Research on Humanities and Social Sciences
ISSN 2224-5766 (Paper) ISSN 2225-0484 (Online)
Vol.12, No.2, 2022

Standardization as Key to Precautionary Principle Handling: Risk Mitigation for Shale Gas Production in Brazil

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We thank the support from the National Agency for Petroleum, Natural Gas and Biofuels Human Resources Program (PRH-ANP), funded by resources from the investment of oil companies qualified in the RD&I clauses from ANP Resolution number nº 50/2015 (PRH 33.1 – Related to Call Nº 1/2018/PRH-ANP; Grant FINEP/FUSP/USP Ref. 0443/19). We appreciate the support of the Gasbras R&D Network Finep Project 01.14.0215.00 through the granting of a research grant. The authors gratefully acknowledge the support of the RCGI – Research Centre for Greenhouse Gas Innovation, hosted by the University of São Paulo (USP) and sponsored by FAPESP – São Paulo Research Foundation (2014/50279-4 and 2020/15230-5) and Shell Brasil, and the strategic importance of the support given by ANP (Brazil's National Oil, Natural Gas and Biofuels Agency) through the R&D levy regulation.

Abstract

Since 2013, after the 12th ANP (National Regulatory Agency for Petroleum, Oil, and Biofuels) Bid Round hosted in Brazil, several public civil actions (PCA) put unconventional resources on hold due to the precautionary principle as main reason for legally restraining shale gas exploitation. Essentially, scientific uncertainties and possible irreversible and negative impacts to human health and environment are core to the precautionary principle. Shale gas has provided an unprecedented role for the U.S among natural gas global traders since its soaring exploitation has started more than a decade ago. As of 2009, though the 'shale boom' assisted the natural gas settlement within energy transition discussions, harnessing an unconventional resource still negatively resonates in some countries, i.e., France, and even in some of the U.S. states due to potential risks to human health and environment. Lacking scientific certainty to deal with these risks may also contribute to public opinion's rejection and legal restraints to additional exploitation, as seen with the precautionary principle application in Brazil. As further suggested in this paper, some of the risks (i.e., structural building failures, wastewater disposal, and fugitive emission) may represent lesser concerns whenever technical standards are rigorously followed, since their voluntary yet compelling guidelines have been designed and tested toward safety and quality for consumers. The paper objective is to fill some of the constraining gaps for the shale gas development and broaden qualified discussion to reduce complexity and increase transparency of the Brazilian regulatory regime. By presenting benchmarked technical standards applied in successful experiences related to shale gas, this paper finds reasonable arguments to resume unconventional resources debate in Brazil, specifically to address shale gas risk matters. An orderly risk management supported by specific standards may induce a precautionary principle ease, alongside with additional geology studies regarding sedimentary basins to avoid continued scientific uncertainties.

Keywords: shale gas, precautionary principle, standardization
DOI: 10.7176/RHSS/12-2-02
Publication date: January 31st 2022

Introduction to shale gas scenario

According to EIA (2014), promising unconventional resources are located in several basins around the world and China ranks first among top 10 countries with technically recoverable shale gas resources, while Brazil places in last position (Figure 1). On the other hand, the U.S. spearheads among top 10 shale gas production, as represented in Figure 2, expected to represent more than 70% of total domestic natural gas production by 2040 (EIA, 2016).

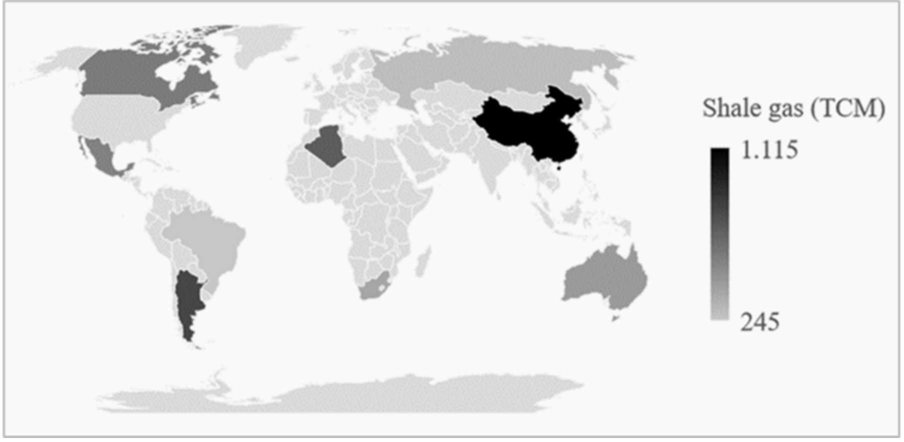

Figure 1. Top 10 countries with technically recoverable shale gas resources
Source: based on EIA (2014).

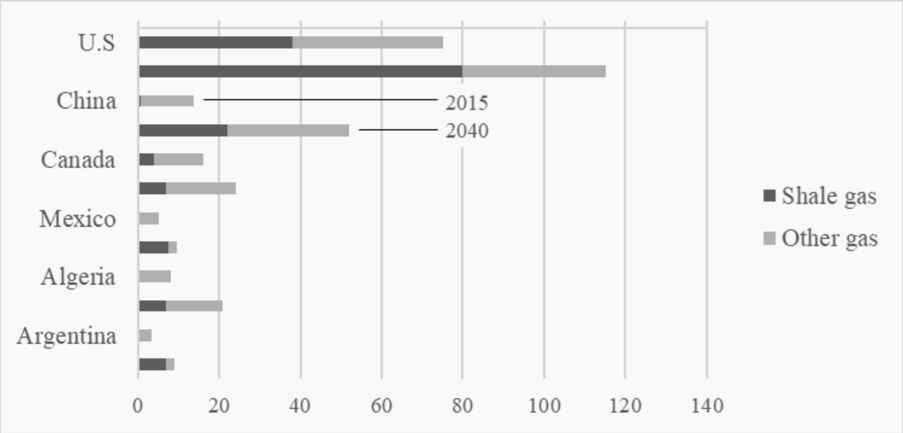

Figure 2. Shale gas and other natural gas in selected countries, 2015 and 2040 (billion cubic feet per day)
Source: EIA (2016).

Each country aforementioned shows different development levels, reflecting their particular circumstances in terms of infrastructure, regulation, and technology, but primarily anchored by federal support and its willingness to set the natural gas from various sources as determinant for climate change tackling. Eventually, negative impacts linked to the applied technology (fracking or hydraulic fracturing combined with horizontal drilling) sealed the shale gas chances in some countries, which are now under moratorium or even banned due to unanswered potential risks.

Shale gas has provided an unprecedented role for the U.S among natural gas global traders since its soaring exploitation has started more than a decade ago (Kaden; Rose, 2016). As of 2009, though the 'shale boom' assisted the natural gas settlement within energy transition discussions, harnessing an unconventional resource still negatively resonates in some countries, i.e., France, and even in some of the U.S. states due to potential risks to human health and environment. Lacking scientific certainty to deal with these risks may also contribute to public opinion's rejection and legal restraints to additional exploitation. As further suggested in this paper, some of the risks (i.e., structural building failures, wastewater disposal, and fugitive emission) may represent lesser concerns whenever technical standards are rigorously followed, since their voluntary yet compelling guidelines have been designed and tested toward safety and quality for consumers.

Since 2013, after the 12th ANP (National Regulatory Agency for Petroleum, Oil, and Biofuels) Bid Round hosted in Brazil, several public civil actions (PCA) put unconventional resources on hold due to the precautionary principle as main reason for legally restraining shale gas exploitation. Essentially, scientific uncertainties and possible irreversible and negative impacts to human health and environment are core to the precautionary principle. Despite having specific aspects, i.e., geology, water availability, and technology readiness, the U.S. and China's previous experiences on applying technical standards may ease certain restrictions found in Brazil, with respect to environmental and human health risks. Throughout the U.S. and China's benchmark regarding shale gas-related standards, this paper suggests that Brazil may find reasonable arguments to resume unconventional resources discussion with the expansion of its natural gas supply and foster energy security. The paper objective is to fill some of the constraining gaps for the shale gas development and broaden qualified discussion to reduce complexity and increase transparency of the Brazilian regulatory regime.

In fact, though used as benchmark in this paper, hardly will other country replicate such successful endeavor just as the U.S. did, mostly because, among all its overarching favorable pre-conditions (i.e., gas pipeline infrastructure, regulatory framework, industry capabilities, and economic incentives), the private ownership of petroleum rights stands as one of the most distinctive and exclusive characteristics compared to those countries with shale gas reserves, which has eased intrinsic social tension associated to the production. As opposed to Brazil, the U.S. also sustain an accumulated knowledge from the comprehensive mapping of hydrocarbon sweet spots (zones of high productivity) and production of relevant geologic information (Gao et al., 2021; Lozano-Maya, 2016; PROMINP/CTMA, 2016; Amec Foster Wheeler, 2015).

Precautionary principle definition[1]

Adopted as Principle 15 of the Rio de Janeiro Declaration during the 1992 United Nations Conference on Environment and Development, the precautionary principle set a milestone in the international environmental law, including the duty of early action when facing environmental damage risks (Machado, 2014):

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (UNCED, 1992)

But even before the 1992 Rio de Janeiro Declaration, international agreements had previously indicated the necessity of decision making based on scientific research and measurable methods for the environment protection (Miranda, 2018). The 1992 Rio de Janeiro Declaration brought the precautionary principle to light as a soft law or soft norm, which designates as not being compulsory and nor traditional source for international law (Sadeleer, 2004). It also represents instruments that establish guiding or general principals and are precursors of compulsory legal rules adoption (Silva, 2004).

Miranda (2018) points out the precautionary principle characteristics and consequences:

(i) a tool for risk management and planning;
(ii) require proportional action in relation to the risks identified;
(iii) consider the analysis of costs and benefits, including the economic tradeoffs;
(iv) guaranteeing democratic participation and bringing transparency to the evaluation and decision-making process;
(v) indicate a possible reversal of the burden of proof of safe level in relation to the defined risk level; and
(vi) to adopt temporary measures, which should be reviewed at any time in the light of scientific developments to be encouraged through the continuity of assessments in order to transform the potential risk into known risk.

Miranda (2018) analyzed several courts based on a potential jurisprudence over precautionary principle: International Court of Justice, International Tribunal for the Law of the Sea, World Trade Organization, European Courts, and Mercosur. The author states that, in general, international courts acknowledge the precautionary principle validity for guideline but not as an applicable norm, and that countries should adopt a reasonable risk level to support decision-makers in addition to scientific evidence. The author also concludes that whenever an activity has known impacts and, hence, not subject to the precautionary principle, other tools such as environmental licensing may be applied to avoid risks; if such possibility is unavailable, mitigating or rather compensating measures might act as preventive tools, even considering a license refusal.

According to the European Commission (EC) (2000), mixed and sometimes contradictory views often surround the precautionary principle discussions since its understanding and effects are yet inconclusive. Foster

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[1] For further discussion about precautionary principle, see:
De Carvalho, J.F.; Mercedes, S.S.P.; Sauer, I.L. (2010); Fleming, R.; Reins, L. (2016); Persson, E. (2016) cited on the References.

(2002) and VanderZwaag (2002) ratify the precautionary' "slippery" aspects regarding its lack of definition, calling attention for the political, economic, and ideological use of the principle. Sharing a common standpoint, Tawonezvi (2017) states that, at this infant stage of the shale gas industry development, environmental and social regulatory risks will put pressure on operators as policy makers try to correct the deficiencies in the current legislation in shale gas practices and trying to achieve their nations' social needs.

Therefore, decision-makers are constantly faced with the dilemma of balancing interests of individuals, industry, and organizations with the need to reduce the risk of adverse effects to the environment, human, animal, or plant health (EC, 2000). On one hand, the principle stands as an anticipated measure toward greater threats, for example, climate change and greenhouse gases emission, and used as a strategy upon scientific and risk uncertainty; on the other hand, it also acts as a potential hurdle to human activities and an excessive regulation source (Bocchi, 2016).

Within the EC Communication COM/2000/1 (EC, 2000), the following general principles are not limited to application of the precautionary principle, but to all risk management measures. Moreover, the precautionary principle, which is essentially used by decision-makers in the management of risk, should not be confused with the element of caution that scientists apply in their assessment of scientific data (EC, 2000). The general principles are:

- *Proportionality* to the desired level of protection;
- *Non-discrimination* to avoid different treatments in an arbitrary manner, without invoking the geographical origin or the nature of the production process;
- *Consistency* with the measures already adopted in similar circumstances or using similar approaches;
- *Examination of the benefits and cost of action or lack of action*, including an economic cost/benefit analysis whenever appropriate and feasible, though decision-makers may be guided by non-economic considerations;
- *Examination of scientific developments* in order to continuously review measures taken.

By this approach, the European Commission's communication contributed to settle a common ground for the precautionary principle application. However, Bocchi (2016) points out that a minimum risk level is yet to be defined and thus, represents a difficulty for its application. Proportionally to a desired level of protection, the decision of acting or not leads to a diversified risk management portfolio, eventually expressed as an ordinary risk communication to the society or even a temporary prohibition (EC, 2000). Sunstein (2005) recalls cultural and organizational aspects to highlight differences on perceived risks and the likelihood to apply the precautionary principle. For instance, Europeans are more prone to its application than Americans because of their higher risk aversion to climate change and genetically modified food, whereas Americans tend to be more concerned about national security and terrorism.

Environmental risks associated to shale gas development[1]

Pivotal to shale gas production, the hydraulic fracturing (HF) or fracking technique added to horizontal drilling applies the needed well stimulation to extract trapped gas from low permeability shale reservoir. By combining water, proppant material, and other chemicals, this blend runs down a multi-layered casing under high pressure, opening pre-existing or creating new fractures within the formation and resulting in gas release (Kaden; Rose, 2016).

As shale gas production and interest grew rapidly, so did negative public response to environmental and human impacts often linked to the HF process, specially to short-term effects related to the well construction activity itself, also including water and air contamination (Tan et al., 2019; Yu et al., 2018). Most of these impacts disappear once the well is completed, and all the equipment moves offsite, but the impacts can be significant during the development process (Soeder, 2018). Amec Foster Wheeler (2015) has pointed out the importance of mitigating risks from the very beginning (i.e., site selection in exploration phase), coming across technology, construction practice, operation, and decommissioning stages.

Table 1 explores potential environmental risks associated to gas exploration and production, highlighting some exclusive risks related to unconventional in comparison to conventional gas, but mainly sharing common risks/impacts with different magnitudes and spillovers. With regard to risks arising from HF alone, potential risks are likely to include induced seismic events; the local sourcing of water, creating additional demand during periods of water stress; the management of chemical and the mixing, storage, and use of the fracture fluid, the management of flowback water and fugitive greenhouse gas emissions (Amec Foster Wheeler, 2015).

However, from this distinction, one may not conclude that unconventional gas exploration and production activities are riskier than those associated to conventional resources; applying proper risk assessment approaches and developing adequate tools is relevant to understanding the potential environmental impacts from shale gas

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[1] For further discussion about environmental risks associated to shale gas development, see:
Arent, D. et al. (2015); Digiulio, D.C., Jackson, R.B. (2016); Jackson, R.B. et al. (2014); Meng, Q. (2019); U.S. EPA. (2016) cited on the References.

(Rodak; Silliman, 2012). Additionally, quantifying the impacts of shale gas wells on human and environmental perspectives is needed to improve both environmental monitoring to detect exposures, and management practices to minimize problems (Soeder, 2018). For instance, Kuwayama et al. (2015) concluded that water quantity impacts of shale gas and tight oil developments are, on average, not significantly worse than for their conventional counterparts, though the specific location and timing of withdrawals for energy development matter.

In essence, shale gas development exceeds solely technical and economic perspectives, to intermingle environmental, social, and political risks that interlink a plethora of stakeholders. That said, a multidisciplinary approach is recommended to overcome the multiple challenges correlated to shale gas development, shifting to a more inclusive problem-based approach (Lozano-Maya, 2016). The author developed an interdependent 3-domain framework (Access to Natural Resources; Governance; and Industry Capabilities), which the latter includes "the adherence to practices, including industry standards, to minimize risks to industrial safety, to the environment, and to local communities, in order to affect the way in which the general public perceives shale-gas-related operations". Furthermore, based on this assumption, this paper shall link standardization to risk mitigation and, hence, to the precautionary principle handling in particular to the Brazilian shale gas scenario.

Table 1. Potential Environmental Risks Associated with Conventional and Unconventional Gas Exploration and Production

Theme	Risk/Impact	Conventional	Unconventional
Biodiversity	Direct loss and/or fragmentation of habitat from construction and operation of well site and well pad activities	x	x
	Indirect impacts on habitats/species due to, for example, disturbance from noise, human presence and light pollution and the introduction of invasive species and the exposure to pollution through causal pathways	x	x
Land Use and Geology	Land requirements for pad and pipelines, disruption to soil layers and compaction and resulting impacts on removal of land for alternative uses (natural or anthropogenic) and ecology/ environment impacts	x	x
	Induced seismicity from hydraulic fracturing activities and the potential impact on well integrity, creation of geological pathways for pollutants and possible minor earth tremors	x (in limited circumstance)	x
Water Resources	Surface spillage of pollutans such as diesel and drilling fluids and silt-laden run-off resulting in surface water pollution	x	x
	Surface spillage of hydraulic fracturing fluids and wastewaters resulting in surface water pollution		x
	Well failure resulting in pollutants released from the well to groundwaters	x	x
	Introduction of pollutants due to induced fractures providing pathways to groundwater resources through either pre-existing man-made or natural structures		x
	Inappropriate selection of chemicals in hydraulic fracturing and/or unsuitable assessment leading to unacceptable risks to the environment from releases		x
	Water consumption associated with hydraulic fracturing activities affecting the availability of water resources, aquatic habitats and ecosystems and water quality		x
	Well pad development at risk of flooding and/or resulting in increased flood risk off site due to increase in impermeable area and/or location of facilities in areas of flood risk	x	x
Air Quality	Emissions to air from well pad construction and drilling resulting in adverse local air quality impacts	x	x
	Emissions associated with hydraulic fracturing activities resulting in adverse local air quality impacts		x
Climate Change	Greenhouse gas (GHG) emissions from well pad construction and drilling	x	x
	GHG emissions associated with hydraulic fracturing activities		x
	GHG emissions arising from well completion	x	x
	Fugitive GHG emissions	x	x
	Combustion of extracted hydrocarbons generating GHG emissions	x	x
Waste Arisings	Generation of construction and drilling wastes	x	x
	Generation of flowback water following hydraulic fracturing activities		x
Cultural Heritage	Direct loss of or damage to cultural heritage features and landscapes from construction of well pad and associated infrastructure	x	x
	Indirect effects on the setting of cultural heritage assets as a result of the well pad construction and operation	x	x
Landscape	Impacts and landscape character and visual amenity due to well pad construction and operation activities	x	x
Human Health	Emission to air, dust and noise associated with construction and drilling activities resulting in adverse impacts on nearby receptors	x	x

Source: Amec Foster Wheeler (2015).

Shale gas discussion in Brazil

Despite hydraulic fracturing and horizontal drilling technologies have reached a robust development level and being covered by a multitude of safety and quality measures specific to the shale gas activity, uncertainty[1] and risks still remain unanswered in countries such as Brazil, without a proper assessment to sedimentary basins and respective impacts. By the end of 2013, the 12th ANP Bid Round was organized and oriented to this matter, with great expectations for knowledge building around unexplored basins (PROMINP/CTMA, 2016). However, the

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[1] Notwithstanding the importance of scientific uncertainties, these are not stressed through the paper. To reach some of the uncertainties discussed in the peer-reviewed and nonpeer-reviewed literature, see Kaden; Rose (2016) cited on the References.

bid's aftermath put Brazil's shale gas development contracts under moratorium and banning, frustrating federal government plans to explore and exploit at least 26 underdeveloped wells in five years (PROMINP/CTMA, 2016; Miranda, 2018).

Furthermore, the absence of basic parameters for environmental safety and protection fueled an already uncertainty and risk-filled scenario. A response to this matter arrived later on with the ANP Resolution n. 21/2014 and the Decreet n. 8437/2015 which, though belatedly, set the unconventional resources essential guidelines in Brazil (Miranda, 2018). Yet described as a risk management guide to human health and the environment, the Federal Public Ministry required further evidence and requested an Environmental Assessment of the Sedimentary Area, as defined in Ordinance 198/2012, to resume any discussion regarding unconventional exploration activities (Amec Foster Wheeler, 2015).

As such, the precautionary principle played a leading role among several public civic actions (PCA) in the State level, nullifying unconventional resources production and indicating an urgent need for a comprehensive environmental assessment before any decision making (Miranda, 2018). Though perceived as a slow down to shale gas development, Jasanoff (2015) underlines the precautionary principle as a means of adopting best available practices rather than a state of paralysis or inaction. Wolfrum (2004) complements that, once the best technology is applied, the precautionary principle contributes to technological development.

The Constitution of the Federative Republic of Brazil (1988) does not explicitly mention the aforementioned principle, nonetheless, it is extractable from the supreme law. Miranda (2018) emphasizes the precautionary principle use in a plethora of legal instruments, including a climate policy norm, indicating an inner connection with environmental aspects for energy policy. The author reinforces the precautionary principle's adoption in Public Administration within the proportionality boundaries, even facing a potential freedom and rights limitation, in order to act toward the environmental conservation and population's well-being (Article 225).

Also referring to the Brazilian Constitution, Machado (2014) cites the Article 37 to underscore the consequences of not adopting the precautionary principle in face of potential risks, which could lead to administrative morality and legality violation, as well as withdrawing popular participation in decision-making processes would contradict the publicity and impersonality principles.

By analyzing the application of the precautionary principle to the case of unconventional resources and fracturing in Brazil, the assumptions of application of the principle were confirmed, but not all the consequences of the precaution were considered. Though it is possible to find similarities in the conventional oil and gas exploitation with regards to impacts, one may not guarantee its resemblance to the magnitude yet to be discussed among unconventional resources.

In addition, general principles of the precautionary principle were not sufficiently contemplated as follows: (i) a tool for risk management and planning; (ii) proportionality; (iii) an adequate analysis of costs and benefits; and (iv) an adequate and sufficient participation in decision-making process. That said, judging by the jurisprudence observed in related cases in the Brazilian Supreme Court of Justice and Supreme Federal Court, Miranda (2018) understands that, if once reaching a higher judiciary instance, both courts would sustain the aforementioned insufficiency of measures taken and, therefore, maintain the bid contracts nullification.

Standardization as key to precautionary principle handling in Brazil

Standards are the outcome of a co-operative process and agreement among the participants of technical committees (TC's), ideally representing the interests of various stakeholders (Tassey, 2000; DTI, 2005). The standards' application is voluntary and organized by a range of long-term representatives, either worldwide or regional, such as ISO (International Organization for Standardization), API (American Petroleum Institute), and ABNT (Brazilian Association of Technical Standards).

By using a common language among interested parties, standards are a set of valuable tools for societal, environmental, and economic transformation and innovation. While standardization often focus on technical and economic aspects, consumer and environmental protection requirements are becoming more relevant. For instance, the ISO 14000 series provide managerial means for companies and organizations to address environmental responsibilities, also reflecting on policy goals achievement (CEN/CENELEC, 2020).

According to API (2020), standards and technical regulations are essential drivers of economic growth, technology development, and global trade in a modern economy. Moreover, regulations may benefit from standards to build their very basis, hence, evolving from a previous in-depth discussion and leading it to a national policy. Standards can provide better compatibility for products and services, also quality enhancement, variety reduction (thus, allowing economies of scale) and, generally speaking, promote understanding of technology by providing information (Tassey, 2000; DTI, 2005; Espinal et al., 2013; CEN/CENELEC, 2020). A common standpoint for the energy sector is additionally shared: industry standards play a critical role in the development of markets and global spread of technologies and products to enhance environmental, health, safety, and sustainability performance.

A relationship of standards as key to productivity, thus, to economic growth is not likely to be obvious and arguably seen to hinder the process of innovation. The DTI (2005) report, however, emphasizes that the extent to which standards help or constrain innovation in a particular enterprise is strongly related to a multitude of characteristics of the enterprise, not depending solely on the condition of the standard on its own. For instance, enterprises whose main market is local or regional tend to see standards as constraining, whereas a national or international market-oriented enterprise would underpin standards as competitiveness factor.

Moreover, the DTI (2005) report mentions different influence of median age and total number of standards, with regard to perceived effects on innovation. New standards may in principle be the ideal, but may not be fully effective until broadly diffused, while old ones tend to be ineffective. In this sense, Swann (2000) argues that the first locks the innovator into legacy systems; and the latter because it challenges the innovator. Also, a sector with only a handful of standards might not perform well, similar to those with excessive ones. Therefore, an optimum set of both variables is sought, which may lead to an intermediate age or number of standards.

This information may be reflected on the shale gas development in Brazil, which infancy stage takes time to evolve and ameliorate a standards portfolio before reaching a higher level, as seen in the U.S. and China. Both countries stand in the forefront with regard to shale gas-related standards, which were established as soon as a national commitment to develop this market was settled. Regarding structural and contextual divergences among these countries, the following standards may serve as best practices reference, but Brazil's standards portfolio must reflect its own raised concerns and specific regulatory thresholds. According to Amec Foster Wheeler (2015), there is an undoubted opportunity to Brazil capitalize on the studies and experience of regulators and policy makers in Europe and elsewhere to identify the key effects arising from HF and develop measures necessary to minimize risks. Lozano-Maya (2016) reinforces the benchmark as knowledge source to design transferable policies and also to avoid negative examples and major risks dealt in previous experiences.

Tables 2 and 3 refer to the API safety standards specifically addressing risk management issues attributed to shale gas well construction, supported by a set of technical standards initially placed for conventional oil and gas exploitation but additionally shared with unconventional resources[1]. As to risks, one of the precautionary principle's foundations, the Brazilian ANP Resolution n. 21/2014 could be improved based on the following standards, providing a comprehensive description of each technique and procedure (PROMINP, 2016).

Table 2. The U.S. upstream technical standards set for shale gas production

	S/N	API Standard	Standard description	Release year
Shale gas Fracking-related API standards	1	API HF1	Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines	2009
	2	API HF2	Water Management Associated with Hydraulic Fracturing	2010
	3	API HF3	Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing	2011
	4	API RP 51R	Environmental Protection for Onshore Oil and Gas Production Operations and Leases	2009
	5	API Std 65-2	Isolating Potential Flow Zones During Well Construction	2010

	S/N	API Standard	Standard name	Release year
Additional API Upstream Safety Standards	1	Spec 14A	Subsurface Safety Valve Equipment	1973
	2	RP 14B	Design, Installation, Operation, Test, and Redress of Subsurface Safety Valve Systems	1973
	3	RP 14C	Analysis, Design, Installation, and Testing of Safety Systems for Offshore Production Facilities	1975
	4	RP 14G	Fire Prevention and Control on Fixed Open-Type Offshore Production Platforms	1978
	5	RP 14J	Design and Hazards Analysis for Offshore Production Facilities	1993
	6	Spec 16A	Drill-through Equipment	1986
	7	Std 16AR	Repair and Remanufacture of Drill-Through Equipment	2017
	8	Spec 16C	Choke and Kill Equipment	1993
	9	Spec 16D	Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment	1993
	10	Std 18LCM	Product Life Cycle Management System Requirements for the Petroleum and Natural Gas Industries	2017
	11	RP 49	Drilling and Well Servicing Operations Involving Hydrogen Sulfide	1974
	12	Std 53	Blowout Prevention Equipment Systems for Drilling Wells	2012
	13	RP 54	Occupational Safety for Oil and Gas Well Drilling and Servicing Operations	1981
	14	RP 55	Oil and Gas Producing and Gas Processing Plant Operations Involving Hydrogen Sulfide	1983
	15	RP 59	Well Control Operations	1987
	16	RP 64	Diverter Equipment Systems	1991
	17	RP 67	Oilfield Explosives Safety	1992
	18	RP 74	Occupational Safety for Onshore Oil and Gas Production Operation	2001
	19	RP 75	Development of a Safety and Environmental Management Program for Offshore Operations and Facilities	1993
	20	Bull 75L	Development of a Safety and Environmental Management System for Onshore Oil and Natural Gas Production Operation and Associated Activities	2007
	21	RP 76	Contractor Safety Management for Oil and Gas Drilling and Production Operations	2004
	22	RP 90	Annular Casing Pressure Management for Offshore Wells	2006
	23	RP 90-2	Annular Casing Pressure Management for Onshore Wells	2016
	24	RP 96	Deepwater Well Design and Construction	2013
	25	Bull 97	Well Construction Interface Document Guidelines	2013
	26	RP 98	Personal Protective Equipment Selection for Oil Spill Responders	2013
	27	RP 99	Flash Fire Risk Assessment for the Upstream Oil and Gas Industry	2014
	28	Bull E2	Management of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Production	1992

Source: based on API (2012), IHS Markit (2021).

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[1] For a detailed list of ISO TC67 (Materials, equipment, and offshore structures for petroleum, petrochemical, and natural gas industries) standards and their status with API, CEN and various regional and national standards developing organizations, see ISO (2020) cited on References.

Table 3. Overview of API industry standards relating to hydraulic fracturing (HF)[1]

API Standard	Standard description	Main points	Release year
API RP 100-1	Hydraulic Fracturing – Well Integrity and Fracture Containment	Highlights practices for onshore well construction and fracture stimulation design and execution relating to well integrity and fracturing containment. Identifies actions to protect and isolate useable quality groundwater through application of appropriate barriers and controlled fracture design and execution practices.	2015
API RP 100-2	Managing Environmental Aspects Associated with Exploration and Production Operations Including Hydraulic Fracturing	Provides proven practices applicable for the planning and operation of wells, including hydraulic fracturing. It includes topics on managing environmental aspects during site planning; site selection; logistics; mobilization; rig up and demobilization; and stimulation operations.	2015
API Bulletin 100-3	Community Engagement Guidelines	Outlines what local communities and other key stakeholders can expect from operations. It is designed to acknowledge challenges and impacts that can occur and provides flexible and adaptive strategies for managing expectations and engaging with the community.	2014
API RP 51R	Environmental Protection for Onshore Oil and Gas Production Operations and Leases	Provides environmentally sound practices for domestic onshore oil and gas production operations, including fracturing. Applies to all production facilities, including produced water handling facilities. Operational coverage begins with the design and construction of access roads and well locations, and includes reclamation, abandonment, and restoration operations.	2009
API Std 65-2	Isolating Potential Flow Zones During Well Construction	Helps ensure the well is properly designed and constructed to contain the hydrocarbons through the wellbore and isolate them from ground water aquifers. This is accomplished through the use of casing, cement, and mechanical barriers. Includes information on industry cementing practices. A well-designed cement job optimizes cement placement through considerations such as laboratory tested slurry design, honoring pore pressure/fracture gradient window, use of spacers/pre-flushes, proper density and rheological hierarchy, fluid compatibility and adequate centralization.	2010

Source: based on API (2019).

A closer look to the release year reinforces the importance and urgent need for standards elaboration in early stages of development, as of 2009 with the 'shale boom' in the U.S. In general, early shale gas development presents more intricate technical and operational challenges, with higher economic costs and lower profitability margins (Lozano-Maya, 2016). Notwithstanding these challenges, Swann (2000) stands that, depending on the context, the publication of a standard creates a more 'credible' broadcast effect, or substantially increases the rate of interaction between the potential adopter population. Arguably, this may ease the social tension caused by shale gas production impacts. Also, as DTI (2005) states, the potential impact of a standard is even greater at early stages of innovation, surrounded by several competing technologies and standard setting deals with initial uncertainties, which are core to the precautionary principle application.

According to Gao et al. (2021), though not reached the break-even point, the successful practice of shale gas development in China relies on few factors: a thorough understanding of geological characteristics and innovation in engineering technology, combined with policy incentives. At first glance, similarities to the U.S model are immediate. Indeed, both countries share common knowledge devoted to shale gas since 2005, which has led to a recent soaring production curve and self-innovation stance in China. However, the Chinese shale gas practices are entirely different, including geological characteristics, mining rights management systems, and market mechanisms, pushing China (also Brazil) to develop its own development model (Mei et al. 2022; Wei et al., 2019).

Established in August 2013, the Shale Gas Standardization Technical Committee (SGSTC) coordinated the rapid development of shale gas standardization in China to support its industry needs (Yue et al, 2020). Table 4 highlights the construction and prospect of China's shale gas technical standard system, which is planned to encompass 114 shale gas standards in 2025, also adopting 1,599 existing conventional natural gas standards (CSCSG, 2019).

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[1] API HF1, API HF2 and API HF3 standards were further replaced, as shown in Table 3.

Table 4. China's technical standards set for shale gas value chain

	S/N	Standard No.	Standard name	Release year
Geological evaluation	1	GB/T 34533-2017	Determination of Shale Porosity by the Helium Method and Permeability by the Pulse Attenuation Method	2017
	2	GB/T 35110-2017	Target Optimization Methods for Marine Shale Gas Exploration	2017
	3	GB/T 35206-2017	Identification of Shale and Mudstone Rock Thin Sections	2017
	4	GB/T 35210.1–2017	Methane Isotherm Adsorption/Desorption Determination of Shale Part 1: Volumetric Method	2017
	5	SY/T 6940-2013	Method for Measuring Shale Gas Content	2013
	6	NB/T 14007-2015	Technical Specifications for Shale Gas Resource Evaluation	2015
	7	NB/T 14008-2015	Determination of Total Pore Size Distribution of Shale by Mercury Injection–Adsorption Combined Method	2015
	8	NB/T 10117-2018	Methane Isotherm Adsorption Determination of Shale– Gravimetric Method	2018
	9	NB/T 10118-2018	Recommended Practices for Coring And Sampling in Shale Gas Wells	2018
	10	NB/T 10122-2018	X-Ray CT Scanning and Imaging Methods of Shale	2018
Seismic and logging	1	SY/T 6994-2014	Shale Gas Logging Data Processing and Interpretation Specifications	2014
	2	NB/T 14011-2016	Technical Specifications for Shale Gas Seismic Data Processing, Interpretation and Prediction	2016
Gas reservoir development	1	GB/T 34163-2017	Technical Specifications of Development Plan for Shale Gas	2017
	2	NB/T 14001-2015	Technical Specifications for Shale Gas Reservoir Description	2015
	3	NB/T 14005-2016	Specifications for Shale Gas Development Conceptual Design Compilation	2016
	4	NB/T 14013-2016	Specifications for Well Test Interpretation of Shale Gas Well Production Data	2016
	5	NB/T 14014-2016	Technical Specifications for Gas Testing of Shale Gas Wells	2016
	6	NB/T 14015-2016	Technical Specifications for Shale Gas Development Dynamic Analysis	2016
	7	NB/T 14016-2016	Technical Requirements for Shale Gas Development Evaluation Data Admission	2016
	8	NB/T 14024-2017	Technical Specifications for Shale Gas Well Production Prediction	2017
	9	NB/T 14025-2017	Technical Specifications for Shale Gas Well Testing	2017
	10	NB/T 10119-2018	Technical Requirements for Preparation of Shale Gas Test Production Plan	2018
Drilling & completion	1	GB/T 14004.1–2015	Shale Gas Cementing Engineering Part 1: Technical Specifications	2015
	2	NB/T 14004.2–2016	Shale Gas Cementing Engineering Part 2: Technical Requirements and Evaluation Methods of Cement Slurry	2016
	3	NB/T 14004.3–2016	Shale Gas Cementing Engineering Part 3: Quality Supervision and Acceptance Requirements and Methods	2016
	4	NB/T 14009-2016	Shale Gas Recommended Practice for Drilling Fluids: Oil-Based Drilling Fluids	2016
	5	NB/T 14010-2016	Recommended Practices for Safe Drilling and Wellbore Quality Control of Horizontal Wells in Shale Gas Cluster Well Groups	2016
	6	NB/T 14012.2–2016	Recommended Practices for Shale Gas Factory-Like Operation Part 2: Drilling	2016
	7	NB/T 14017-2016	Technical Specifications for Shale Gas Logging	2016
	8	NB/T 14018-2016	Technical Requirements for Shale Gas Horizontal Well Location Design	2016
	9	NB/T 14019-2016	Recommended Practices for Drilling Engineering Design of Shale Gas Horizontal Wells	2016
	10	NB/T 14021-2017	Operation Requirements of Civil Engineering Before Drilling for Shale Gas Platform	2017
	11	NB/T 14026-2017	Technical Requirements for Geosteering in Horizontal Shale Gas Wells	2017
	12	NB/T 10121-2018	Evaluation Method of Inhibitive Behavior of Drilling Fluid to Shale	2018
Reservoir stimulation	1	GB/T 14002.1–2015	Shale Gas Reservoir Stimulation Part 1: Fracturing Design	2015
	2	NB/T 14002.3–2015	Shale Gas Reservoir Stimulation Part 3: Fracturing Flowback Fluid Recovery and Treatment Methods	2015
	3	NB/T 14002.4–2015	Shale Gas Reservoir Stimulation Part 4: Recommended Practices for Horizontal Well Pumping Bridge Plug-Perforation Combined Technology	2015
	4	NB/T 14003.1–2015	Shale Gas Fracturing Fluid Part 1: Slickwater Performance Index and Evaluation Method	2015
	5	NB/T 14002.5–2016	Shale Gas Reservoir Stimulation Part 5: Requirements for Drilling and Grinding Bridge Plugs in Horizontal Wells	2016
	6	NB/T 14002.6–2016	Shale Gas Reservoir Stimulation Part 6: Requirements for Cluster Perforation of Horizontal Wells	2016
	7	NB/T 14003.2–2016	Shale Gas Fracturing Fluid Part 2: Performance Index and Test Method of Drag Reducer	2016
	8	NB/T 14002.2–2017	Shale Gas Reservoir Renovation Part 2: Technical Specifications for Factory-Like Fracturing Operations	2017
	9	NB/T 14003.3–2017	Shale Gas Fracturing Fluid Part 3: Performance Indicators and Evaluation Methods of Continuous Mixed Fracturing Fluid	2017
	10	NB/T 14020.1–2017	Shale Gas Tools and Equipment Part 1: Composite Bridge Plug	2017
	11	NB/T 14022-2017	Recommended Practice for Evaluation of Water Sensitivity of Shale Core Working Fluid	2017
	12	NB/T 14023-2017	Recommended Method for Determining Long-Term Conductivity of Shale Proppant Packs	2017
	13	NB/T 10120-2018	Recommended Method for Measuring Conductivity of Shale Gas Self-Supporting Fractures	2018
Safe & clean production	1	NB/T 14006-2015	Specifications for Design of Shale Gas Gathering and Transportation System	2015
	2	NB/T 10116-2018	Recommended Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing	2018

Source: Yue et al. (2020).

Yue et al. (2020) also mentioned perceived benefits resulting from the standards application in China, which include a favorable selection of shale distribution areas in the Sichuan Basin; lesser errors in seismic-based prediction of shale gas reservoir depth; preparation of development plans for several areas; reduction of average drilling period in demonstration zones; increase in drilling rate and cement quality; higher operating efficiency and quality of fracturing operations; and optimized flowback fluid recycling rate.

Compared to the U.S and China, some of the hazardous chemical products commonly used in HF are still not categorized in IBAMA's Normative Instruction n. 6[1] (PROMINP, 2016), which may lead to insecurity regarding potential spills and water contamination in Brazil. To this matter, Patterson et al. (2017) comments that enhanced and standardized regulatory requirements for reporting spills could improve the accuracy and speed of analyses to identify and prevent spill risks and mitigate potential environmental damage. Good construction standards and practices are important for minimizing potential impacts on both surface water and groundwater. Moreover, proper monitoring and maintenance (i.e., avoiding overfilling, maintaining the integrity of liners and berms) are also important for protecting surface water and groundwater (U.S EPA, 2016).

Conclusions

By presenting benchmarked technical standards applied in successful experiences related to shale gas, this paper finds reasonable arguments to resume unconventional resources debate in Brazil, specifically to address shale gas risk matters.

In order to improve ANP Resolution n. 21/2014 content based on shale gas standards, further discussion may be conducted by ABNT (Brazilian Association of Technical Standards) within a specific technical committee mirrored from ISO, API and CSCSG, amplifying the possibilities of better decision-making with regard to shale gas development in Brazil. Additionally, while ABNT promotes an open dialogue among

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[1] IBAMA: Brazilian Institute of Environment

stakeholders concerning applicable mitigating solutions for the shale gas case, best practices adopted by the U.S and China would contribute to a better uptake in due course in Brazil.

For future research, the authors recommend an orderly risk management supported by specific standards that may induce a precautionary principle ease. Moreover, additional geology studies regarding sedimentary basins in Brazil are strongly advised to avoid continued scientific uncertainties.

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