Research Article

Global trends, Local threads. The Thematic Orientation of Renewable Energy Research in Mexico and Argentina between 1992 and 2016

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ABSTRACT

Setting research agendas requires a substantial allocation of resources. Non – hegemonic countries lack the means to influence global trends in knowledge production. Still, some margin is available. By selecting specific topics to focus on, these countries build a national approach to global issues. This paper examines how two Latin American countries, namely Mexico and Argentina, have tackled the global challenge of developing new and renewable forms of energy through their research activities between 1992 and 2016. It stresses the historical and national specificities of global quests in a Latin-American setting by choosing two countries with central roles in the region and research systems of similar size and distinctive traditions. This research utilizes textual data from bibliometric sources. More precisely, the fields title, abstract, and keywords from the energy collection at the Scopus database. Text is processed using natural language detection techniques (NPL) to find a complex and relevant set of describing terms. The query line was built to grasp the discussion in detail, drawing on literature reviews and technology briefs. Findings show threads and rhythms bounded to the national dimension. Continual and harmonious evolution of research efforts stands out for Mexico. In Argentina, a distinctive set of preoccupations emerges in different moments during the studied period. The article provides relevant evidence that enables a reflection on how strategic-oriented efforts effectively unfold in a particular set of time and spatial coordinates. It also brings forward a methodological take to assess local competencies and trajectories on issues of global public concern.

Keywords: Renewable Energy, Argentina, Mexico, Thematic Orientation, Textual Analysis, Historical and National Specificity.

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INTRODUCTION

The relation with major countries has been a critical feature of the studies on how Latin American countries shape their scientific work. Some researchers have stressed the relevance of international collaboration;[1,2] others have pointed out the complexity of Latin American integration into the international division of scientific work.[3,4] Limited financial resources make any attempt from these countries to steer global trends in knowledge production rather than futile. To address this matter, Losego and Arvanitis[5] coined the concept of non-hegemonic countries. It stressed the bounded space that some states have to navigate their scientific endeavors' international constraints. This margin can be grasped by looking at choices in research partners and subjects. This article will focus on the latter, building on the idea that these choices are embedded in local environments and, mostly, a result of direct interaction between financing agencies and scientists.[6,7] Researchers have set the importance of understanding aggregated research options,[8] which here will be addressed at the country level. Scientific papers are one of the results of these processes of prioritization; hence, they can be interpreted as aggregated results of these decisions.

Renewable Energies are a crucial component of the international response to Climate Change. The climate governance scheme, consolidated from 1992 and onwards, increasingly framed environmental issues as global and climatic.[9] As the reduction of CO_2 emissions became one of the main approaches to face this challenge, research in new technical forms of energy production, transmission, storage, and consumption gradually rose as critical for their long-term relevance and strategic value.[10] Scientific research became a key piece to solve this puzzle, emphasizing its role in technological development and innovation processes. Experts posed renewables as the spearhead of a new and rising technology system: the 'next big technological opportunity' with the potential to transform the entire economy.[11] Given this scenario, renewables stand as an example of strategic technoscientific endeavors, but also as a mediating term between scientific efforts and societal problems.[12] This enduring social relevance goes along with climate summits. Therefore, this study covers the years from the Rio Summit in 1992 to the ratification of the Paris Agreements in 2016.

Investment in science and technology in Mexico and Argentina has a similar volume compared to their gdp-ppp[1].[14] Over the years, both countries have shown a strategic interest in renewables.[15-21] Nevertheless, scientific traditions in both countries stand out as quite different. The early Argentinean start in the first part of the twentieth century was affected by social and political unease from 1950 and onwards. Institutional efforts to organize scientific activities were often truncated, incomplete or branded by financial limitations.[22,23] There, a notorious group scientists stressed the link between science, technology, and socio-economic development.[24] The development of scientific institutions in Mexico was tardy, but, in contrast, more steady and sustained.[25] A significant institutional innovation was the introduction of merit-pay systems during the mid-1980s to prevent brain drain and boost scientific research.[26,27] These performance-based instruments were not so relevant in Argentina, even during the funding shortage of the 1990s. They had some presence in universities, responsible only for a fraction of the S&T efforts.[28] Specific characteristics in these two countries' renewable energy research contribute to understanding how these global quests are adopted and adapted in different contexts.

In the past, researchers that have studied scientific production on renewable energies have focused on emerging technologies and the development patterns of different energy types.[29-31] Some analysts have also focused on specific fields, such as solar energy and its evolution as a research field.[32] This kind of assessment had a global scope that stressed general trends world-wide. When focusing on specific countries, research has mostly centered on European cases.[33-35] Studies focusing on how alternative energies have become an object of research in Argentina and Mexico have been scarce. Studies conducted in Mexico focused mostly on the research's technological orientation, emphasizing institutional profiling.[36,37] Regarding methods, co-word analysis has been a critical feature[38] as well as traditional bibliometric approaches such as citations, co-authorships, and journals of publication.

This paper interprets the strategic value of the analyzed research in renewable energy from three perspectives: the optimization and adaptation of existing infrastructure,[39-41] the development of generation alternatives or technologies with potential applications in a new scenario,[11,41] and the development of the knowledge base needed to face rising challenges in energy planning and policymaking.[42-44] This paper emphasizes the historical and national specificity of this strategic quest in a Latin-American setting. It pushes forward a kind of approach that allows an understanding of how researchers in México and Argentina have navigated a highly dynamic and internationalized research front. It does so by stressing the semantical structure from a historical perspective.

METHODOLOGY

This is a descriptive study based on documental and textual analysis assisted by computers. The main source was the Scopus database. A controlled text-mining strategy was run on the *energy* collection. This subject area gathers journals related to energetic matters. In order to identify main descriptors for technological options, technical literature from international agencies was revised[45-57] as well as scientific reviews briefing on the main features and advances of specific technologies.[58-63] As a result, the following query line was custom made for this research.SUBJAREA (ener) AND TITLE-ABS-KEY (renewable* OR sustainab* OR (climate PRE/1 change) OR (global PRE/1 warming) OR biogas OR biomass OR biodiesel OR bioethanol OR solar OR wind* OR tidal OR (wave PRE/1 (energ* OR resource*)) OR geotherm*) OR AFFILORG (sustentabilidad OR renovable* OR renewable* OR sustainab* OR (climate PRE/1 change) OR (global PRE/1 warming) OR biogas OR biomass OR biodiesel OR bioethanol OR solar OR wind* OR geotherm*) OR EXACTSRCTITLE (renewable* OR sustainab* OR (climate PRE/1 change) OR (global PRE/1 warming) OR biogas OR biomass OR biodiesel OR bioethanol OR solar OR wind* OR geotherm*) AND (PUBYEAR > 1991 AND PUBYEAR < 2017)

The query was used limiting the results separately for Argentina and Mexico. It aimed to capture relevant production in relation to specific renewable technologies in textual fields, but also in affiliations and journals. By this mean, it was a way to catch possible national variations related to clean energies sources.

Metadata of bibliometric records was enriched, taking advantage of Natural Language Processing (NLP) tools and its analytic potential to apprehend underlying semantic structures.[64] Using NLP, abstracts were processed, taking into account their role in drawing attention to the most important threads of the document it summarizes, not being just a mere teaser.[65] Abstracts were processed along with tittles and keywords in order to grasp other consuetudinary publication practices. This allowed stressing the mapping of technical

1. Nevertheless, it is relevant to mention that the structure of the investment is quite different. Argentinean Researchers triple their weight in the country's labor force(13:p.23). There, the spending seems to be more concentrated in fewer hands in the Mexican case.

concepts over other bibliometric approaches that prioritize actors –authors or institutions– and collegiate relationships –citations or co-citations.

The result of this query was a total of 7,996 documents for Mexico and 3,138 for Argentina. The information of each record was exported in .bib format and analyzed using CorText platform.[66] By the means of natural language processing tools from this platform –namely, the script *term extraction*– the most pertaining noun phrases were detected.[67] As a result, a list of the most salient multi-terms was extracted[1].

They were later manually curated to exclude noise. Information from the country and the year of each bibliometric record was kept. The results were analyzed by applying the script network analysis in order to grasp the relation between descriptive terms. Most salient thematic clusters were detected using the Louvain algorithm.[68] Clusters have been tagged in two ways: using an alphanumerical short label –i.e., c1Ar– and taking their two most relevant salient terms. Interpretation, merging and depuration of specific terms was obtained and enriched by situating terms in their enunciation context and revisiting technical literature and scientific reviews. Complementary sources were used to expand on semantic results' meanings and implications to grasp national particularities better. Using the script period detector, the frequency on the distribution of the most salient multi-terms over the years was used to detect different periods. Later, thematic evolution was captured using the epic epoc script, also available in the CorText engine. Here, each topic's relevance has been computed, counting the number of documents assigned to each cluster.

Semathic clusters of renewable energy research in Mexico and Argentina

An overall look at the thematic structure of the Argentinean production in renewable energies is available in Figure 1 and shows nine different topic groups. Most of these clusters have a dense structure –for cluster density and composition, Table 1, meaning that the kind of discussion they support is rather endogamic and auto-referential. Nevertheless, some cases stand out and show meaningful connections. There, three groups of interlinked preoccupations rise. The first and most notorious –composed by the clusters c4Ar POWER SYSTEM AND ELECTRIC

Table 1: Thematic clusters detected for Argentina between 1992 and 2006. Terms composing each cluster and its density. Original elaboration with data from scopus.

Cluster	Terms	Density
c8Ar - Heavy water reactors and Atucha II	*safety analysis, computational fluid dynamics, heavy water, nuclear power plants, Atucha II, heavy water reactors, wind tunnel, boundary layer, water reactors*	0.971
c4Ar - Power system and electric power	*active power, monte carlo simulation, distributed generation, power quality, distribution systems, power distribution, principal component analysis, electric power, transmission expansion, neural networks, electric system, power system, induction motors, distribution networks, energy storage, harmonic distortion, transmission system, electric power distribution, power plants, power markets, monte carlo, control techniques, power transmission, power system stabilizer, electric power transmission, power transmission networks, monte carlo methods, energy storage systems, power flow, electric power systems, state estimation*	0.930
c1Ar - Material characterization and electrochemical properties	*surface area, high temperature, electrochemical impedance spectroscopy, hydrogen peroxide, cyclic voltammetry, electrochemical properties, electrical properties, electric conductivity, absorption spectroscopy, ion exchange, X-ray diffraction, electron microscopy, carbon nanotubes, grain boundaries, electrochemical techniques, temperature range, impedance spectroscopy, oxide fuel cells, acid solutions, thermal treatment, scanning electron microscopy, transmission electron microscopy, x ray, reaction rate, kinetic parameters, methanol fuel cells, X-ray photoelectron spectroscopy, electrocatalytic activity, X-ray absorption, transport properties, room temperature, activation energy*	0.926
c9Ar - Vegetable oils and biodiesel production	*vegetable oils, escherichia coli, biodiesel production, free fatty acids*	0.925
c5Ar - Wind energy and energy conversion systems	*power generation, permanent magnet, wind power, control strategy, energy conversion, wind farms, control scheme, wind turbines, sliding mode control, electric utilities, synchronous generators, wind energy, energy conversion systems, electric power generation, wind energy conversion, induction generator, power control, reactive power, electricity generation*	0.924
c6Ar - Energy consumption and environmental impact	*energy efficiency, natural gas, energy consumption, environmental impact, energy sources, energy use, renewable energy sources, developing countries, carbon dioxide, fossil fuels, solar collector, energy resources, renewable energy resources, renewable energies, South America, activated carbon, energy utilization, gas pipeline, land use, Buenos Aires, climate change*	0.905
c7Ar - Oil fields petroleum and reservoir evaluation	*case study, gas industry, mechanical properties, horizontal wells, Society of Petroleum Engineers, oil fields, petroleum reservoir evaluation, petroleum reservoir, oil wells, Vaca Muerta, oil production*	0.884
c2Ar - Exchange membrane fuel and membrane fuel cells	*fuel cells, ethanol steam, proton exchange membrane, pem fuel cell, reforming reactions, exchange membrane fuel, membrane fuel cells*	0.732
c3Ar - Thermodynamic properties and electronic properties	*electronic structure, high temperature superconductors, single crystals, phase transitions, density of states, hydrogen adsorption, molecular dynamics simulations, density functional theory, electronic properties, phase diagrams, thermodynamic properties*	0.686

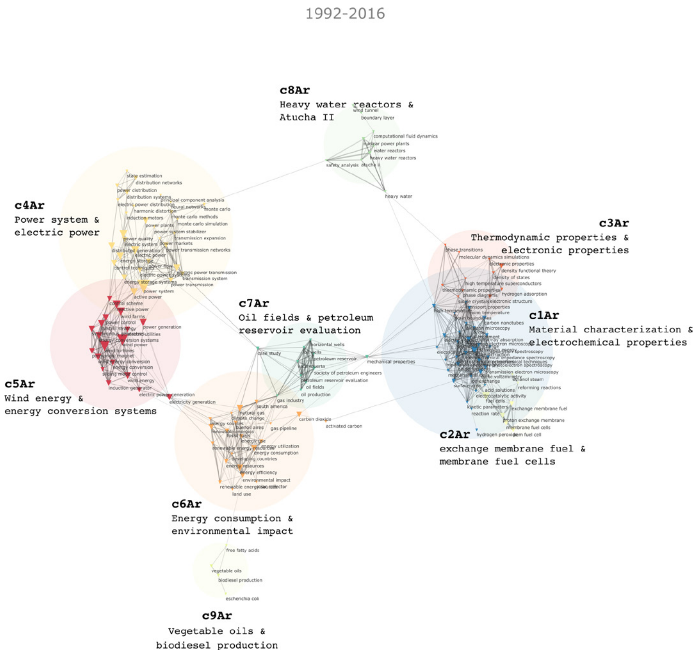

Figure 1: Semantic structure of Renewable Energy research in Argentina. Co-occurrence of detected terms between 1992 and 2016.

power and c5Ar wind energy and energy conversion systems– blends different development areas in wind energy and power systems. In contrast, a body of research on materials and fuel cells –c1Ar material characterization and electrochemical properties, c2Ar exchange membrane fuel and membrane fuel cells, and c3Ar thermodynamic properties and electronic properties– links to material research and the energetic potential of hydrogen applications. This cluster group has some of the lower density rates registered, which means they share interests, objects, and research methods. Third and last, two clusters –c6Ar energy consumption and environmental impact and c7Ar oil fields and petroleum reservoir evaluation– become relevant as they serve as a point of passage between research in wind energy and hydrogen. Both of these technologies appear to be somehow complemented by the reflection on the structure of the energy mix and alternatives in energy management.

When studying renewables, Argentinean researchers have paid particular attention to future energy pathways. Here a debate around a possible new energy mix is addressed in c6Ar energy consumption and environmental impact. The focus is set rather on technical alternatives. Vocabulary related to climate governance efforts is rare, only a minimum mention to climate change and carbon dioxide. Environmental impact becomes an addressed topic, but this is a broader issue that relates just partially to global warming. There is, also, a crucial element to understand the interest of Argentinean research in energy efficiency and energy consumption. As Argentina experienced energetic problems during the early 2000s, rational energy use plans were an issue of vital interest.[69,70] New energy sources such as natural gas –known as a 'transition fuel' for energy transition– and reservoir evaluation became critical. Innovative production methods for oil and gas strike as the central issue of other cluster that deals with future energy pathways, c7Ar oil fields and petroleum reservoir evaluation. Assessing conventional energetic sources is a relevant matter for scientific inquiry around renewables.

Regarding renewable sources, Argentinean research deals with the question of how to deal with their inclusion in the grid in the cluster c4Ar power system and electric power. Most of the work done here aims to understand how to insert renewable sources into the generation scheme. Control techniques and power quality are relevant issues studied to understand the possibilities of distributed generation. Mathematical simulations using Monte Carlo methods are used to model interactions with power transmission networks. Although renewable sources often variate, the research analyzed mostly focuses on understanding and controlling wind generation variations. Most of the investigation results seem to be connected with power generation from wind farms.

Wind generation appears as one of the two key technologies addressed by research being conducted in Argentina between 1992-2016. Wind energy has a long tradition in the South American country,[15] where an immense generation potential has been mapped, mostly in Patagonia. This line of research is represented in the cluster c5Ar wind energy and energy conversion systems. The design of wind turbines is a key issue, but also measuring their performance and their energy conversion rates. Control strategies during the generation process are a key component for electric generation utilities and transmission planning. Since electric networks demand high levels of confidence and robustness, so much of the research conducted on wind powers points towards incremental improvements to generation devices. Systems for energy storage are vital for the control techniques and to guarantee the voltage desired by network operators. These are all threads of the research conducted in the country in the studied period.

The use of hydrogen as a vector of energy storage and accumulation rises as a matching technology for wind generation. Although no specific tie has been mapped, the country has made some material attempts to link these two technologies building the first Hydrogen Generation Station by Wind Energy in South America located at Pico Truncado, in southern Patagonia.[71,72] The research on fuel cells has three different approaches. Since fuel cells run on a variety of electrochemical reactions, much of the attention is oriented towards experimenting and understanding possible materials. This is expressed in the c1Ar material characterization and electrochemical properties cluster. Study of membrane fuel cells can be spotted in c2Ar exchange membrane fuel and membrane fuel cells. This kind of devices, mostly designed for transportation purposes, arises as one key technological feature of fuel cell research in Argentina. Here, much work is done in properties of materials. This is clustered in c3Ar thermodynamic properties and electronic properties. The importance of material research goes along with the rising capabilities and interest in nanotechnology in the country. The use of methods nanotech research is prominent. The scanning electron microscope,[73] a key element in nanotech's technoscientific endeavor, is the most notorious.

The thematic profile of Argentinean research in renewables lacks of a specific attention to solar energy. Work on photovoltaics is rare and most of the work captured is in solar collectors, which are framed as a way of reduce energy consumption. Low-cost collectors, for water heating and other heating purposes are a line of research in the country.[72] Argentina's biodiesel research –captured in c9Ar vegetable oils and biodiesel production– is also a local thread of scientific interest in renewables. Although, it seems to be mostly focused on taking advantage of the countries' agro-industrial complex rather than a technology-focused interest. It is mostly focused on first generation bioenergetics.[63,74] The last of the detected clusters c8Ar heavy water reactors and Atucha ii is dedicated to nuclear energy, which relates to a long tradition and strong relevance for the nation's scientific system.[75] This also speaks of a specific technological trajectory linked to heavy water reactors, a line of research that brands Argentinean learning path on nuclear technology and that has been deployed in the Atucha complex, the first power nuclear central in Latin America.

Regarding the evolution of these insterests, Figure 2 shows how the clusters that describe Argentinean research on the subject evolve in the twenty-five analyzed years. Priorities changed and some issues emerged. This approach allows a better understanding of the structure observed for each period. Clusters related to energy efficiency, like c6Ar, become highly

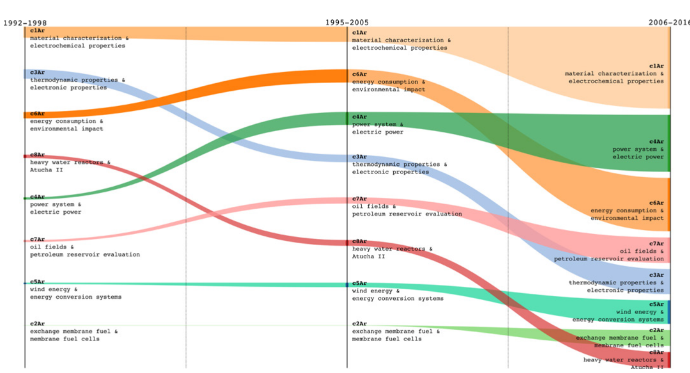

Figure 2: Evolution of main Renewable Energy research thematic clusters in Argentina by the detected period from 1992 to 2016. Original elaboration with data from scopus.

relevant as new conditions for energy production emerged in Argentina. The rising interest in oil and gas reserve, posed by c7Ar, show another important side of how the energy matrix is being projected.

The relations between terms and clusters showed Figure 1 that thematics groups related to material science and hydrogen research like c1Ar, c2Ar, and c3Ar have strong interconnection bonds. Although the work characterizing materials is very much present throughout the studied period, the relevance of each of these clusters shift notoriously over time. This point towards some underlying evolution and a process of epistemic shift. This happens with c3Ar, a very important thematic group from 1992 to 1998 that steadily looses relevance in the following periods. As contrast a cluster related to hydrogen fuel cells, c5Ar, has a rising importance. Research on fuel cell is inexistent till 2006. The strong observer links between these three clusters allow to better understand how fuel cell research emerged and the kind of capabilities it put to use. This promissory technology's interest matched the thematic profile that already existed, as material and their properties were already an important issue in Argentina. It stresses the role of these methods and interests to pivot to swing and re-orientate priorities.

Argentina had an active interest in Wind Power as an emerging technology. The strong links between c4Ar and c5Ar showed that this technology's big issues link to power and electric systems. This paired research fronts showed two sides of the same challenge: inserting wind as a robust generation alternative in electric networks. The rise of c4Ar from the first to the second period talks about how capabilities from different electric and mechanical engineering fields were put to use in this research area.

The situation in Mexico has been different and, there, there is another kind of knowledge base in alternative energies. The semantic structure of Mexican scientific research on renewables –for details, Figure 3 has seven distinctive groupings of descriptive terms. As for the structure of these clusters –for details and full composition, see Table 2 it stands out for the specificity of the topics addressed. Issues dealt with here are densely connected inwards with specific connections to the other distinctive interests. Some interconnections are to be seen, mostly between three clusters: c1Mx fossil fuels and greenhouse gases, c2Mx Los Azufres and geothermal fields, and c3Mx heat transfer and experimental data. Very connected to the last is c4Mx heavy oil and oil production. Remaining clusters, such as c5Mx boiling water reactors and fuel lattice, c6Mx power system and power transmission, and c7Mx x-ray diffraction and cyclic voltammetry, are not central to articulate the discussion as they locate in the sides of the diagram.

Table 2: Thematic clusters detected for Mexico between 1992 and 2006. Terms composing each cluster and its density. Original elaboration with data from scopus.

Cluster	Terms	Density
c7Mx - X-ray diffractioncyclic and voltammetry	*surface area, high temperature, fuel cells, cyclic voltammetry, charge transfer, electrical properties, band gap, X-ray diffraction, carbon nanotubes, oxygen reduction reaction, proton exchange membrane, pem fuel cell, thin films, oxygen reduction, neutron activation analysis, optical properties, scanning electron microscopy, particle size, transmission electron microscopy, conversion efficiency, spray pyrolysis, microbial fuel cells, power density, ion exchange, electrocatalytic activity, exchange membrane fuel, infrared spectroscopy, aqueous solution, zinc oxide, catalytic activity, solar cells, current density, membrane fuel cells, activation energy*	0.999
c6Mx - Power system and power transmission	*power quality, transmission systems, synchronous machines, distribution systems, transmission line, power transmission networks, frequency domain, dynamic behavior, simulation results, transient analysis, control scheme, power transmission, voltage regulators, electromagnetic transients, electric power factor, dc-dc converters, power system, experimental results, power flow, control strategies, pulse width modulation, power converters, system stability, harmonic distortion, induction generator, time domain, power control, fault detection, time domain analysis, power system stabilizer, power factor, multilevel converter, active filters, test system, output voltage, state estimation, reactive power, electric power transmission, control systems, voltage stability, electric power systems, power factor correction*	0.998
c2Mx - Los Azufres and geothermal fields	*Cerro Prieto, geothermal system, geothermal reservoir, geothermal fields, Los Humeros, geothermal wells, Los Azufres*	0.986
c1Mx - fossil fuels and greenhouse gases	*energy consumption, natural gas, power generation, environmental impact, case study, energy sources, energy use, renewable energy sources, renewable energy, energy conversion, fossil fuels, wind power, energy resources, energy demand, wind speed, life cycle, climate change, wind energy, power plants, energy efficiency, air pollution, air quality, permanent magnet, energy systems, greenhouse gases, electricity generation, CO2 emissions, Mexico City, wind turbine*	0.983
c3Mx - heat transfer and experimental data	*flow patterns, pressure drop, steam generators, heat transfer, thermal performance, numerical results, gas turbine, computational fluid dynamics, heat transformer, parabolic trough, artificial neural network, solar collectors, solar concentrators, experimental data, heat transfer coefficients, numerical model, solar energy, working fluid, heat engines, good agreement, two-phase flow, coefficient of performance, heat flux, heat exchangers, absorption heat transformer*	0.952
c4Mx - heavy oil and oil production	*fractured reservoirs, porous media, nuclear magnetic resonance, heavy crude oil, oil fields, oil recovery, oil production, production rate, heavy oil*	0.895
c5Mx - boiling water reactors and fuel lattice	*boiling water reactors, fuel lattice, nuclear power plants, genetic algorithms*	0.879

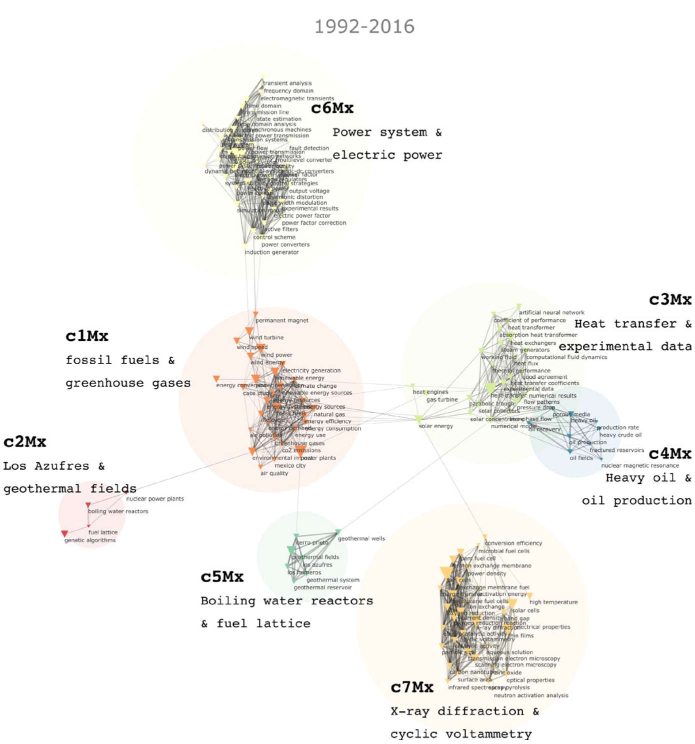

Figure 3: Semantic structure of Renewable Energy research in Mexico. Co-occurrence of detected terms between 1992 and 2016.

Mexican research on renewables is strikingly articulated into the jargon of the climate regime. Mexico has played a prominent role in climate negotiations over the years,[76] with a longstanding national trajectory climate policy.[77] Being also oil-country, the relation between c1Mx FOSSIL FUELS AND GREENHOUSE GASES is a broad public concern that has made it into the Mexican scientific agenda. This cluster has a central position, as is connected with four of the remaining ones. As it articulates different research lines that are active in the country, it also builds evidence on the availability of renewable energy resources. Research conducted in Mexico treats wind as the most notorious source for electricity generation. The focus on wind speed issues concerning wind turbines and wind power points towards the importance given to resource assessment for power generation. The wind sector size in Mexico expanded during the 2000s and consolidated in the early 2010s.[78] The interest in wind shines to be more for technology implementation and improvements than for technology development, as was the case of research conducted in Argentina. Electric networks are complex infrastructure work and require a robust regulatory approach based on evidence and precise simulations. Optimization of its performance with new energy mixes requires extensive scientific work. So, wind energy implementation relates to the interest in c6Mx power system and power transmission, which summarizes research done from different angles on the electric power systems. The transmission lines' adaptation becomes quite relevant since this new kind of generation scheme require a new topology of the electric networks in the system's different scales. Results show how dynamic behavior was simulated by researchers precisely to study system stability. Another notorious approach to these matters has cared for power quality, focusing on voltage control strategies. Voltage variation calls for more complex simulations. The variability in wind power injections affects electric networks; results show how research wonders about the best conditions of power distribution systems' performance.

Mexican scientists push forward the question about the kind of place fossil fuels have in a context of higher volumes of renewable generation. The cluster c3Mx heat transfer and experimental data mostly focuses on optimizing heat transfer in different devices, such as solar thermic devices and gas turbines. The study of applications for thermal solar energy has two different approaches. Research on solar collectors relates to their use for water heating purposes and different applications, from water desalinization to heating purposes. Solar concentrators and parabolic troughs represent another set of preoccupations that share some aspects of the same knowledge base, but aim for larger applications, mostly for electric generation. Electric generation via gas turbines constitutes one of the main incorporations of the Mexican generation system.[78] The natural gas combined cycle is the central technology implemented there. It builds on the optimizing and re-utilization of waste heat that results from using gas turbines to produce electricity. But also, research of heat transfer dynamics in Mexico mostly focuses on optimizing the use of heat and finding ways to adapt fossil-fuel burning infrastructure. This establishes some common interests with oil reserves and production dynamics, which are represented in c4Mx heavy oil and oil production.

As for alternative technologies, research in Mexico leans mostly towards solar photovoltaics and geothermal energy. Nuclear power plants also rise as a distinctive thread of the inquiry lines conducted in the North-American country. The country's approach towards geothermic energy summarizes in c2Mx Los Azufres and geothermal fields. Capacities in the sector are not new and date back to the 1950s.[79] Most of the research done examines the properties of main geothermal fields in Mexico. Los Azufres –188 MWe[2]–, Los Humeros –35 MWe–, and Los Azufres –720 MWe– are the country's main geothermal fields and centers for the scientific work on the subject. Mexican research centers have grown and diversified on different aspects of the geothermal industry.[80,81] Geothermal expertise puts to use much of the geological knowledge and experience available in the country due to oil exploration and exploitation.

The last cluster of the country's research is devoted to the development of a knowledge base in emerging technologies. The thematic group of c7Mx x-ray diffraction and cyclic voltammetry leans towards a set of potential applications. First, there is a pronounced interest in thin films. Thin films –TF– gather a range of technologies of second generation photovoltaics. Their main characteristic is to use slim layers of materials with photoelectric qualities to generate electricity. Control the synthesis of materials becomes a key element of research in the matter—methods like x-ray diffraction measure experimental results' performance, a fundamental issue when developing photovoltaic applications. This is an area of detailed engineering that aims to decrease production costs in solar technology. TF's potential is fueled by the promise of automation of production processes by depositing materials –silicon and other complex compounds– in smaller amounts and higher efficiency.[82] Understanding these solar cells' electrical properties stands out as one of the most recurrent issues dealt in this line of research. Mexican research also focuses on knowing more about how to store this generated electricity, so documents inform on experiments and results on storage possibilities such as fuel cells –much of these studies build from the knowledge on material sciences. Hence, the complementarity between fuel cells, solar cells, and complementarity is notable.

A smaller but still significative set of work reflects on nuclear energy and its generation potential. Nuclear sources are one of the so-called clean energy sources.[2] Nuclear, then stands out as a good option for its compliance with environmental protection requirements. This line of work can be traced in the cluster c5Mx boiling water reactors and fuel lattice. The contrast of the Mexican nuclear profile with the Argentinean case is notorious as in Mexico the technological choice was of boiling water reactors.[3] Then, most of the work done here concentrates on finding optimal conditions for the operation and control of nuclear power plants. Nuclear plays the role of base load of electrical grids –as well as Geothermal energy– they are a strategic asset to develop a low-cost energy mix that is reliable and available. Nevertheless, the history of nuclear power in Mexico is quite complex.[84][4]

Research on Renewables has developed according to two different sets of interest in Argentina and Mexico. When looking at how this topic evolves in each country, it has become clear that both have a rhythm of its own. Understanding how thematic clusters have developed over the studied period also

2 'MWe' stands for Megawatts electric and refers to the units of electric power produced by a generation plant.

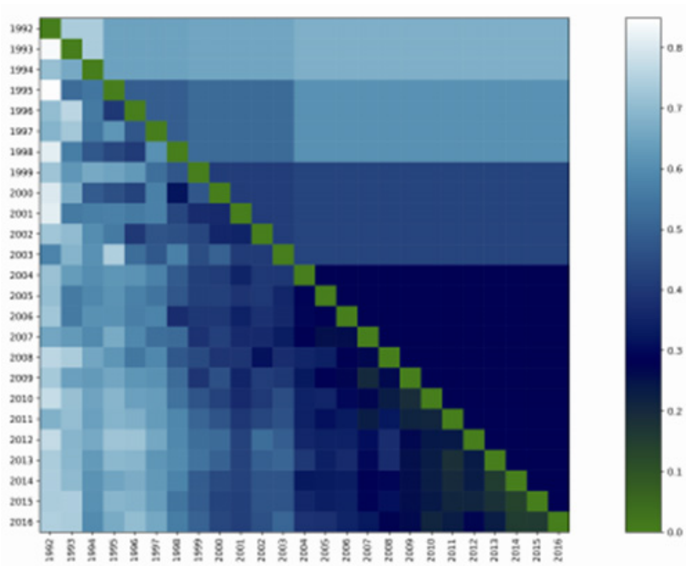

Figure 4: Temporal periods according to semantic similarity of Renewable Energy research in Mexico, from 1992 to 2016. Original elaboration with data from scopus.

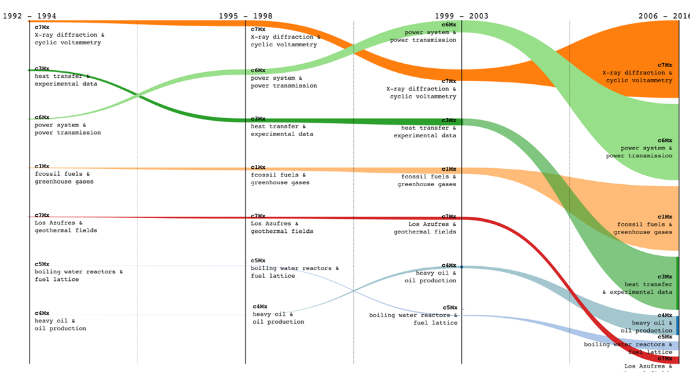

Figure 5: Evolution of main Renewable Energy research thematic clusters in Mexico by the detected period from 1992 to 2016. Original elaboration with data from scopus.

helps to understand how these priorities have shifted along the way.

As will be further discussed when analyzing Figure 4 and its results, the semantic structure of research in Mexico has shifted a lot between 1992 and 2016. A quick look at Figure 5 shows that the four most important fields have been the same during the twenty-five studied years. This means that the changes in the semantic structure happened mostly inside each of the clusters. Some features have been selected and developed but not dropped.

Figure 2 has shown that Mexico has a great interest in photovoltaics, and more precisely in Thin-Film technology. As Figure 5 shows, c7Mx has remained as the top interest in three of the four periods detected for Mexico. The setback between 1999 and 2003 points towards a process of reconfiguration on the orientation of this line of research.

On the other side, the increase in the relevance of c3Mx is steady and important. Over time c3Mx escalated positions from being the third priority –1992-1994– the first between 1999 and 2003. As it finally consolidates on the second place on the fourth and last period, it points towards the increasing relevance that electric systems and transmission lines had as the investment in renewables became steep from 2006 and onwards.[85]

The central that c1Mx had Figure 2 in articulating different interests from renewable research in Mexico correspond to a relevance that has remained steady over the studied period. C1Mx has not had the biggest volume of scientific production. Nevertheless, when its continued relevance is contrasted with its central role in the thematic network, this clus ter rises as one of the most important to understand this thematic prioritization process in México. The selection of specific research areas has made Mexico move fast and mobilize a rapid transformation in its research. There, c1Mx's role appears as very explicative of these changes. Last, c3Mx has dropped its relative volume of research. Nevertheless, at the end of the studied years, it remains an important area of interest. The role of optimization processes in the ways of using heat and fossil fuels points towards the importance that energy efficiency has for a more renewable energy matrix.

Semantic structures in time

New forms of energy have emerged as a response to climate change. Renewables have an essential role in this rising scenario. The semantic structure of scientific research shows how priorities are different for Argentina and México. But the evolution of the knowledge base in these urgent matters evolves rapidly. As the pathway to a more sustainable matrix unfolds, the research scenario tends to change. The development of new policy sets goes along with technology deployment and rising social, political, and economic interests and expectations. Also, as this analysis has shown so far, energy is very sensitive to nation bounded scenarios. Hence, matters of interest shift over time at different rates depending where the research is being conducted. To better understand this, this paper takes a semantic approach to understand the field's historical evolution. This approach captures the research area's semantic cohesion, showing how each year's research resembles the others of the studied period. Based in this logic, periods are detected and some structural features are sketched.

The analysis over the time of the terms' correlation in research conducted in Argentina is available in Figure 6. The Figure charts how similar the production is during the analyzed years, comparing each year to the rest included in the series. The scale from 0 to 1 measures the dissimilarity and is reflected in a color scale from white to green. The higher the score is, the most dissimilar those two years are, and the whiter the cell is.

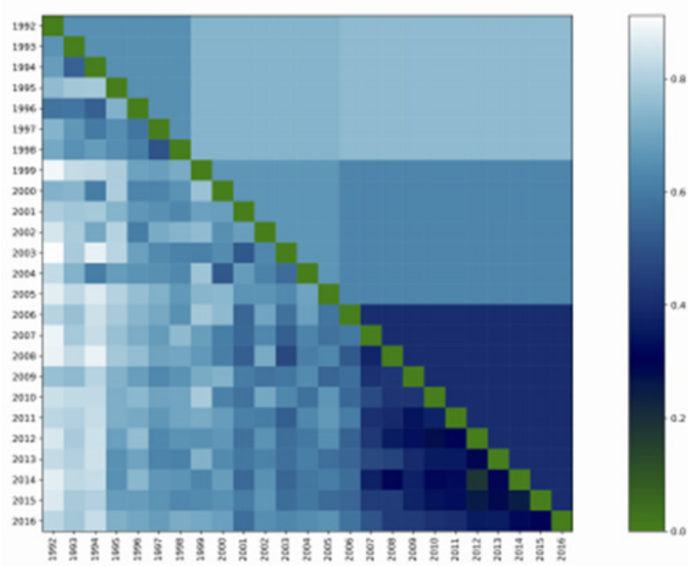

Figure 6: Temporal periods according to semantic similarity of Renewable Energy research in Argentina, from 1992 to 2016. Original elaboration with data from scopus.

On each graphic's upper right, detected most similar periods are represented using a homogeneous color from the scale included on the Figure's right. Three different periods have been found in documents signed by Argentinean authors, two covering six years and one that lasts ten. The first period goes from 1992 to 1998, the second from 1999 to 2005, and the third from 2006 to 2016.

Research conducted in Argentina between 1992 and 1996 has a high level of correspondence between years. Some continuity can be traced intra-period. Research carried from 1996 highly resembles the one conducted from 1992 to 1994, but this vanishes in 1995. By the end of the period, a distinctive thematic cohesion arises. Terms describing research published in 1998 highly resemble those from 1997. When looking at the period as an aggregate, it is possible to compare it o the rest of the series. It is important to stress that the research coherence level from 1992 to 1998 is higher than the one following, from 1999 to 2005. This means that a new set of methods, objects, and interests have emerged during the second period in renewable research in Argentina. The second period shines as a pivotal moment in renewable research for the South American country. As methods, topics, and objects interesting until 1998 lost relevance, a sense of vagueness defines the period. Terms coherence seems erratic; there is only some resemblance between 2001 and 2003 and between 2000 and 2004.

The third and more extended period has the stronger coherence of the period, as expected. When comparing all the years to the last one analyzed, 2016, it is possible to see how the descriptive terms resemble more as time goes by. The critical year for this structure is 2007. After that year, the structure of the field grows tighter and more coherent. Comparing this period to the following two is enlightening. It becomes clear that many issues dealt with in the bygone years are here recovered. When looking from this third stage, a specific incremental trajectory becomes clear. The low correspondence with terms from 1992 to 1998 shows that many of the preoccupations from those years have been abandoned.

The analysis of documents published by Mexican authors shows four different periods in the thematic structure of research on renewables energies in the country. As Figure 4 shows, periods vary a lot in their length, but they increase their duration as time goes by. This means that the consolidation of a country's thematic profile moves fast from a stage to other. The first period goes from 1992 to 1994, the second from 1995 to 1998, and the third from 1999 till 2003. The fourth extend for twelve years, lasting from 2004 to 2016.Research from 1992 to 1994 seems rather unstructured and with a low level of coherence. Topics appear to be addressed without continuity except for 1994, which has a reasonable equivalence rate with the forthcoming years. From 1995 to 1998, the thematic structure got more robust as a strong correlation unfolds between 1995, 1996, and 1998. Some of the topics addressed in this period got later picked up during the following years, mostly in the next period.The third period, from 1999 to 2003, is the pivot moment of research in Mexico. Terms describing scientific production resemble more to future years than to the ones before. For instance, the year 2001 shares much of its semantic characteristics with the rest of the series's years. The same happens for the rest of the cases; they seem to keep a strong resemblance to the topics addressed as far as 2009. Then, the correspondence vanishes, and other scientific approach to renewables in Mexico consolidates.

The fourth and last detected period, from 2004 to 2016, builds from a strong internal coherence. As the terms describing documents published in 2004 keep appearing in all the forthcoming years, the period's duration strikes as something rather remarkable. This is more relevant when compared to the series of brief and fluctuating periods that preceded it.

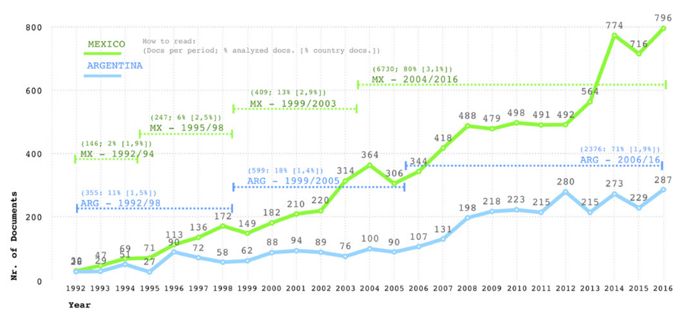

Figure 7: Volume of production in Renewable Energies in Mexico and Argentina between 1992 and 2016.

All in all, when compared with Argentina, Mexico reaches a higher level of coherence in this last period.

Figure 7 presents the time trends for analyzed publications in renewable energy in México and Argentina. The periods detected for thematic coherence have been signaled using a dot line. Also, total documents for each period are stated in the Figure; as well as the relative weight of that period towards the total of analyzed documents and the total national production per year. This allows to get a good idea of what is the role of research in renewable energy in the national scenario.

Following the text structure of the periods detected, the first two periods for Mexico –1992 - 1994; 1995 - 1998– have a marginal proportion of the documents published; only an 8%. Nevertheless, when considered along to the loose correlation of terms between years already showed, it points towards some specific dynamism. One could expect that, if the production of documents remains low in the whole series, topics will not change so much. That is not the case for Mexico.

As work on renewables tends to gain relevance in the Mexican research arena –for details, see Table 3 along the studied years, this dynamism points towards a learning and selection process being on the way during these early years. The consolidation of the volume of documents and the relative size in the third and fourth periods –1999-2003; 2004-2016– shows that some topics did indeed became a priority.

The number of documents in the Argentinean case tends to be more stable along the 25 analyzed years. The distribution between each of the periods is more balanced than in the Mexican case. This means that the relative increase of works published is smaller in Argentina. In terms of growth Argentina clearly has a more steady behavior. Some increment starts in the beginning third period –2006-2016–. Between 2006 and 2008 there is an increase of number of documents, just to find

Table 3: Number of analyzed documents and the total count of published documents per country, from 1992 to 2006. Original elaboration with data from scopus.

	Argentina				México			
Year	Docs. Per year.	Docs. in RE. *Per year.*	% of analyzed docs. from country total. *Per year.*	% of analyzed docs. from country total. *Per period.*	Docs. Per year.	Docs. in RE. *Per year.*	% of analyzed docs. from country total. *Per year.*	% of analyzed docs. from country total. *Per period.*
1992	2050	28	1.366%	1.5%	2173	30	1.381%	
1993	2220	29	1.306%		2542	47	1.849%	
1994	2538	51	2.009%		2802	69	2.463%	1.9%
1995	2756	27	0.980%		3394	71	2.092%	
1996	4251	90	2.117%		4921	113	2.296%	
1997	4864	72	1.480%		5508	136	2.469%	
1998	4893	58	1.185%		5953	172	2.889%	2.5%
1999	5246	62	1.182%	1.4%	6405	149	2.326%	
2000	5584	88	1.576%		6691	182	2.720%	
2001	5802	94	1.620%		7147	210	2.938%	
2002	6225	89	1.430%		7839	220	2.806%	
2003	6329	76	1.201%		9097	314	3.452%	2.9%
2004	6639	100	1.506%		9862	364	3.691%	
2005	7111	90	1.266%		11440	306	2.675%	
2006	7914	107	1.352%	1.9%	12828	344	2.682%	
2007	8242	131	1.589%		13192	418	3.169%	
2008	9156	198	2.163%		14417	488	3.385%	
2009	10211	218	2.135%		15469	479	3.097%	
2010	10853	223	2.055%		16243	498	3.066%	
2011	11812	215	1.820%		17328	491	2.834%	3.1%
2012	12330	280	2.271%		18753	492	2.624%	
2013	12530	215	1.716%		19902	564	2.834%	
2014	13546	273	2.015%		21441	774	3.610%	
2015	13626	229	1.681%		21708	716	3.298%	

a new equilibrium later on. A slight oscillation is also visible in the general relevance when compared with the rest of the national scientific production, as it decreases from first period –1992-1998– to the second –1999-2005. It recovers in the third –2006-16. Although at the end renewable energies also gain importance in Argentina, they do in a softer way than in the Mexican case.

One quest, two countries: contrasts in national trajectories in Renewable Energies.

This paper has focused on grasping how two Latin-American countries, Mexico and Ar gentina, have developed their research portfolios on renewable energies. As investment in research activities is mostly sustained by the use of public money and done by personal em ployed in public institutions,[13,14] the thematic profile of research has specific implications for reflecting on the performativity of science policy in non–hegemonic countries. Results of this study show that these two countries have taken different paths towards renewable energy. Then, national level policies and local affairs stand out as important dimensions to consider when thinking about how to address global challenges of different kinds.

Table 4 summarizes the specific characteristics of the research efforts done by these two Latin-American nations. It builds from the given interpretations for the strategic value of this line of research. The attention given to the generation alternatives expected to be strategic in a new scenario[11,41] is presented while stressing the principal technologies prioritized. Reflections on each country's plan towards energy planning and policymaking[42-44] describe the approaches towards their future energy matrix included in the table. Attention to restructuring existing electric facilities[39-41] is outlined as infrastructure optimization and adaptation. Last, the main features of the evolution of these issues were included. It aims to emphasize what these different paths have meant for each case. Effectively, Renewables imply different things for researchers in Mexico and Argentina. Each country has built its own approach to a global matter, mostly due to their local circumstances.

Table 4: Summary of the main features of research on Renewable Energy conducted in Argentina and Mexico between 1992 and 2016.

	Argentina	Mexico
Main prioritized technologies	Wind Power Fuel cells	Solar PV (Thin Films) Geothermal
Approaches to future energetic matrix	Increment efficiency in energy consumption	Reducing emissions Better use of fossil fuels
Infrestructure optimizaton and adaptation	Electric systems (to accept higher rates of wind energy) Reserves evaluation and better use of fossil fuels.	Electric systems (interconnection and network topology) Improvements in the use of heat (gas turbines, thermal solar, etc.)
Evolution of addressed topics	Time sensitive preocupations Rapid rise of specific threads	Highly dynamic Incremental and oriented

Evolution in Argentina has been branded by historical circumstances, giving some par ticular rhythm to its preocupations. Changes in the energetic markets[69,70,86] have been mostly responsible for that. A long-perceived potential for wind generation[15,16] and prior capabilities on material research complete to this profiling. Specific issues quickly rise in the South-American country. Argentina has seen hydrogen and fuel cells as a promising avenue for research and development activities[5]. Wind generation has been the other grand techno logical bet. It has coupled with research capabilities on mechanic and electrical engineering to devise solutions that would manage the intermittencies and limitations in wind gener ation. As researchers pay attention to the possible evolution of the energetic matrix, the attention focuses on finding ways of increment efficiency in energy consumption to address power shortages. Reserves on fossil fuels become a relevant area for research, given this set of necessities.

In Mexico, the incremental development of an institutional design to address climate change has been quite relevant. It situated renewables as the spearhead of the desired transition towards sustainability.[77,78] The country's great stock in wind, solar, and geothermic resources has impacted research. As a result of the promotion scheme, wind farms started to appear in southern Mexico in the mid-2000s; research focused on building and controlling new electric networks. Geothermic resources are a rare commodity that has been widely studied and developed in Mexico because of its abundance.[80] As regarding solar panels, thin-film stands as a promising technology mostly because it can be mass-produced. To an export-oriented economy like Mexico with a rising industry, this technology poses a good fit. Energetic integration with the United States[78] has meant for Mexico access to abundant and cheap gas. Most of the late-installed generation capacity of the country has been in gas turbines. It has then been quite relevant to study available gas reserves and ways of improving the efficiency in their use.

Final remarks and future research possibilities

This paper has developed an alternative approach to understanding how Latin-American countries develop their research activities. It has also shown that the study of knowledge production dynamics in Latin-American countries have a lot to gain from understanding their thematic structure from a national point of view. It has stressed how local threads make sense when situated in a broader social, economic, and political context. By doing so, it relates to an emerging interest in relating scientific research to societal needs.[87] Analyzed documents are not exempt from being affected by mechanisms underpinning the production, circulation, and consumption of scientific journals[88] and neither is this methodological approach. It seems necessary to reflect further on the publications practices' broader implications to build better interpretations of this kind of findings. The use of semi-automatic text analysis has a lot of potential for the development of this research agenda.

Implications of these results for renewable energy research are also relevant. As energy transition advances at different paces in different countries, understanding how scientific capabilities have accumulated brings a useful tool to reflect future possibilities and limitations. Expert communities have a critical role in boosting technology adoption rates, but also in identifying their optimal configuration and finding potential failures. This research has provided an approximation to describe and profile these capacities.

Bibliometric research has always been an important tool to grasp the complexity of scientific research. Their use to map technological trends has been narrow-focused by concentrating on specific technologies.[29,30,32] This research stresses how important the links that support any knowledge base are. They go beyond those applied to a particular technological interest. To analyze more than one technology side by side has shown that it is possible to grasp some of these links. Here, one promissory avenue for future research is developing different ways of incorporating expert knowledge into the mix. The development of participation methods to further the reflection of expert communities[89] is one of many possible ways. With the emergence of innovative computational methods, new interesting applications for expert participation are on the rise.

Taking a look to two national cases allowed to take a look to two different approaches to the same concept. The variations in national interpretations of it show how the idea of Renewable Energy mediates differently between science and society in different spatial and temporal coordinates. Although results are interesting, more evidence is needed to know how much is the concept helping to steer and govern research.[12] Possible research can be done in understanding public perception of these technologies in these two countries.

Finally, this research has shown the relevance of the national perspective toward strategic efforts in science. It has shown that research can have national specificities beyond the limitations that international collaboration posit. This could falsely lead to think that non-hegemonic countries can disconnect from the global research landscape. This is, of course, not true. Further research should be done to map how, when, and who helps countries with international constraints to build such a particular approach to global issues. This kind of research would help to bring to light how knowledge in these urgent matters circulate. It would do so by showing which specific threads get amplified in the process of connecting national traditions and international communities.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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FOOTNOTE

1. For period detection, in order to better grasp variation, four hundred muti-terms were detected. For text and cluster analysis, looking to grasp a better synthesis of topics addressed, two hundred terms were detected. From these two hundred terms, non-descriptive terms were curated. From the results, one hundred and fifty were used when building network analysis. When building the temporal evolution diagram, the whole set of two hundred terms was chosen to better capture semantic variations over time in each country.

2. Mexico defined nuclear power as part of clean energy sources in 2014 by its law of electric industry.[83]

3. This is an option mostly developed in the United States by General Electric as opposed to the Argentinean case, where the first heavy water reactor was purchased to Siemens in Germany with a technology transfer agreement.

4. Laguna Verde is the only nuclear plant in México. It was built on a long-time span. The construction started in 1976, and operation began in 1991. Mexico has a long tradition of anti-nuclear movements that opposed and slowed the construction.

5. The country passed a Law to promote hydrogen technology development and application as a fuel source and a vector for energy in 2006.[83]