits Peru's advancement (Innova Arequipa, 2023c).

For residential markets, falling technology costs boost demand for photovoltaic and solar thermal systems, but imported technologies dominate, displacing local industry. Financial mechanisms for renewable energy adoption remain inactive, further constraining growth (Innova Arequipa, 2023a).

4.2.3. Function 3: Entrepreneurial experimentation

With the aim of evaluating links between research and development projects and entrepreneurial activity interviews with stakeholders considered the impact of research and development projects on the generation of new ventures or the commercialization of technologies. The results reveal that 40% of respondents believe their projects have slightly impacted the development of new product or process innovations. Furthermore, only 10% of respondents believe their projects have fostered the emergence of a new company. On the other hand, 10% indicated that their project impacted sales growth and profit generation within the commercial sphere. Finally, only 10% determined that their project positively impacted international market expansion. These findings indicate that while there is a certain level of academic research and development activity, the impact on entrepreneurial activity is relatively low.

Additionally, the database of consultants and state suppliers was analyzed, as this information may indirectly contribute to delivering insights about entrepreneurial activity. According to the State Supplier Directory, 971 suppliers include the term "solar" in their name, sector, or contracts; 113 are located in Arequipa, accounting for 11.64% of the total. This demonstrates a significant level of entrepreneurial activity compared with other Peruvian regions, considering that Arequipa generally contributes only 5% to the national GDP.

4.2.4. Function 4: Market formation

In evaluating the formation of renewable energy markets, two market types were considered: residential-commercial and industrial-mining. Additionally, two types of energy use, thermal and electrical, were considered.

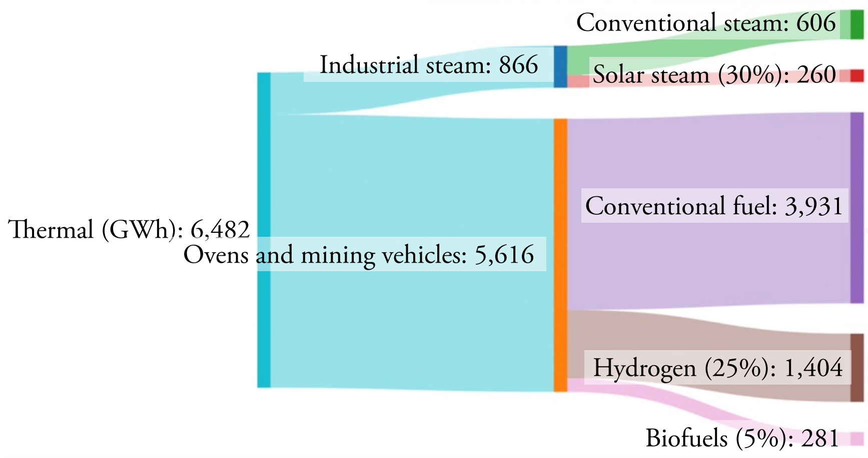
Regarding the residential sector, the Arequipa region accumulates over 90% of the national market for domestic water heating systems (Tinajeros & Morante, 2011). Moreover, the region holds the highest potential market for these systems due to its high solar radiation. Currently, approximately 30 companies in the region manufacture water heating systems, representing 47% of all such companies in Peru. Informal businesses involved in the fabrication and installation of heaters also exist. Although the region had several companies and workshops manufacturing residential water heating systems (mostly flat plate heaters), most now import Chinese systems, particularly vacuum tubes, and heat pipe heaters. This displacement of local manufacturing by imports is due to the more competitive prices offered by Chinese companies. It should be noted that policies to support local manufacturing are nonexistent not only in Arequipa but in the rest of the country (Alatrista, 2022).

On the other hand, more than 20 companies offer photovoltaic systems for residential applications, water pumping, and other purposes. These technologies are typically imported from China. However, according to interviewed experts, the sector lacks the technical standards needed to regulate these markets; this may contribute to the introduction of low-quality products that undermine the credibility of other brands. Although some efforts are devoted to developing new standards, there is still limited interest from stakeholders.

Although Arequipa is recognized as a significant market in Peru, its potential has yet to be fully realized. According to the interviews, the volume of the residential technology market remains low due to the absence of financial support programs or market and technology incentive programs compared to other substitute technologies.

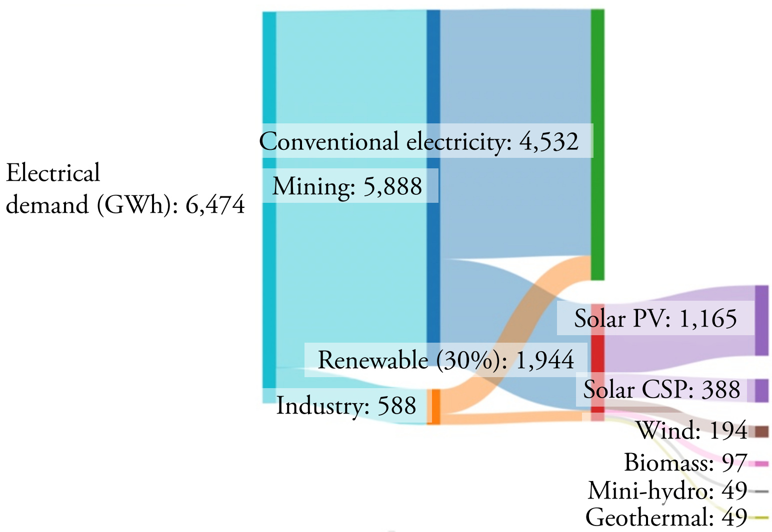
On the other hand, although excellent renewable resources can be used, there is also a potential demand for energy in the industrial-mining sector that can give rise to a thriving market. Currently, this sector shows some use of renewable energy, such as low-temperature solar thermal installations for textile washing processes. However, there is still a great untapped potential for different solar technologies and derivatives, such as the production of green hydrogen.

FIGURE 1.
Estimation of regional thermal demand and potential use of thermal renewable energy



Source: Innova Arequipa (2023b).

FIGURE 2.
Estimation of regional electrical demand and potential use of electrical renewable energy



Source: Innova Arequipa (2023b).

According to Figure 1 and Figure 2, there is an estimated potential thermal demand of 260 GWh/year for industrial solar steam that could be used for industrial applications. On the other hand, it has been calculated that the mining sector could generate a demand of 1404 GWh/year for hydrogen in large trucks, a fuel that could be produced using solar energy. Furthermore, the potential for electrical energy (for mining and industry) from solar sources has been estimated at 1165 GWh/year for photovoltaic systems and 388 GWh/year for concentrated solar power (CSP) systems. Additionally, there is a potential market for green solar-hydrogens for export due to the highly competitive prices expected (Innova Arequipa, 2023b).

4.2.5. Function 5: Legitimation

This section examines solar energy potential, stakeholder dynamics, and efforts to strengthen legitimacy in the renewable energy ecosystem. Workshops in 2021 identified solar energy as a priority within "Resilient and Green Arequipa," recognizing the region's high solar radiation levels. Despite this, adoption has been limited, often tied to cost-benefit criteria rather than proactive promotion. Interviews reveal that interest groups are mainly academic, with limited representation from industry associations or producer guilds, reducing their capacity to advocate for legislative changes like micro-generation incentives.

Experts also pointed out a growing market for solar-powered equipment, such as lighting and pumping systems, that faces challenges due to the absence of protocols for evaluating imported equipment quality, undermining consumer trust. On the other hand, virtual information groups focus on renewable energy projects but lack emphasis on innovation or technological development in solar energy. This limits the commercial dissemination of products and university-led advancements.

In 2023, two projects were financed to promote solar energy through actor network strengthening, technology fairs, and field studies (COPASA, 2022). This effort is considered relevant for legitimate the importance of the sector for the region.

4.2.6. Function 6: Resource mobilization

This section analyzes funding, regional potential, and challenges for solar energy development in Peru. The Innovation, Science, and Technology Fund (FINCyT) has financed over 2,900 projects since 2010, but only 15 were solar energy-related. Similarly, FONDECYT funded over 3,400 projects, with just 31 focusing on solar technologies. These projects typically received $70,000 each, concentrated mainly in Lima, contrasting sharply with Arequipa's significantly higher solar radiation levels (6.5-7.03 kWh/m²) compared to Lima's 4.06 kWh/m² (SENAMHI, 2003; OSINERGMING, 2019).

This centralization of resources misaligns with national regional specialization strategies, hindering regional technology development. Interviews revealed medium to low integration with international experts in solar projects, with only 10% involving some degree of international technology transfer.

Additional funds for renewable technology adoption include international cooperation initiatives like FASERT, GIZ, and PROFONANPE, which focus on rural development. Domestic mechanisms, such as COFIDE, have supported clean technologies in the past but face challenges like complex credit applications and limited dissemination. Proposals for reactivating these funds are under discussion, but private sector venture capital remains limited and centered in Lima.

Private sector interest in solar energy primarily focuses on electricity generation. By 2022, 32 renewable energy plants operated nationally, contributing 5.5% to electricity production. This included nine photovoltaic plants and other renewable installations with a combined capacity of 881.3 MW. This capacity is projected to grow as additional solar plants become operational (Innova Arequipa, 2023c).

4.2.7. Function 7: Development of positive externalities

This section evaluates the creation of positive externalities in Peru's solar energy sector, focusing on political influence, market dynamics, and institutional coordination. Political influence remains weak, with business groups in the residential sector primarily composed of small enterprises exhibiting limited technological innovation. In the industrial sector, most companies are subsidiaries of foreign corporations focused on broader energy management applications rather than local technological development.

Specialized intermediaries and labor markets for renewable energy have declined, largely due to the influx of imported products such as water heaters, which have displaced locally manufactured goods. This shift underscores the challenges faced by companies in specializing exclusively in renewable energy, as the market size often necessitates diversification into other products and services (Innova Arequipa, 2023c).

Photovoltaic solar plants generally operate independently of local suppliers and stakeholders, highlighting a lack of coordination among government entities. While the Ministry of Energy prioritizes diversifying the energy matrix, the Ministry of Production focuses on fostering economic development, resulting in fragmented efforts. This disjointed approach suggests that renewable energy is perceived more as a tool for energy diversification than as an industrial sector capable of driving regional economic growth.

4.3. Evaluation of blocking mechanisms

The Arequipa region in Peru holds significant potential for technological development in solar and renewable energy. However, various factors hinder the regional TIS. This analysis examines these barriers based on the framework of seven key functions identified in the context of the region's technological landscape.

Knowledge Development and Dissemination: Despite growing academic interest and research activities related to solar technology, many of these efforts lack technological innovation. Only 20% of the analyzed theses exhibited innovation and had a measurable impact on industry, highlighting a gap between translating knowledge into technological advancements. This issue may stem from insufficient prioritization of funding and limited interaction networks among stakeholders.

Direction of Search: Centralized policies and limited regional empowerment hinder the promotion of innovation in the renewable energy sector; there are noticeable discrepancies in governmental strategies for renewable energy promotion are noticeable. While solar power plants have been established, their establishment aligns more with diversifying the energy matrix than fostering the regional development of a solar technology industry. The historical political centralization in Peru and the limited regional empowerment in innovation policy could impede the formation of the TIS.

Entrepreneurial Experimentation: The impact of research and development projects on entrepreneurial activity is relatively low. Only a small percentage of projects contribute to new product innovations or the emergence of new companies, This gap reveals a lack of synergy between research institutions and entrepreneurial activity.

Market Formation: In the residential sector, the absence of financial support programs and regulatory frameworks for quality standards hinders market formation for solar and renewable energy technologies. Moreover, the dominance of imported technologies over locally manufactured products exacerbates market development challenge. Despite the presence of world-class mining and industrial enterprises, they have not embraced extensive initiatives and remain loosely integrated within innovation networks. The mining and industrial market, however, represents an untapped opportunity for growth.

Legitimation: The legitimacy of solar technologies is undermined by limited interest groups and the absence of clear protocols for evaluating product quality. Without cohesive interest groups and standardized quality evaluations, solar technologies are often perceived as low-quality, hindering broader market acceptance, especially in the residential sector.

Resource Mobilization: Resource mobilization for technological innovation in solar energy is highly centralized, and the region's potential is not fully aligned with national strategies. Despite the region's high solar potential, funding and support mechanisms are disproportionately directed toward Lima, creating a disparity resource allocation that stifles innovation in Arequipa.

Development of Positive Externalities: Weak political influence, declining specialized labor markets, and limited coordination between government actors pose challenges to the development of positive externalities in the solar and renewable energy sector. The perception of renewable energy as a solution for diversifying the national energy matrix rather than a catalyst for regional economic development further exacerbates these barriers.

According to Bergek et al. (2008), technological innovation systems progress through three developmental phases: formative, growth, and development-diffusion-utilization. The findings suggest that the technological innovation system in solar energy currently resides in the formative stage. Despite recognizing the considerable developmental potential of these technologies, the innovation system has historically faced limited incentives and has primarily evolved through supply and demand dynamics. Nevertheless, Arequipa remains the primary market for solar technologies in Peru.

4.4. Identification of development strategies

In order to promote the solar technology industry, a series of strategies should be implemented, not only at the national level but especially at the regional level. At the national level, the objectives of diversifying the energy matrix should be aligned with regional objectives of developing a technological system that could produce new entrepreneurs and companies that could foster an industry that generates economic growth. To make both objectives compatible, mechanisms must be created to legitimize the technology at the national level, including, within development policies, a regional focus on specific support for the solar energy sector, such as the deployment of resources for research and entrepreneurship in the field of solar energy, support for local industry, and the development of standards. These last initiatives could be of special interest to the solar energy residential sector.

Furthermore, it is recommended that regional mechanisms be strengthened to finance demonstrative and prioritized projects related to high-potential technologies. These mechanisms can be coordinated with private and public stakeholders at the national level. Additionally, funding should be allocated for studies demonstrating the real energy potential, technological foresight, and potential for industrial development, such as solar thermal concentration systems for industrial applications or the production, processing, and logistics of green hydrogen. These studies and projects should be aligned with a consistent roadmap that allows for the optimization of resource deployment.

Moreover, the interactions between stakeholders must be strengthened. In particular, it is recommended that networks be enhanced with the mining and industrial sectors, which have a significant potential impact on developing a solar technology market. The mining sector is particularly interesting due to its substantial influence on the regional economy and large energy consumption. Implementing project financing programs to integrate solar solutions into the mining industry and forming new technological suppliers is recommended. In order to straighten networks among actors, the involvement of intermediary institutions is advised to create or strengthen an institution that coordinates research and development efforts, as well as industry expectations, to enhance the impact of projects and optimize R&D resources. This institution should help align the interests of various stakeholders and position the technology at the regional and national levels.

Lastly, it is essential to enhance local capabilities to establish mechanisms for promoting innovation through regional innovation policies and generate local public-private participation funds to support the solar industry. Effective governance and strong innovation management capabilities among decision-makers are necessary to achieve this.

5. Conclusions

In this article, we present a functional analysis of the technological system of solar energy innovation, considering a territorial approach; in this case, the analysis focuses on the Arequipa region. Solar energy has positioned itself as a strategic area of specialization in this region, given its exceptional solar radiation potential and its status as Peru's largest market for solar technologies. Based on the regional specialization approach, this sector has been incorporated into the region's strategic plans for promoting innovation and technology.

The analysis allows us to conclude first of all that the solar energy innovation technological system is still in the initial stage of development due to the presence of small markets with significant uncertainty and lack of standards, weak advocacy coalition, poorly articulated demand from customers and limited resources and capabilities; This implies the need to strengthen the regional TIS with general initial initiatives such as the development of pilot demonstration projects, incentives for market development, cluster formation, among others, as it is shown by (Bergek et al., 2008). In addition, specific strategies have been identified, such as developing market development initiatives based on solutions for the mining-industrial sector, strengthening specialized networks of collaboration between stakeholders, and creating regional institutions to coordinate the allocation of research and innovation funds.

On the other hand, the development of a certain TIS, whether it has a national or regional focus, is influenced by social, technological, and/or political territorial factors. In this case, it can be seen that although the territorial focus on smart specialization has been implemented in Arequipa to promote economic development and innovation, the TIS development has been hindered by the lack of innovation capabilities, limitations in scientific and technological infrastructure, challenges in multilevel governance, and low regional capacity for promoting innovation, typical of several Latin American regions (Alatrista, 2022; Arza & López, 2021).

The territorial approach to the analysis of the TIS has made it possible to identify a gap between national and regional visions and efforts. In this case, national institutions led by the Ministry of Energy and Mines seek to develop renewable energy, mainly with the objective of diversifying the energy matrix. In contrast, regional actors seek to promote technological and economic development, focused on developing the renewable and solar energy industry. This difference in visions shows the need to legitimize solar technologies at both the national and regional levels (Rohe & Chlebna, 2021). Additionally, the centralization of political power and resources for research and innovation represents a risk that must be mitigated.

Finally, we conclude that the functional analysis approach of a technological innovation system, from a territorial or regional perspective, could be particularly beneficial for regions with limited scientific and technological infrastructure. By adopting a territorial perspective and leveraging smart specialization principles, a regional TIS analysis can help identify barriers to innovation, leading to proposing specific initiatives that could ultimately allow regions to capitalize on their unique resources and capabilities to foster innovation and economic development effectively.

References

Agenda Innovación Arequipa. (2019). *Agenda Regional de Innovación como Marco Estratégico para la Promoción de la Ciencia, Tecnología e Innovación en la Región de Arequipa.* Fondo Editorial de la Universidad Católica de Santa María.

Alatrista, A. (2022). Regional Innovation Policy in Latin America: Exploratory Analysis. *Journal of Technology Management & Innovation*, *17*(3), 25–39. https://doi.org/10.4067/S0718-27242022000300025

Alatrista-Corrales, A., & Coaquira-Flores, A. (2023). Challenges for the Promotion of Innovation and R&D in Latin America: A Territorial Perspective. In L. Aldieri (Ed.), *Innovation - Research and Development for Human, Economic and Institutional Growth*. Intechopen. https://doi.org/10.5772/intechopen.112289

Alshamsi, A., Pinheiro, F., & Hidalgo, C. (2018). Optimal diversification strategies in the networks of related products and of related research areas. *Nature Communications*, *9*. https://doi.org/10.1038/s41467-018-03740-9

Arza, V., & López, E. (2021). Obstáculos y capacidades para la innovación desde una perspectiva regional: El Caso de la Patagonia Argentina. *Investigaciones Regionales - Journal of Regional Research*, *49*, 131-156. https://doi.org/10.38191/iirr-jorr.21.004

Asociación Peruana de Energía Solar y del Ambiente. (n.d.). *Simposios Peruanos de Energía Solar.* https://www.perusolar.org/simposios/

Barroeta, B., Gómez Prieto, J., Paton, J., Palazuelos, M., & Cabrera Giraldez, M. (2017). *Innovación y especialización regional en América Latina.* Oficina de Publicaciones de la Unión Europea.

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*, *16*, 51-64. https://doi.org/10.1016/j.eist.2015.07.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407-429. https://doi.org/10.1016/j.respol.2007.12.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2005). *Analyzing the dynamics and functionality of sectoral innovation systems - A manual.* DRUID Tenth Anniversary Summer Conference 2005. https://www.researchgate.net/publication/257926033

Binz, C., Truffer, B., & Coenen, L. (2014). Why space matters in technological innovation systems—mapping global knowledge dynamics of Membrane Bioreactor Technology. *Research Policy*, *43*(1), 138-155. https://doi.org/10.1016/j.respol.2013.07.002

Bo, X., & Liu, H. (2023). *Mechanism and path of the Technical Innovation Driven Transformation of China's foreign trade development - from the point of view of social reproduction process*. Proceedings of the 2022 2nd International Conference on Business Administration and Data Science (BADS 2022), 701-714. https://doi.org/10.2991/978-94-6463-102-9_72

Camagni, R., & Capello, R. (2013). Regional Innovation Patterns and the EU Regional Policy Reform: Toward Smart Innovation Policies. *Growth and Change*, *44*(2), 355-389. https://doi.org/10.1111/grow.12012

Carayannis, E., & Grigoroudis, E. (2016). Quadruple innovation helix and smart specialization: Knowledge production and national competitiveness. *Foresight and STI Governance*, *10*(1), 31-42.

Carlsson, B. (2006). Internationalization of Innovation Systems: A survey of the literature. *Research Policy*, *35*(1), 56-67. https://doi.org/10.1016/j.respol.2005.08.003

Carlsson, B., & Stankiewicz, R. (1991). On the Nature, Function and Composition of Technological Systems. *Journal of Evolutionary Economics*, *1*, 93-118. https://doi.org/10.1007/BF01224915

Chandra, V. (2006). *Technology, adaptation, and exports: How some developing countries got it right.* World Bank Group.

CONCYTEC. (2023, 11 12). ALICIA - Acceso Libre a Información Científica para la Innovación. https://alicia.concytec.gob.pe/

Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica. (n.d.). Banco de Proyectos. http://proyectoscti.concytec.gob.pe/

COPASA. (2022). *Plan de desarrollo del ecosistema de innovación y emprendimiento (PDE) de la región Arequipa 2022-2032.* Arequipa Innova.

COPASA. (2023). *Estudio de oferta energías renovables.* Innova Arequipa.

Edler, J., & Fagerberg, J. (2017). Innovation policy: What, why, and how. *Oxford Review of Economic Policy*, *33*(1), 2-23. https://doi.org/10.1093/oxrep/grx001

Edquist, C. (2006). Systems of Innovation: Prespectives and Chellenges. In J. Fagerberg, & D. Mowery (Eds.), *The Oxford Handbook of Innovation* (pp. 195-222). Oxford University Press.

Edsand, H. (2019). Technological Innovation Systems and the Wider Context: A framework for developing countries. *Technology in Society*, *58*. https://doi.org/10.1016/j.techsoc.2019.101150

Eklinder-Frick, J., & Åge, L. (2017). Perspectives on regional innovation policy – from New Economic Geography towards the IMP approach. *Industrial Marketing Management*, *61*, 81-92. https://doi.org/10.1016/j.indmarman.2016.07.005

Energías Renovables. (2023, december 28). Arequipa 300 MW, la mayor planta solar de Perú. https://www.energias-renovables.com/fotovoltaica/arequipa-tendra-la-mayor-planta-solar-de-20231228

Esmailzadeh, M., Noori, S., Aliahmadi, A., Nouralizadeh, H., & Bogers, M. (2020). A Functional Analysis of Technological Innovation Systems in Developing Countries: An Evaluation of Iran's Photovoltaic Innovation System. *Sustainability*, *12*(5), 2049-2069. https://doi.org/10.3390/su12052049

Fernández, A., & Watson, J. (2022). Mexico's Renewable Energy Innovation System: Geothermal and Solar Photovoltaics Case Study. *Environmental Innovation and Societal Transitions*, *43*, 200-219. https://doi.org/10.1016/j.eist.2022.04.004

Ferreira, M., & Botero, A. (2020). Experimental governance? The emergence of public sector innovation labs in Latin America. *Policy Design and Practice*, *3*(2), 150-162. https://doi.org/10.1080/25741292.2020.1759761

Foray, D. (2015). *Smart specialization: Opportunities and challenges for regional innovation policy.* Routledge Taylor & Francis Group.

Foray, D., Goddard, J., Beldarrain, X., Landabaso, M., McCann, P., Morgan, K., Nauwelaers, C., y Ortega-Argilés, R. (2012). *Guide on Research and Innovation Strategies for Smart Specialisation (RIS3 Guide)*. EU European Commission.

Guerrero-Lemus, R., Vega, R., Kim, T., Kimm, A., & Shephard, L. (2016). Bifacial solar photovoltaics – a technology review. *Renewable and Sustainable Energy Reviews*, *60*, 1533-1549. https://doi.org/10.1016/j.rser.2016.03.041

Hauser, C., Tappeiner, G., & Walde, J. (2007). The Learning Region: The Impact of Social Capital and Weak Ties on Innovation. *Regional Studies*, *41*(1), 75-88. https://doi.org/10.1080/00343400600928368

Hekkert, M., & Negro, S. (2009). Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. *Technological Forecasting and Social Change*, *76*(4), 584-594. https://doi.org/10.1016/j.techfore.2008.04.013

Hekkert, M., Negro, S., Heimeriks, G., & Harmsen, R. (2011). *Technological Innovation System Analysis, A manual for analysts*. Utrecht University.

Hekkert, M., Suurs, R., Negro, S., Kuhlmann, S., & Smits, R. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change*, *74*(4), 413-432. https://doi.org/10.1016/j.techfore.2006.03.002

Huang, P., Negro, S. O., Hekkert, M. P., & Bi, K. (2016). How China became a leader in solar PV: An innovation system analysis. *Renewable and Sustainable Energy Reviews*, *64*, 777–789. https://doi.org/10.1016/j.rser.2016.06.061

Innova Arequipa. (2023a). *Mapeo de Actores de la Red de Energías Renovables.* Innova Arequipa.

Innova Arequipa. (2023b). *Informe de estudio de demanda de energía renovable Arequipa.* Innova Arequipa.

Innova Arequipa. (2023c). *Informe de soporte para elaboración de hoja de ruta energías renovables Arequipa.* Innova Arequipa.

Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual. (n.d.). Dirección de Invenciones y Nuevas Tecnologías. Obtenido de https://servicio.indecopi.gob.pe/portalSAE/Personas/tituloOIN.jsp?pListar=SI&pIdTipoExpediente=0#

Jacobsson, S. (1986). *Electronics and industrial policy: The case of computer controlled lathes.* Allen & Unwin.

Jacobsson, S., & Bergek, A. (2006). A Framework for Guiding Policy-makers Intervening in Emerging Innovation Systems in 'Catching-Up' Countries. *The European Journal of Development Research*, *18*(4), 687-707. https://doi.org/10.1080/09578810601094902

Jacobsson, S., Bergek, A., & Sandén, B. (2017). Improving the European Commission's analytical base for designing instrument mixes in the energy sector: Market failures versus system weaknesses. *Energy Research & Social Science*, *33*, 11-20. https://doi.org/10.1016/j.erss.2017.09.009

Jaiswal, K. K., Chowdhury, C., Yadav, D., Verma, R., Dutta, S., Jaiswal, K. Sangmesh, B., & Karuppasamy, K. (2022). Renewable and sustainable clean energy development and impact on social, economic, and environmental health. *Energy Nexus*, *7*. https://doi.org/10.1016/j.nexus.2022.100118

Kokt, D., & Makumbe, W. (2020). Towards the innovative university: What is the role of Organisational Culture and Knowledge Sharing? *SA Journal of Human Resource Management*, *18*, 1-11. https://doi.org/10.4102/sajhrm.v18i0.1325

Lazzeretti, L., Oliva, S., & Innocenti, N. (2022). Unfolding smart specialisation for regional economic resilience: The Role of Industrial Structure. *Investigaciones Regionales - Journal of Regional Research*, *54*, 5-25. https://doi.org/10.38191/iirr-jorr.22.015

Malerba, F. (2002). Sectoral Systems of innovation and production. *Research Policy*, *31*(2), 247-264. https://doi.org/10.1016/S0048-7333(01)00139-1

Malerba, F. (2004). Sectoral Systems of Innovation: Basic Concepts. In F. Malerba (Ed.), *Sectoral Systems of Innovation: Concepts, Issues and Analyses of Six Major Sectors in Europe* (pp. 9-41). Cambridge University Press

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*, *37*(4), 596–615. https://doi.org/10.1016/j.respol.2008.01.004

Marques, P., & Morgan, K. (2018). The Heroic Assumptions of Smart Specialisation: A Sympathetic Critique of Regional Innovation Policy. In A. Isaksen, R. Martin, & M. Trippl (Eds.), *New Avenues for Regional Innovation Systems - Theoretical Advances, Empirical Cases and Policy Lessons* (pp. 275-293). Springer. https://doi.org/10.1007/978-3-319-71661-9_14

Marshall, A., & Groenewegen, P. (2013). *Principles of Economics.* Palgrave Macmillan.

McCann, P., & Ortega-Argilés, R. (2013). Smart specialization, regional growth and applications to European Union Cohesion Policy. *Regional Studies*, *49*(8), 1291-1302. https://doi.org/10.1080/00343404.2013.799769

Ministerio de Energía y Minas (MEM). (2023). *Plan Nacional de Electrificación Rural (PNER).*

Mitma-Ramírez, R. (2023). *Servicio de consultoría para verificar los permisos, autorizaciones y otras normas legales para energía eléctrica producida con energías renovables no convencionales.* Universidad Católica de Santa María.

Navarro, J., Benavente, J., & Crespi, G. (2016). *The new imperative of innovation Policy perspectives for Latin America and the Caribbean.* Inter-American Development Bank.

Nelson, R. (1993). *National Innovation Systems: A Comparative Analysis.* Oxford University Press.

Nelson, R. (1995). Why should managers be thinking about technology policy? *Strategic Management Journal*, *16*(8), 581-588. https://doi.org/10.1002/smj.4250160802

Osinergmin. (2019). *Energías Renovables Experiencia y Perspectivas en la Ruta del Perú hacia la Transición Energética.* Osinergmin.

Porter, M. E. (1998). Clusters and the New Economics of Competition. *Harvard Business Review*, 1-10. https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition

Rohe, S., & Chlebna, C. (2021). A spatial perspective on the legitimacy of a technological innovation system: Regional differences in onshore wind energy. *Energy Policy*, *151*. https://doi.org/10.1016/j.enpol.2021.112193

Romão, J., & Neuts, B. (2017). Territorial Capital, smart tourism specialization and sustainable regional development: Experiences from Europe. *Habitat International*, *68*, 64-74. https://doi.org/10.1016/j.habitatint.2017.04.006

Sagasti, F. (2011). *Ciencia, tecnología, innovación: políticas para América Latina.* Fondo de Cultura Económica del Perú.

SENAMHI. (2003). *Atlas de Energía Solar del Perú. Servicio Nacional de Meteorología e Hidrología.* Ministerio de Energía y Minas.

Suurs, R. (2009). *Motors of Sustainable Innovation Towards a theory on the dynamics of technological innovation systems.* [Doctoral dissertation, Utrecht University]. https://dspace.library.uu.nl/handle/1874/33346

Tinajeros Salcedo, M., & Morante Trigoso, F. (2011). Sistemas de Calentamiento de Agua con Energía Solar en la Ciudad de Arequipa. In APES (Ed.), *XVIII Simposio Peruano de Energía Solar y del Ambiente (XVIII- SPES).* Asociación Peruana de Energía Solar.

Tödtling, F., & Trippl, M. (2005). One size fits all?: Towards a differentiated regional innovation policy approach. *Research Policy*, *34*(8), 1203-1219. https://doi.org/10.1016/j.respol.2005.01.018

Trippl, M., Zukauskaite, E., & Healy, A. (2019). Shaping smart specialization: The role of place-specific factors in advanced, intermediate and less-developed European regions. *Regional Studies*, *54*(10), 1328-1340. https://doi.org/10.1080/00343404.2019.1582763

Ulmanen, J., & Bergek, A. (2021). Influences of technological and sectoral contexts on technological innovation systems. *Environmental Innovation and Societal Transitions*, *40*, 20-39. https://doi.org/10.1016/j.eist.2021.04.007

UNIDO - United Nations Industrial Development Organization. (2005). *Capability building for catching-up: Historical, empirical and policy dimensions.*

UNIDO - United Nations Industrial Development Organization. (2009). *Industrial Development Report: Breaking In and Moving Up - New Industrial Challenges for the Bottom Billion and the Middle-Income Countries.*

Vovchenko, N. G., Ivanova, O. B., Kostoglodova, E. D., Otrishko, M. O., & Dzhu, O. S. (2016). Innovations and fighting global economic problems. *Contemporary Economics*, *10*(4), 289-298. https://doi.org/10.5709/ce.1897-9254.216

Wang, Y. (2023). Research on the evolution mechanism and function of science and technology innovation ecosystem from the perspective of Technological Progress. *Proceedings Volume 12625, International Conference on Mathematics, Modeling, and Computer Science* (MMCS2022). https://doi.org/10.1117/12.2670433

Wibisono, E. (2022). Multilevel Governance and smart specialization in EU regions: An evidence-based critical review. *European Journal of Government and Economics*, *11*(2), 234-250. https://doi.org/10.17979/ejge.2022.11.2.9004

Zapata-Cantu, L., & González, F. (2021). Challenges for Innovation and Sustainable Development in Latin America: The Significance of Institutions and Human Capital. *Sustainability*, *13*(7), 1-21. https://doi.org/10.3390/su13074077

Zurita, M. (2023, May 22). *¿Cuánto han avanzado y cuál es el potencial de las energías renovables en Perú?* Forbes Perú. https://forbes.pe/sostenibilidad/2023-05-22/que-retos-y-oportunidades-tienen-las-energias-renovables-en-peru

ORCID

Arturo Alatrista-Corrales	https://orcid.org/0000-0003-4897-0519
Maritza Chirinos-Marroquín	https://orcid.org/0000-0002-1867-4412
Jackeline Lucía Campos-Vera	https://orcid.org/0009-0004-5371-2017
Maribel Jessica Chullunquia-Pari	https://orcid.org/0009-0006-4727-107X
Angel Jeancarlo Coaquira Flores	https://orcid.org/0000-0002-0422-0954
Cecilia Arace Escobar-Huisa	https://orcid.org/0000-0002-9547-3008

Annex

Survey of expert in innovation and solar technology

General data

First name:

Middle name:

Last name:

The institution where you work:

Phone:

E-mail:

Questionnaire

Indicate one or more professional conditions that you currently have:

a) University researcher researcher

b) University teacher / technological institute

c) Businessman/entrepreneur

d) Public servant/promoter

e) Consultant

If you want, you can supplement your previous answer:

Please indicate your level of experience related to the field of solar energy systems:

a) Low knowledge: in training process (0 years of experience)

b) Medium knowledge: with expertise, short experience (0 - 3 years of experience)

c) High knowledge: with expertise, professional field experience (3 - 8 years of experience)

d) Expert knowledge: 8 or more years of experience

Type of technology that is your expertise (you can check more than one option):

a) Solar electric photovoltaic and components: panel, battery, inverter, solar cells, others
b) Concentrated solar power: concentrator, thermal battery, turbine, others
c) Low-temperature solar thermal (hot water): solar collectors, pumping, and others
d) High-temperature solar thermal (thermal oil - steam): concentrators, receivers, steam systems, others
e) Hybrid Solar
f) Other technology
g) Another technological area

If you indicated "Other technology" or "Other technological area" in the previous question, please detail your answer:

Indicate your perception of the level of knowledge, experience, and interest of your institution in the topic of renewable-solar energy present in the following aspects:

	1 (Very weak)	2	3	4	5 (Very strong)
Presence of undergraduate study programs					
Presence of postgraduate study programs					
Specialist human resources					
Experience: developed projects/initiatives					
Investment in laboratories/pilot plants for research					

From your position within your institution, what relationships do you have with other institutions in the ecosystem? Point out how strong the relationship is:

	1 (Very weak)	2	3	4	5 (Very strong)
University - company					
Company - company					
University - State					
University - others					

About the previous question, what institutions have been related to your institution? Indicate at least three institutions:

If you want, you can supplement your previous answer:

Of your most relevant completed project or projects, indicate the current level of impact it has:

	1 (Very weak)	2	3	4	5 (Very strong)
Impact on the university and development of new knowledge					
Impact on the industry: development of new product or process innovations					
Impact on the emergence of new companies					
Commercial impact: growth in sales and profit generation					
Impact on expansion to the international market					

Indicate the level of use of expert resources in your projects.

	1 (Very weak)	2	3	4	5 (Very strong)
Local experts					
National experts					
International experts					

If you want, you can supplement your previous answer:

Indicate the level of barriers to the growth of the solar-renewable energy technologies industry:

	1 (Very weak)	2	3	4	5 (Very strong)
Entrepreneurial activity: Barriers to the emergence of entrepreneurial and business activity					
Research orientation: Lack of a vision about what type of technologies should be developed					
Knowledge development: Few specialists and few specialist training programs					
Legitimacy: The technologies developed lack technical or political legitimacy					
Market formation: The demand for these technologies is low. The market needs to be developed more.					
Resource mobilization: There are no resources for the development of new knowledge or technologies					
Development of externalities: Little coordination of actors or low exchange of knowledge					

If you want, you can supplement your previous answer:

¿What area of knowledge should be promoted for developing the solar industry in Arequipa?

	1 (Very weak)	2	3	4	5 (Very strong)
Solar electric photovoltaic and components: panel, battery, inverter, solar cells*, etc.					
Concentrated solar power: concentrator, thermal battery, turbine, etc.					
Low-temperature solar thermal (hot water): plate, pipe, pumping, etc.					
High-temperature solar thermal (thermal oil - steam): concentrator, receiver, pipe, etc.					
Hybrid Solar					
Other					

If you want, you can supplement your previous answer:

Please indicate your general appreciation of how the solar energy technology industry in Arequipa can take off: