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Technology intelligence analysis to identify perspectives of shale gas in Mexico

Análisis de inteligencia tecnológica para identificar perspectivas del gas en lutitas en México

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Technological innovation: use of bibliographic analysis to identify opportunities for shale gas exploitation.

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Resumen

En este documento se presenta un análisis de información para identificar requerimientos, retos y perspectivas relacionados con el aprovechamiento del gas en lutitas en México. El estudio se basa en los métodos de Inteligencia tecnológica y se aplica en el periodo 2000 a 2019. El resultado muestra una tendencia creciente en las publicaciones científicas de 2000 a 2016 y un comportamiento oscilatorio en los últimos tres años; un total de 11720 documentos científicos se publicaron en el periodo de estudio. La contribución de México a la producción científica global es de sólo el 0.3%. Respecto a la información tecnológica, se registraron 9090 solicitudes de patentes en todo el mundo; de entre ellas, sólo 27 solicitudes fueron recibidas por el Instituto Mexicano de la Propiedad Industrial. El tópico más frecuente en las solicitudes de patentes corresponde a Química y Metalúrgica (20%) y a Construcciones fijas para la obtención de petróleo, gas, agua, materiales solubles o fundibles y lodos de minerales (14%). Las tecnologías transversales son un tópico emergente que ya concentra 8% de las solicitudes de patente. La información analizada se utilizó para proponer una estrategia general, basada en la Teoría de la Resolución Innovadora de Problemas, para un aprovechamiento sustentable de este hidrocarburo. A partir de este análisis de información, es posible concluir que el aprovechamiento del gas en lutitas en México implica retos importantes para todos los sectores de la sociedad.

Palabras clave: gas shale; hidrocarburo no convencional; combustible fósil alternativo; TRIZ.

Abstract

This paper introduces an information analysis to identify requirements, challenges, and perspectives related to shale gas exploitation in Mexico. The study is based on Technology intelligence for the period 2000 to 2019. The results show an increasing trend concerning scientific publications from 2000 to 2016, and an oscillatory behavior in the last three years; a total of 11720 scientific documents have been published in the period of study. The contribution of Mexico to global scientific production is only 0.3%. Regarding industrial information, 9090 patent applications have been generated worldwide; among them, only 27 were received by the Mexican patents office. The most frequent topics in the patent applications are Chemistry and Metallurgy (20%) and Fixed constructions for obtaining oil, gas, water, soluble or meltable materials, or minerals slurry from wells (14%). Cross technology is an emerging topic that concentrates 8% of the patent applications. The analyzed information is used to propose a general strategy, based on the theory of inventive problem solving, for the sustainable exploitation of shale gas. From all the analysis performed, it is possible to conclude that shale gas implies critical challenges for Mexican society's different sectors.

Keywords: Shale gas; unconventional hydrocarbon; alternative fossil fuel; T.R.I.Z.

1. Introduction

Unconventional fossil fuels are nowadays considered as possible choices to supply energy. Some examples of these resources are bitumen, tight oil, extra-heavy oil, oil sands, tight gas sandstone/limestone, coal seam gas, gas hydrates, and shale gas (Chew, 2014; Kuwayama et al., 2013). Shale gas is methane embedded in shale rocks with low permeability at a few thousand feet deep (Gao and Yu, 2017; Zendehboudi and Bahadori, 2017). According to the U.S.A. Energy Information Administration (E.I.A.), shale gas deposits are distributed in the five continents; six countries concentrate more than 60% of the global resources: China, Argentina, Algeria, U.S.A., Canada, and Mexico (E.I.A., 2013). In Mexico, several shale gas resources have been identified in Veracruz, Tamaulipas, and Coahuila.

The exploitation of this resource implies several challenges in all its life cycle. For this reason, it has become an important element in the current energy context all around the world (Gao and Yu, 2017; Zendehboudi and Bahadori, 2017b). Besides, there are international discussions about the environmental sustainability of shale gas. One of the main controversial topics concerns the extraction stage since hydraulic fracking is the most useful method to recover shale gas. For instance, this technique has been associated with severe environmental and health impacts, such as water pollution and earthquakes. These precedents have caused debates on different sectors of Mexican society (Manzanares Rivera, 2014; de la Vega Navarro and Ramírez Villegas, 2015). The current government seeks to avoid the exploitation of shale gas, even if the national production of natural gas is not enough to supply the demand as well.

For all these reasons, it is necessary to know the local and global context of shale gas to identify challenges and design an integrated strategy to promote and exploit this resource. In this study, an information analysis has been performed to define requirements, challenges, and perspectives related to shale gas exploitation in Mexico.

2. Methodology

The methodology is based on the technology intelligence (Durand, 2010) and the theory of inventive problem solving (T.R.I.Z.) (Ilevbare et al., 2011) approaches; it is resumed in Figure 1.

The Scopus database was considered as the source of scientific knowledge for this analysis. The keyword used to search published documents was "shale gas"; the search criteria were title, abstract, and keywords. After that, the affiliation was also included to find reports from Mexican authors.

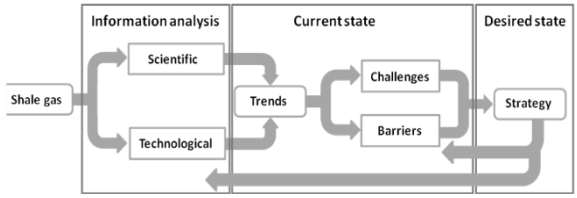


Figure 1. Methodology for the analysis of shale gas information.

The technological information analysis was done by using the Google Patent Search engine. Besides, the S.I.G.A. engine from the Mexican Institute of Industrial Property was employed to search Mexican patents. This research was complemented by the searching engine of the World Intellectual Property Organization (WIPO). Four keywords were used since shale gas is known by different terms in Spanish: gas shale, gas de lutita, gas de esquisto, and gas pizarra. The period of analysis considered was from 2000 to 2019.

3. Results and discussion

3.1. Analysis of scientific information

A total of 11720 documents were found by Scopus. The classification is dominated by articles and conference papers; that means most of the scientific documents include results or original researches preliminary outcomes (Figure 2).

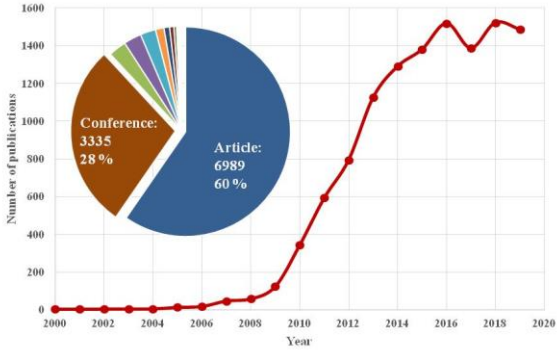


Figure 2. Scientific publications from 2000 to 2019.

Three stages of the publication trend can be observed: initial, exponential, and backward. First stage (2000-2008) corresponds to a few scientific activity: an annual average of 16 items and 144 published documents. Among the topics addressed in that period, it can be mentioned: site characterization, effects of existing shale wells, the study of potential production, and economic aspects.

In the exponential stage (2009-2016), there was an annual average of 897 items; a total of 7170 documents were reported, which corresponds to 61% of the analyzed period. This increase is due mainly to the international alarm about the depletion of fossil fuels, which motivated an exhaustive activity concerning territories exploration to identify new oil deposits in deep water and lands a few explored. Also, this stage is associated with the “shale revolution”: the successful incorporation of shale gas as a key fuel in the U.S.A., then several countries were searching to follow similar pathways. For example, in Canada, shale gas became one of the leading energy sources substituting coal (Rivard et al., 2014). European Union has developed several studies to determine if it is possible to reproduce the American shale revolution in European territory (Saussay, 2018). China counts the most considerable

shale gas resources globally; this country has been facing its issues to become the leading shale gas producer since several years ago (Li et al., 2016). On the other hand, different voices expressed their concerns regarding the adverse effects and risks of shale gas exploitation. Among those factors, it can be mentioned: water and air pollution (Vengosh, 2013; Annevelink et al., 2016;), seismic events (Sovacool, 2014), health (Bunch et al., 2014), on the markets economy (Bădileanu et al., 2015; Muehlenbachs et al., 2015), and other environmental effects (Costa et al., 2017). All these situations promoted the application of researches to assist and to complement the development of shale industries, to explain phenomena associated with shale gas, to identify risks, and also to propose alternatives for more sustainable exploitation of this resource (Yuan et al., 2015; Bilgen and Sarikaya, 2016; Goldthau, 2016; Centner, 2016; Lozano-Maya, 2016).

Finally, a decrease in the publications is remarked in 2017. That year, 1387 documents were published, which represents a decrease of 9% concerning the previous year; the published documents increased in 2018 and 2019 but did not reach the number of prior years. The interpretation of this behavior is as follows: shale gas has become a consolidated topic; the knowledge generation is entering a stationary stage; then, new subjects and challenges are being identified (Striolo and Cole, 2017; Gao and You, 2017; Le, 2018). This situation induces the variations in the number of publications showed in the figure; then, an oscillatory behavior on scientific papers could be expected shortly.

This stage of re-orientation of scientific development represents an opportunity area for different countries, such as Mexico. It is possible to promote collaborations with international research groups to take advantage of the knowledge generated at the international level as a basis for the generation of new knowledge applied to the national situation.

Besides, shale gas is addressed from different disciplines; the Scopus engine classifies the research areas in 24 items: from Energy to Health and even Arts and Humanities. It implies a multidisciplinary interest in shale gas; this is a typical situation since this resource's production chain is extensive, and it has influence in almost all the knowledge areas. The research areas were reorganized into eight categories, as shown in Figure 3. The interest in shale gas is based on its potential for energy generation; for this reason, the subject area “Energy” is classified as the main category. The other seven categories were stated by analyzing the keywords and abstracts of papers; besides, this analysis allowed identifying the main topics for each category; they are presented by relevance.

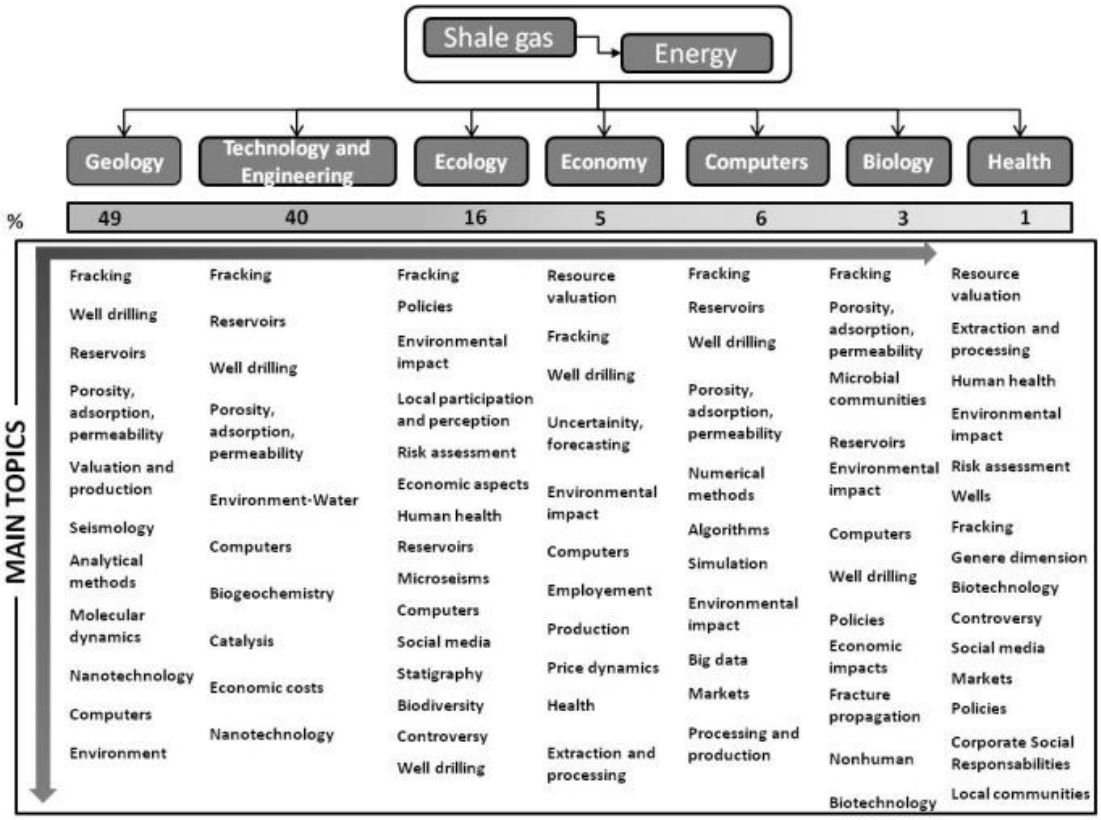


Figure 3. Classification of publications by topics.

"Fracking" appears in all the categories, becoming the most relevant topic; even if this technology was developed many years ago, there are still open aspects to be solved, such as the minimization of risks and the secondary effects on the ecosystems. The different elements of "Reservoirs" are studied from different perspectives: production valuation, exploration, geology, etc. "Well drilling" is the other topic appearing in all the categories (it is the second relevant topic); this is an important subject since the drill methods and technology depends on specific characteristics of reservoirs; in addition, the risks and secondary effects should also be assessed. The environmental aspects are also a frequent topic in the different categories; the studies deal with the assessment of effects shale gas exploitation on water and air, as well as on the ecosystems and biodiversity. However, the relevance of Environment is less than the one of Fracking and Well drilling. Another recurrent topic is related to the use of Computers, which have proven to be a useful tool to study different aspects of shale gas exploitation: molecular dynamics, numerical modeling, and simulation, big data analysis, forecasting, and many others. The publications concerning Economy, Social, and Health areas are few in comparison with the items classified in the other categories; however, these topics are being studied further.

On the other hand, Figure 4 shows the distribution of publications by geographic origin; 88 countries from the five continents report documents related to shale gas.

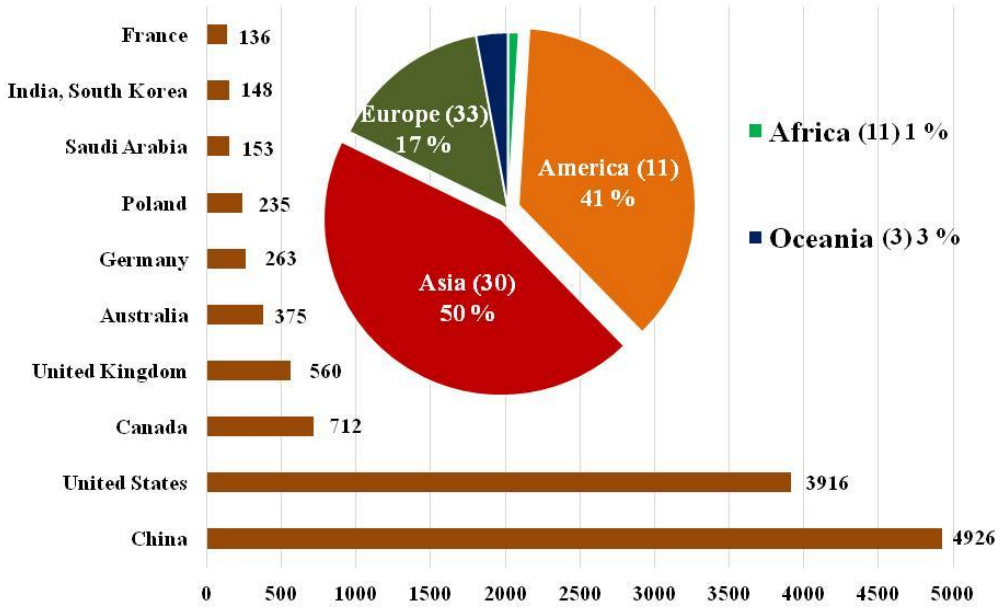


Figure 4. Classification of publications by origin.

Asia produces 50% of the reported documents. This behavior is mainly due to the contribution of China (4926 items), which is developing the shale industry. In the American continent, the United States and Canada are the most contributing countries due to the incorporation of shale gas in their energy sector. Those countries keep promoting scientific research. In Europe, 35 countries have taken this topic to assess shale gas development.

An inference from this analysis is that shale gas is studied all around the world from different perspectives. In particular, the U.S.A., Canada, China, Australia, and Argentina are examples of success cases regarding shale gas exploitation. These countries have incorporated this non-conventional resource into their energy matrix and still develop research to improve the performances of the system, as well as the different impacts and risks associated (Cooper et al., 2016; Shar et al., 2018; Wang, 2018; Marcos-Martinez et al., 2019; Shcherba et al., 2019).

3.2. Analysis of technological information

The Google Patents engine found 9090 applications and 5853 granted patents, as shown in Figure 5. The stages length for patents is different from the one of scientific publications. The initial stage is more prolonged, the exponential stage is shorter, and the backward stage begins in 2015 instead of 2017, and the decrease of both published and granted patents is more noticeable.

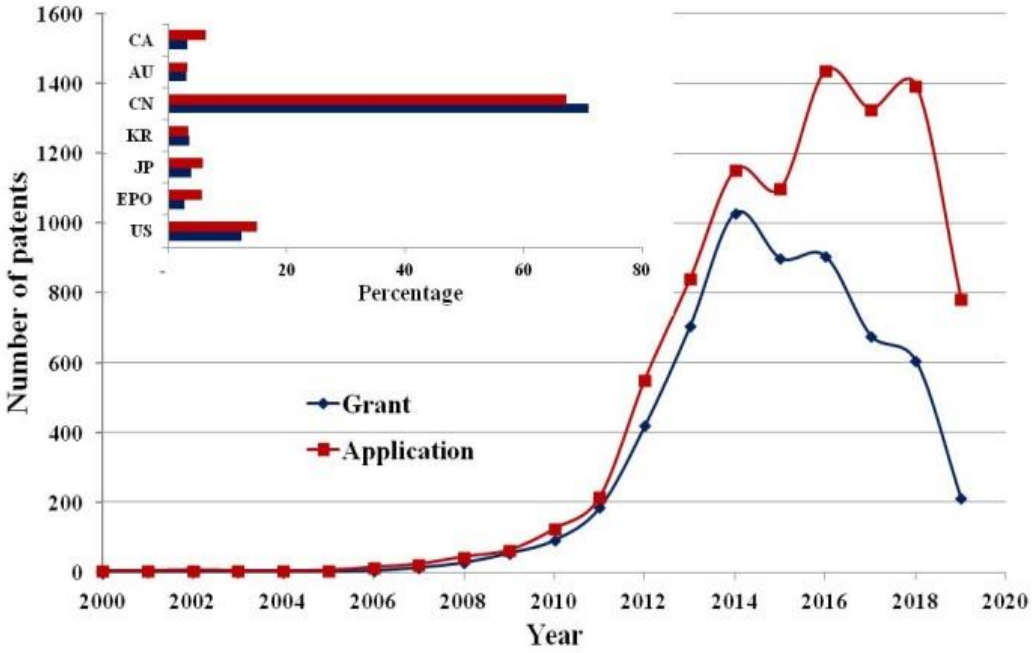


Figure 5. Patents publications from 2000 and 2019.

This behavior could be explained as follows. Before 2010, shale gas was considered a feasible alternative to oil availability reduction; then, only a few countries were developing technology to exploit this resource. The tendency observed from 2010 until 2014 corresponds to the increasing interest in shale gas worldwide; this could be considered the consolidation of shale gas. The technology has reached a certain maturity degree and is now waiting for new knowledge generation to be transferred to technological development and improve technology's current status. Even if the patents generation is oscillating after 2015, with the approval of shale gas exploitation in different countries and the investment in Asia and North America, it could be expected to increase in the patents generation or at least a similar rate the previous years. Asia produces the most significant amount of patents through the offices of China, Japan, and Korea. China (C N) concentrates around 70% of applications and granted patents; this is a normal situation since this country possesses the largest deposits of shale gas; in fact, the Chinese scientific activity is according to the technological development concerning shale gas. On the other side, America (through the patent offices of the U.S.A. and Canada) receives 20% of applications and reports 15% of granted patents.

On the other hand, the patent classification aims to determine the particular topic of shale gas development. An analysis of the granted patents according to the Cooperative Patent Classification (C.P.C.) is done, and the result is presented in Table 1.

Table 1. Granted patents by C.P.C. code.

Code	%	Topic
B01D	3	Material separation
B01J	4	Apparatus for chemical or physical separation
C02F	2	Special arrangements for treating water, wastewater, or sewage
C07C	3	Acyclic or carbocyclic compounds
C09K	7	Materials for miscellaneous applications
C10G	2	Recovery of hydrocarbon oils from oil-shale, oil-sand, or gases
C---	6	Others
E21B	14	Obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells
G01N	5	Investigating materials by determining their chemical or physical properties
G01V	4	Geophysics; gravitational measurements; detecting masses or objects
G---	2	Others
Y02E	2	Reduction of greenhouse gases emission, related to energy generation, transmission or distribution
Y02P	5	Climate change mitigation technologies in the production or processing of goods
Y---	3	Others

Five of the nine categories of C.P.C. are the most recurrent in granted shale gas patents: Performing operations and transporting (B), Chemistry, Metallurgy (C), Fixed constructions (E), Physics (G), and Cross-sectional technologies (Y). As for scientific information, shale gas requires a transversal technical development; that means it is needed a diversity of materials, processes, and systems.

The code E21B is the most frequent: 14% of the items are classified in such categories. Drilling, valuation, well construction, and production are important aspects of shale gas. Several supplies are required, which explains the number of patents in this category; this is consistent with the obtained in the scientific information analysis. The second most recurrent code is related to Chemistry and Metallurgy: C09K, with 7%; the patents classified in this code are related to materials frequently developed exclusively for shale gas.

Another remarkable category is Cross-sectional technologies, mainly due to the implications on sustainable development; the patents on this field are intended for CO_2 capture, greenhouse gas reduction, and climate change mitigation. This is a challenging area offering many possibilities to the knowledge transfer through patents development.

4. The case of Mexico

In 2011, Mexico was ranked fourth with the largest shale gas resources. According to the Mexican Secretary of Energy (SENER) and the National Hidrocarbons Comision (CNH), the reserves are located in the provinces of Coahuila, Chihuahua, Nuevo León (Eguiluz de Antuñano, 2001), Tampico, and Veracruz (Vega-Ortiz et al., 2020) (Figure 6).



Figure 6. Distribution of shale gas in Mexico.

4.1. Information analysis

At an academic level, shale gas has been few addressed. Then Mexico does not stand out yet in the generation of knowledge about this resource. As shown in Figure 7, a total of 36 (0.3% of the world publications) documents were registered by Scopus. The oscillatory trend implies that shale gas has not achieved consolidation in the Mexican scientific sector; this could be related to the governmental directives, which are changing continuously. Nevertheless, almost 90% of the documents have been published from 2014 to 2019, which suggests an increasing interest.

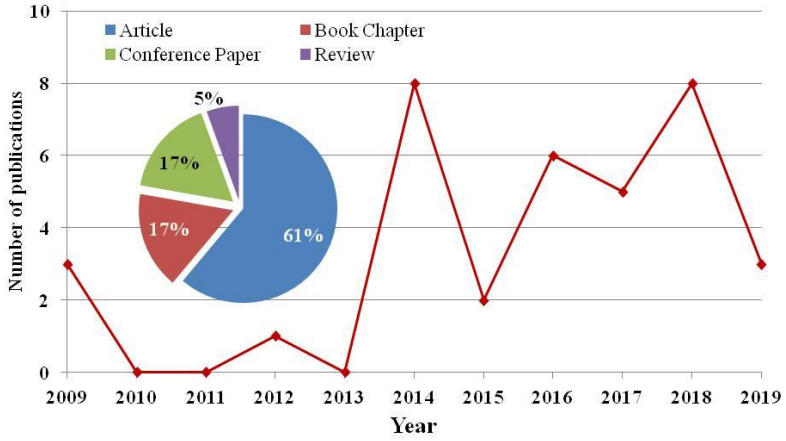


Figure 7. Scientific publications from Mexico.

61% of the documents are journal papers, which imply there are deep researches taking place. In addition, six publications were presented in conferences; participation in these events should be increased since it is an opportunity to promote direct communication with people from other countries and to encourage collaborations.

On the other side, most of the 36 documents were developed in collaboration with people from foreign institutions. This is a necessary strategy to take the opportunity to get knowledge from other countries. The papers are co-authored by researchers from 7 countries. The United States is the main scientific partner since 20 papers include the participation of people from this country (Figure 8); this is expected since the region with shale gas deposits in Mexico is near to the U.S.A. Other collaborators are from Arabia, Russia, and, U.K.; this is interesting because these countries have considerable experiences around shale gas.

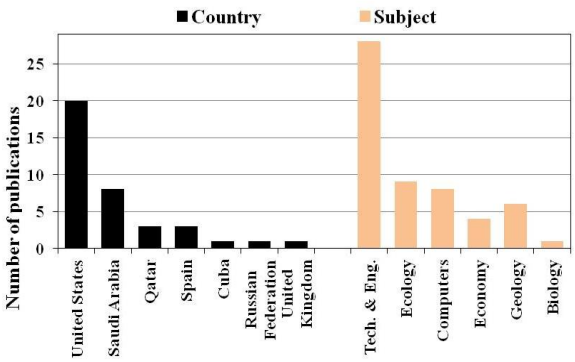


Figure 8. Scientific collaborations and topics.

Technology and Engineering is the most frequent subject instead of Geology (as for the world case); "fracking" is the topic in the top of interest which agrees to the global publications. Since shale gas resources are mainly situated in arid or semiarid regions, "water" is a relevant topic in the category of Technology, Ecology, and Biology. Some other topics, such as the impact on health, agriculture, and society, are not studied yet. In this context, due to the debate generated by the possible exploitation of shale gas (SEMARNAT, 2017), and the need to assimilate knowledge about this resource, it is expected the tendency of the scientific publications will increase in the near years.

Besides the scientific publications, there exist some other documents developed from Mexican institutions regarding non-conventional hydrocarbons. It is important to consider these documents to know particular aspects of shale gas in the country. Table 2 lists some of these documents; most of them were accessed in September 2020.

Table 2. Documents from national institutions.

Document name / Nombre del documento	Source
Geological Atlas, Non conventional resources / Atlas geológico, Recursos no convencionales.	CNH
Natural gas sector. Some proposals to develop the national industry / El sector del gas natural. Algunas propuestas para el desarrollo de la industria nacional.	CNH
Quarterly gazette, January-March, 2017 / Gaceta trimestral, Enero Marzo, 2017.	CNH
Exploration and extraction of oil and shale gas (data sheet, october 2018) / Exploración y extracción de petróleo y gas en lutitas (datos, octubre 2018).	CNH
Guide of environmental criteria for the Exploration and extraction of Hydrocarbons contained in shale. / Guía de criterios ambientales para la Exploración y extracción de Hidrocarburos contenidos en lutitas.	SEMARNAT
Guidelines on industrial safety, operational safety and protection of the environment to develop activities of Exploration and Extraction of Hydrocarbons in Non-Conventional Deposits on land / Lineamientos en materia de seguridad industrial, seguridad operativa y protección al medio ambiente para realizar las actividades de Exploración y Extracción de Hidrocarburos en Yacimientos No Convencionales en tierra.	SEMARNATthrough Diario oficial de la Federación
Prospective of the Natural Gas Market 2012 – 2026 / Prospectiva del Mercado de Gas Natural 2016 – 2026.	SENER
The fascinating world of unconventional deposits and environmental protection / El fascinante mundo de los yacimientos no convencionales y la protección al ambiente.	IMP
Gazette, January 2016 / Gaceta, Enero 2016.	IMP
Gazette, August 2017 / Gaceta, Agosto 2017.	IMP
Technical reports (Project 249984): / Reportes técnicos (Proyecto 249984): Asimilación y desarrollo de tecnología en diseño, adquisición, procesado e interpretación de datos sísmicos 3D-3C con enfoque a plays de shale gas/oil en México.	CONACYT-SENER
Technical reports (Project 26962): / Reportes técnicos (Proyecto 267962): Instrumentación del Programa Estratégico de Formación de Recursos Humanos en materia de Hidrocarburos no convencionales para el Estado de Coahuila.	CONACYT-SENER

Concerning the industrial information, the Mexican Institute of Industrial Property receives few patent applications regarding shale gas (Figure 9).



Figure 9. Record of patents in the Mexican office.

Only 27 records have been found; 12 were directly submitted at the Mexican office and 15 from other members of the Patent Cooperation Treaty (P.C.T.). Also, the trend of patent applications is oscillating as for scientific publications.

Besides, the classification of patents is presented in Table 3. As for the global case, the most recurrent codes are E21B (six items) and C09K (nine items). The former is related to inventions for obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells. The code C09K focuses on the development of materials for miscellaneous applications.

This number of patents is low since there are vast reserves of shale gas in the country. This situation implies that, for the exploitation of this hydrocarbon, Mexico will resort to foreign technology, at least in the short term. But it also means that there is an important area of opportunity for the national scientific and technological sector since it is possible to think of a productive symbiosis for the generation and transfer of knowledge.

Table 3. Classifications of patents by C.P.C. code.

Code	No.	Topic
B01D	2	Material separation
B01J	1	Apparatus for chemical or physical separation
C04B	3	Mortars, concrete or like building materials
C10G	4	Recovery of hydrocarbon oils from oil-shale, oil-sand, or gases
C09K	9	Materials for miscellaneous applications
C08L	2	Recovery of hydrocarbon oils from oil-shale, oil-sand, or gases
C---	2	Others
E21B	6	Obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells
G01V	3	Geophysics; gravitational measurements; detecting masses or objects

4.2. Conceptualization of a strategy for shale exploitation in Mexico

From 2013, a Mexican institutional framework was specially created to ease the application of the Energy reforms, which include shale gas (Villanueva González, 2016; Alpizar Castro, 2016; Condon, 2016). The SENER, the Ministry of Finance

(SHCP), and the Energy Regulatory Commission (CRE.) were involved in determining what policies, laws, fiscal aspects, technical analysis, and other factors are required in the new Mexican energy sector. In this context, the National Hydrocarbons Commission (CNH) is responsible of regulation and supervision of the exploration and extraction of hydrocarbons in the country. Besides, two organisms were explicitly created to manage the life cycle of hydrocarbons resources: The National Center of Natural Gas Control (CENAGAS) and the National Agency for Industrial Safety and Environmental Protection from the Hydrocarbon Sector (ASEA). The former is devoted to manage all the issues associated to the transportation and storage of natural gas, including the developing of rules of pricing. The ASEA is charged on the regulation and supervision of the operational safety and environmental protection of the hydrocarbon industry activities.

However, in 2019 there was a change in the federal administration, and even if the new government has promoted fossil fuels, shale gas has not been considered. The main argument is the environmental risks imposed by fracking, but some other political and economic aspects are less discussed in the official directives. But, according to a projection done by SENER., from 2020 to 2030, the national production of natural gas will be less than the demand by 4000 mcfd (millions of cubic feet per day). The short term option to supply the deficit of natural gas is the importation from the U.S.A., Canada, or some other country. Moreover, for the long term, shale gas could be a feasible option; the energy reforms should be adequately implemented since this could provide great opportunities to increase gas and oil production, which will boost the Mexican economy (Ventocilla, 2016).

In this context, the development of a national shale gas industry represents a significant opportunity for the country. However, an integrated strategy is required to overcome the main challenges imposed by shale gas exploitation. Among these challenges stand out the lack of a robust legal framework that could keep on despite government changes. Also, the lack of infrastructure, geological aspects (physical properties, depth of reservoirs, gas composition), socio-economic factors (local perception, employment generation, social, and environmental risks), and the global energy markets are issues to be attended (Arredondo-Ramírez et al., 2016). The challenges are similar to the identified in other regions of the world, and they should be addressed considering local conditions, as discussed by Li et al. (2016), Prpich et al. (2016), Zendehboudi and Bahadori (2017b), Sun et al. (2019), and other authors. Besides, the shale gas exploitation should correspond with the Agenda 2030 (U.N.O., 2015). Specifically, the objectives which require to be considered are:

- Build resilient infrastructure, promote inclusive and sustainable industrialization, and promote innovation. If this objective is achieved, it is possible to reach other objectives: ensure access to and the sustainable management of water and sanitation for everyone, and ensure access to affordable, reliable, sustainable, and modern energy for everyone.
- Promote continuous, inclusive, and sustainable economic growth, full and productive employment, and decent work for everyone. Several benefits from shale gas exploitation have been identified: promotion of high-income investments, generation of new jobs, and reducing external energy dependency (de la Vega Navarro and Ramirez Villegas, 2015).

Based on the information analysis presented previously, a general strategy is proposed in order to promote optimal exploitation of shale gas in Mexico. This strategy is based on the T.R.I.Z.: theory of inventive problem-solving. T.R.I.Z. integrates the concepts of contradiction, ideality, and pattern systems evolution to provide a knowledge-based method that allows finding innovative solutions to challenging problems (Ilvebare et al., 2011).

The proposed strategy is represented in Figure 10. The sustainable exploitation of shale gas is considered as the Ideal Final Result (IFR). This implies the benefits for the economy, society and environment should be larger than costs and harms (IFR=∑benefits/(∑costs + ∑harms); in fact, harms should be avoided or at least minimized, and costs should be in agreement with the available resources to achieve the sustainable exploitation of shale gas. Reaching the IFR requires identifying contradictions (apparent incompatibilities of desired features) in the shale gas life cycle, and using the available resources by considering the pattern evolution of systems to solve the contradictions through the transfer of knowledge and technology.

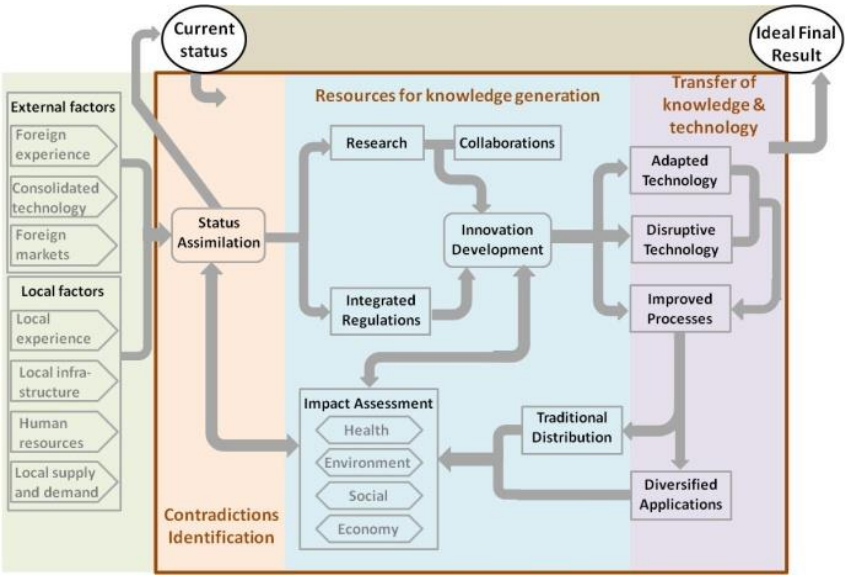


Figure 10. A strategy for shale gas exploitation in Mexico.

Complete and recurrent assimilation of shale gas status must be performed since it is continuously changing; this assimilation becomes the current status of a so-called Mexican shale gas industry. The main objective of this stage is to identify both the specific contradictions of the shale gas life cycle in Mexico and the required resources to solve those contradictions.

The local factor analysis should allow pointing out and measuring the specific challenges and then determining the particular contradictions. Some examples of contradictions are: a large volume of water is required and the shale region present water scarcity; the country has a deficit of natural gas, but the official directives avoid extraction of shale gas; the shale gas is a clean fuel with low environmental impacts, but its extraction produces wastes and emissions

which affects the environment; economic support is required for boosting local economies, but a shale gas industry is not well accepted yet. The regional factor analysis also implies identifying the available resources to solve contradictions: experience and infrastructure about fossil fuels, specialized human resources, knowledge about energy balance and local markets, material resources for shale gas management, etc. An important local factor concerns the necessity of specialized human resources to deal with shale gas challenges; it is important to ensure that Universities and Research Centers include this topic among their alternatives for new students. At the year 2000, only three universities offered an undergraduate program directly related to hydrocarbons; at present, the academic offer has increased around seven times: 20 universities are offering an undergraduate program of this kind.

On the other side, the analysis of external factors should complement the information to assimilate the status of shale gas in Mexico. These factors are important because the international conditions affect the local ones. For this reason, it is advisable to take advantage of the experience (regulations, management, investment strategies, etc.) of countries exploiting shale gas. It is also important to identify the technology currently used in the shale gas life cycle and the trends of the international scientific community working around this unconventional fossil fuel.

The next stage should focus on the contradictions solving process, which requires fundamental and applied research, generation and transfer of interdisciplinary knowledge, development and application of integrated regulations, innovation, and supervision of the shale industry from environmental, economic, and social perspectives. The idea is to generate new knowledge and to complement the local data related to specific conditions on the regions possessing shale gas; in this context, the collaboration with researchers from other countries should also be considered to take advantage of the international experience. As seen in the scientific information analysis, a lot of key topics have been developed, and the open problems are identified; this information could be used as a reference for the Mexican situation.

On the other side, the new energy framework allows foreign investment and also local participation other than the Mexican company devoted to oil (PEMEX.) and the Federal Commission of Electricity (CFE). Then, the regulation laws already approved should be appropriately implemented, and some others should be developed to ensure adequate evolution and to encourage the innovation on the national shale gas industry. Also, these regulations should be adapted to guarantee the local communities development along with the shale industries.
A key aspect that helps to solve the specific contradictions for the Mexican shale industry is the adaptation of technology, but especially to generate new and disruptive technology to optimize the different processes in the life cycle of shale gas. Particular attention should focus on the reduction of water requirements by two pathways: the development of waterless fracking methods and technology (Shi et al., 2020), and the wastewater treatment and reuse (Sun et al., 2019). The optimal use of water is strictly required since this topic is considered in the objectives of the Agenda 2030, as said before.

The innovation will also allow diversifying the applications of shale gas; for instance, in the electricity distributed generation to improve efficiencies, in the refining for the synthesis of added-value products, and in the wastes revalorization to promote a clean industry. Shale gas can be used as raw

material to obtain several products such as syngas, ethylene, propylene, and butadiene (Al-Douri et al., 2017). The methods for these kind of transformations are similar to other fossil fuels used in Mexico; then, it is feasible to adapt the technology to the case of shale gas. That means shale gas is not limited to the energy sector but for industrial applications; it implies the opportunity to create new enterprises or the expansion of the already existing; in both cases, further work posts could be generated.

Mexican research groups are already studying some of these applications; for example, the transformation of shale gas into added-value products such as ethylene (Ortiz Espinoza et al., 2015), benzene (Perez Uresti et al., 2017), syngas (Martinez Gomez et al., 2017) and methanol (Julián-Durán et al., 2014). Some other works are searching for a cleaner production (Martínez et al., 2014; Lira Barragán et al., 2016) and evaluating the infrastructure necessities for the supply chains (Ruvalcaba et al., 2017). Then, the knowledge transfer to the productive sector is indeed an urgent necessity.

Finally, it is necessary to adapt and develop methods to assess risks and impacts on health, environment, society, and economy. The life cycle assessment seems to be an adequate methodology to perform sustainability analyses to supervise ecosystems, local communities, and economic status, as done in other regions (Raj et al., 2016; Tagliaferri et al., 2017; Brown et al., 2017; Costa et al., 2018). From this evaluation, it will be possible to identify the stages representing more risks and design strategies to eliminate or minimize them. This issue requires multidisciplinary participation, which should be encouraged by human resources formation, governmental regulations, and the private sector.

The practical implementation of such a strategy requires the involvement of several actors. It should be lead by a multidisciplinary team including people from industrial, academic, governmental, and social sectors.

As said before, incorporating shale gas into the Mexican energy matrix would have an economic impact on the national energy market. At present, the natural gas deficit is compensated through imports from the United States. Thus, the exploitation of Mexican shale gas would reduce importation costs and modify the price of natural gas, and even diesel used in the generation of electricity. This would imply a reduction in the price of energy, making the national territory more attractive for industrial investment. However, reaching this point requires significant investment since the exploitation cost of shale gas is high; it is estimated that each well requires investments of around 15 million dollars. For this reason, it is necessary to create a regulatory framework that encourages investment in the life cycle of shale gas, especially in the stimulation phase, which is the critical point due to the risks associated with fracking. In this sense, technological innovation should be promoted as the basis for the development of the shale industry; strategies concerning the minimization of water used in the stimulation stage and the reduction of toxic chemicals should be prioritized in that regulatory framework. Nonetheless, it is required a deep study regarding the economic implications of shale gas exploitation considering different market scenarios.

Implementing a strategy of this type requires an interdisciplinary team composed of qualified personnel from the industrial, academic, governmental, and social sectors. The legal guidelines currently established for the exploitation of unconventional hydrocarbons must be updated according to the national and international energy

situation. This is a task that should be promoted by the government sector and accompanied by the academic and industrial sectors. Since the generation and transfer of knowledge are the keys to the generation of disruptive technology, the scientific and industrial sectors should be a fundamental part of this strategy. In this sense, it is advisable to allocate resources and human capital to promote research that allows generating knowledge that can be transferred to the fields of gas exploitation. Likewise, non-governmental organizations should become a supervisory mechanism to ensure that technological development meets the guidelines for the sustainable exploitation of shale gas. Even when the proactive participation of such actors is the principle of the Agenda 2030, it seems like a utopia in Mexican society; however, it is important, as a first step, to create the conditions and believe that it is possible.

5. Conclusions

Shale gas is a subject with broad scientific and technological activity. The study of this resource is done based on multi and interdisciplinary perspectives since shale gas affects several aspects of human activities such as energy, environment, economic, health, and social development. Among the main studied topics, there are fracking, well drilling, reservoirs characteristics, water resources, processing, resources valuation, and computer applications. Health and social impacts (even environmental risks) are few addressed in comparison with technical aspects; then, sustainability assessment is a topic that should be discussed more extensively.

The patents publication presented an increasing tendency from 2010 to 2016, where the main topics are Earth drilling, Chemistry, Metallurgy (materials and reactions), and Physics (measuring). As for the scientific documents, environmental protection issues are addressed for patents development furthermore.

In the case of Mexico, shale gas has been few studied. However, the topic is gaining interest; given the impact of this gas on the energy sector, it is expected that there will be more generation of knowledge in a short time. In this context, it is important to promote collaboration with other countries to get to know and use their experiences. Also, shale gas represents a source of challenges and opportunities which should be solved on the basis of scientific strategies, promoting innovation and knowledge transfer.

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