WORLD RESOURCES INSTITUTE

GLOBAL SHALE GAS DEVELOPMENT

Water Availability and Business Risks

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FOREWORD

For many nations around the world, shale gas represents an opportunity to strengthen energy security while cutting emissions. In fact, shale gas adds 47 percent to the world's natural gas reserves. But as governments and businesses explore this new and abundant resource, freshwater availability is a key challenge they must address. In this study WRI provides unprecedented global information on freshwater availability for governments and businesses considering shale development.

Extracting oil or natural gas from shale poses a number of risks to the environment and requires large quantities of nearby water. Much of this water is needed for fracturing the shale to allow hydrocarbons to flow to the surface. Yet shale resources are not always located where water is abundant. Our analysis shows that China, India, South Africa, and Mexico, for example, have large quantities of shale gas but limited supplies of freshwater. It also shows that roughly 38 percent of the area where shale resources are located is arid or under significant water stress; plus, 386 million people live above these areas. These factors pose significant social, environmental, and financial challenges to accessing water and could limit shale development.

With growing energy demands and attractive financial and employment opportunities for hydrocarbon development, how can regulators and companies determine if enough freshwater exists in a given area to extract natural gas and oil from shale while not degrading the environment?

This report draws on WRI's Aqueduct Water Risk Atlas to identify the key locations, globally and with a special focus on 11 countries, where shale gas and tight oil extraction might face the greatest water challenges. In these areas government policies will be needed to guarantee water security, protect the environment, and avoid business risks, if shale energy is developed.

With interest in shale gas growing, the time is ripe to understand its constraints. This report will be an invaluable resource to businesses, policymakers, and civil society in ensuring water for people and the planet.

Andrew Steer
President
World Resources Institute

EXECUTIVE SUMMARY

Limited availability of freshwater could become a stumbling block for rapid development of shale resources through hydraulic fracturing. Using information from the Aqueduct Water Risk Atlas, WRI provides the first global and country-specific resource to help stakeholders evaluate freshwater availability across shale plays worldwide.

Innovation in hydraulic fracturing and horizontal drilling techniques is driving the rapid development of shale resources (which include shale gas, natural gas liquids, and tight oil) across the United States and Canada.[1] Already, known shale deposits worldwide have significantly increased the volume of the world's natural gas and oil resources. Governments from Argentina and the United Kingdom, to Mexico and China, have started to explore the commercial viability of their shale reserves.

The potential for expansion is huge: known shale gas deposits worldwide add 47 percent to the global technically recoverable natural gas resources, and underground stores of tight oil add 11 percent to the world's technically recoverable oil.

But as countries escalate their shale exploration, limited availability of freshwater could become a stumbling block. Extracting shale resources requires large amounts of water for drilling and hydraulic fracturing. In most cases, these demands are met by freshwater, making companies developing shale significant users and managers of water at local and regional levels, often in competition with farms, households, and other industries.

Although experts agree that critical environmental risks and impacts are associated with developing shale, the risks and impacts specific to surface and groundwater availability have been thinly documented. With *Global Shale Gas Development: Water Availability and Business Risks*, the World Resources Institute (WRI) fills this gap, providing the first publicly available, global and country-specific analysis to help evaluate freshwater availability across shale resources worldwide. Using geospatial analysis to combine indicators from WRI's Aqueduct Water Risk Atlas and other sources (Table ES1) with the locations of shale resources globally from West Virginia University and the National Energy Technology Laboratory, the report:

- Identifies locations most in need of government oversight and robust corporate policies to properly manage freshwater availability in the context of shale development; and

- Informs companies of potential business risks associated with freshwater availability, and builds the case for corporate water stewardship and early source water assessment.

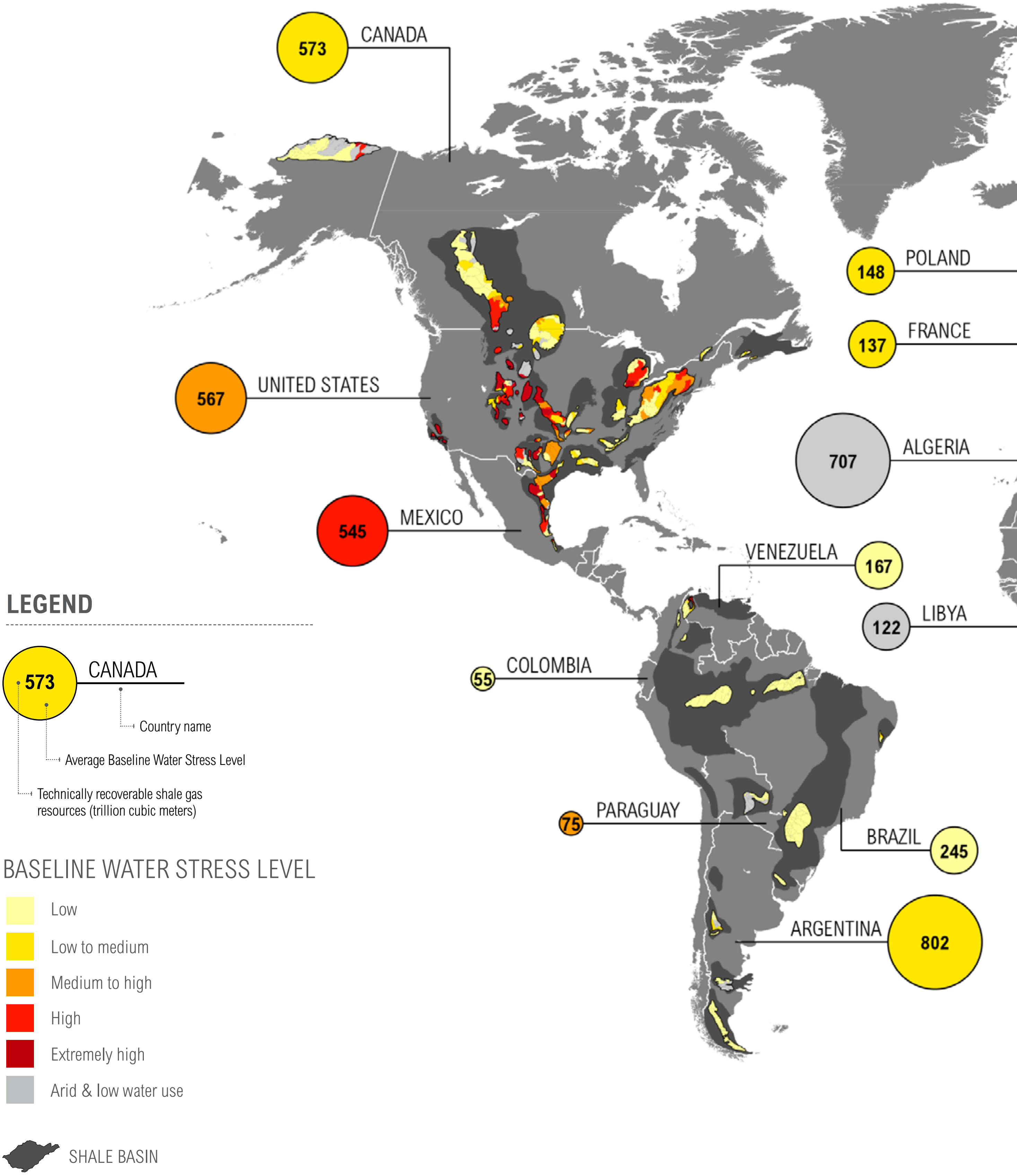
In addition to examining water availability and shale resource development from a global perspective (Figure ES1), this report analyzes for the first time water availability in each shale play (prospective areas within the shale formation where gas and oil could be commercially extracted) for 11 countries: Algeria, Argentina, Australia, Canada, China, Mexico, Poland, Saudi Arabia, South Africa, the United Kingdom, and the United States. WRI selected these countries based on the size of their technically recoverable shale resources (as estimated by the U.S. Energy Information Administration), current exploratory and production activity, likelihood of future development, and feedback from industry, academia, and nongovernmental organization (NGO) experts.

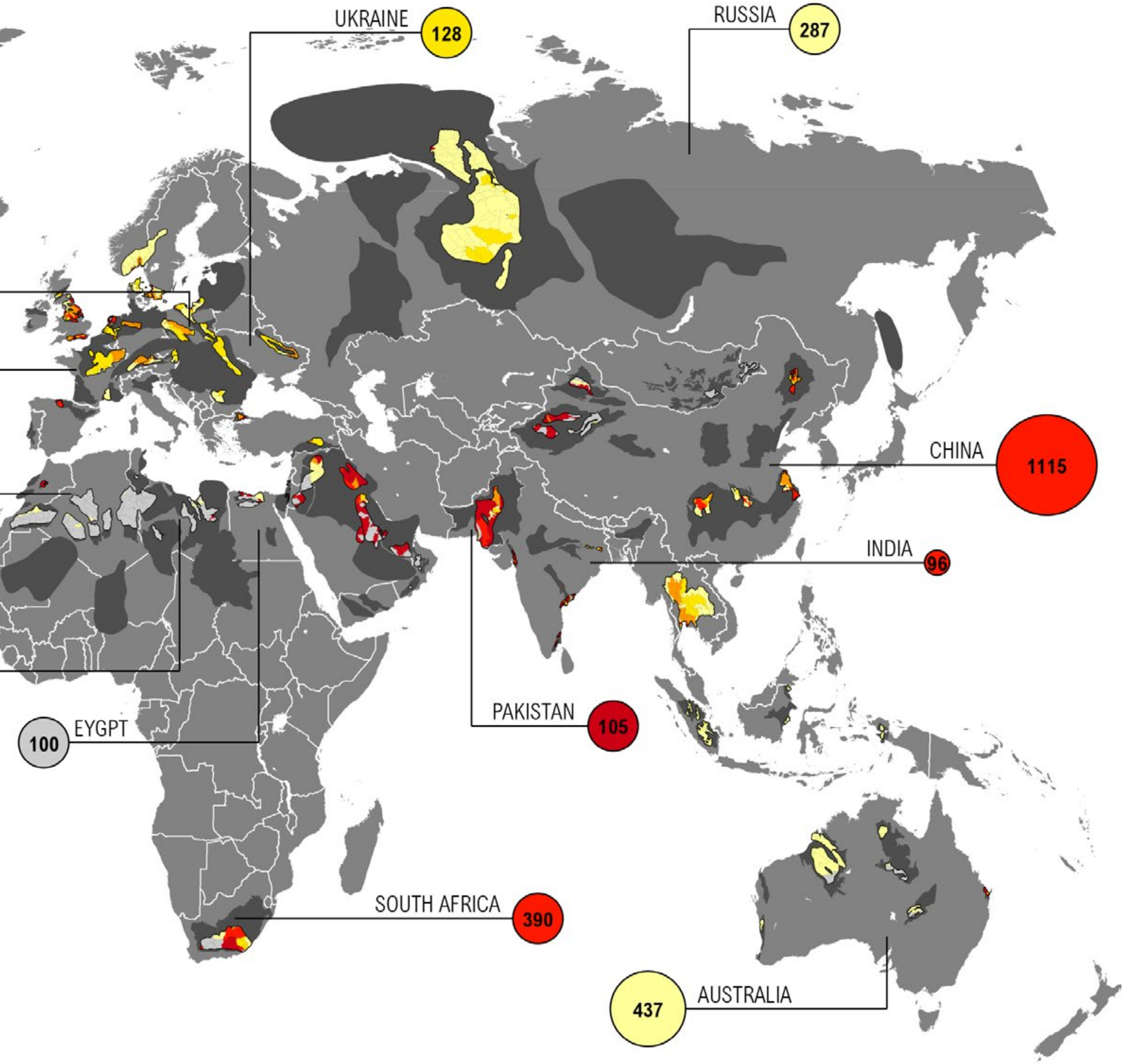
Table ES1 | **Indicators Selected to Evaluate Freshwater Availability and Associated Business Risks**

INDICATOR	DEFINITION
Baseline water stress	The ratio of total water withdrawals from municipal, industrial, and agricultural users relative to the available renewable surface water. Higher values may indicate more competition among users and greater depletion of water resources.
Seasonal variability	The variation in water supply between months of the year. Higher values indicate more variation in water supply within a given year, leading to situations of temporary depletion or excess of water.
Drought severity	The average length of droughts multiplied by the dryness of the droughts from 1901 to 2008. Higher values indicate areas subject to periods of more severe drought.
Groundwater stress	The ratio of groundwater withdrawal to its recharge rate over a given aquifer. Values above one indicate where unsustainable groundwater consumption could impact groundwater availability and groundwater-dependent ecosystems.
Dominant water user	The sector (agricultural, municipal, or industrial) with the largest annual water withdrawals.
Population density	The average number of people per square kilometer.
Reserve depth interval	The range of depths of the prospective shale area. Deeper formations generally require more water for drilling.

This report does not attempt to identify or address risks to water quality associated with the development of shale resources. Nor does it assess the performance of the oil and gas industry in managing water. Instead, it aims to share information that can help increase the dialog among water users from industry, government, and civil society in river basins worldwide. The report results are available online (http://www.wri.org/resources/maps/water-for-shale), providing open access to the underlying information and enabling updates as new data are made available.

Figure ES1 | **Location of World's Shale Plays, Volume of Technically Recoverable Shale Gas in the 20 Countries with the Largest Resources, and the Level of Baseline Water Stress**





Notes
1. Colored polygons are areas that have been identified as shale plays: shale deposits that are viable for commercial production.
2. Dark grey polygons are shale basins. While shale plays fall within basins, other shale resources within basins may not be commercially viable.
3. Circle size denotes the country's total technically recoverable shale gas resources (trillion cubic meters).
4. Circle color denotes the area-weighted average of baseline water stress levels over all shale plays within a country. If more than half of the country's shale play area is in arid and low water use regions, the circle is colored in light grey.

Sources: Location of world's shale basins and plays from West Virginia University and The National Energy Technology Laboratory. Estimates of total technically recoverable shale gas resources from the U.S. Energy Information Administration. Estimates of baseline water stress from WRI's Aqueduct Water Risk Atlas.

Key findings

Shale resources are unevenly distributed worldwide and, for the most part, not located where freshwater is abundant. For example, China, Mexico (Figure ES2), and South Africa have some of the largest technically recoverable shale gas resources (based on estimates from the U.S. Energy Information Administration), but face high to extremely high water stress where the shale is located.

This report reveals that lack of water availability could curtail shale development in many places around the world:

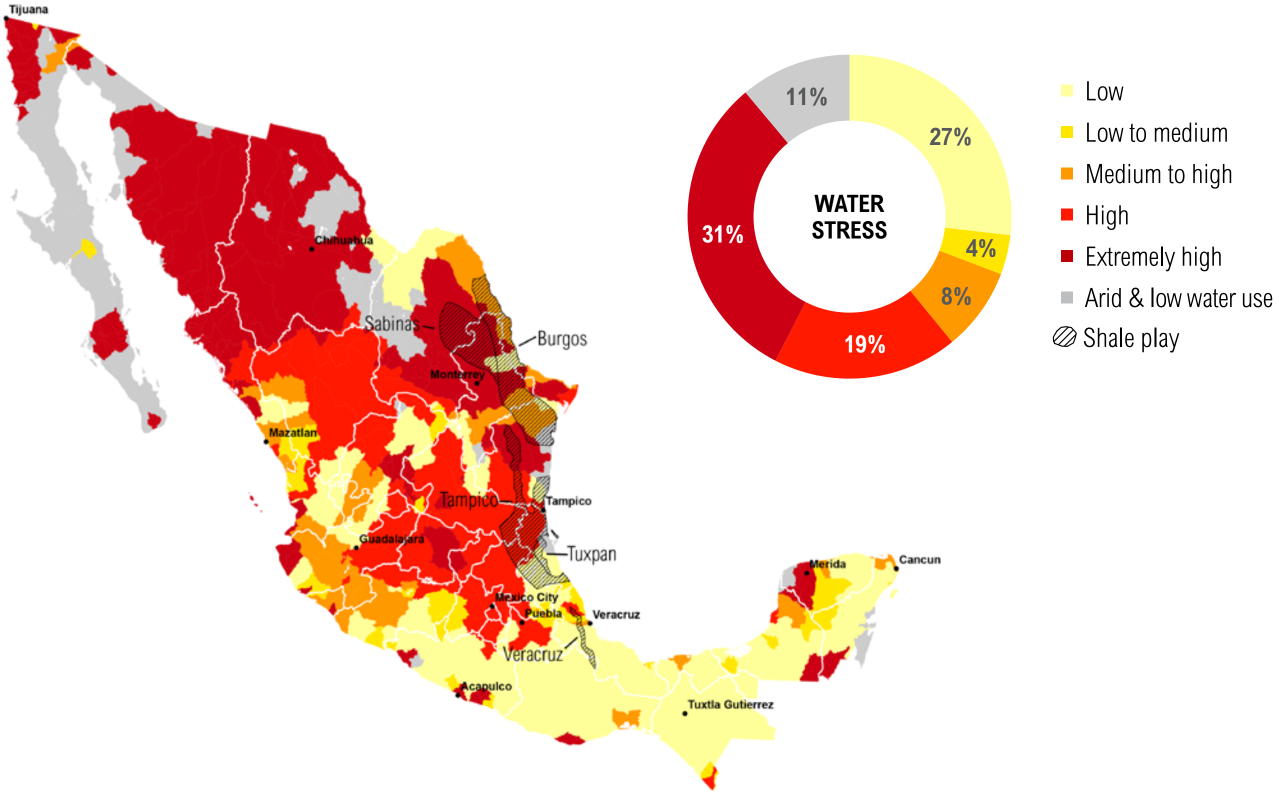
- 38 percent of shale resources are in areas that are either arid or under high to extremely high levels of water stress;
- 19 percent are in areas of high or extremely high seasonal variability; and
- 15 percent are in locations exposed to high or extremely high drought severity.

Furthermore, 386 million people live on the land over these shale plays, and in 40 percent of the shale plays, irrigated agriculture is the largest water user. Thus drilling and hydraulic fracturing often compete with other demands for freshwater, which can result in conflicts with other water users. This is particularly true in areas of high baseline water stress, where over 40 percent of the available water supplies are already being withdrawn for agricultural, municipal, or industrial purposes.

The 20 countries with the largest shale gas or tight oil resources that are recoverable using currently available technology are shown in Table ES2.

- Eight of the top 20 countries with the largest shale gas resources[2] face arid conditions or high to extremely high baseline water stress where the shale resources are located; this includes China, Algeria, Mexico, South Africa, Libya, Pakistan, Egypt, and India.

Figure ES2 | **Mexico's Shale Plays Often Overlap with Areas with High Baseline Water Stress**



Sources: Location of shale plays from West Virginia University and The National Energy Technology Laboratory. Estimates of baseline water stress from WRI's Aqueduct Water Risk Atlas.

Table ES2 | Average Exposure to Water Stress across Shale Plays

A. TWENTY COUNTRIES WITH THE LARGEST TECHNICALLY RECOVERABLE SHALE GAS RESOURCES

RANK[a]	COUNTRY	AVERAGE EXPOSURE TO WATER STRESS OVER SHALE PLAY AREA
1	China	High
2	Argentina	Low to Medium
3	Algeria	Arid & Low Water Use
4	Canada	Low to Medium
5	United States	Medium to High
6	Mexico	High
7	Australia	Low
8	South Africa	High
9	Russian Federation	Low
10	Brazil	Low
11	Venezuela	Low
12	Poland	Low to Medium
13	France	Low to Medium
14	Ukraine	Low to Medium
15	Libya	Arid & Low Water Use
16	Pakistan	Extremely High
17	Egypt, Arab Rep.	Arid & Low Water Use
18	India	High
19	Paraguay	Medium to High
20	Colombia	Low

a. Based on size of estimated shale gas technically recoverable resources

B. TWENTY COUNTRIES WITH THE LARGEST TECHNICALLY RECOVERABLE TIGHT OIL RESOURCES

RANK[a]	COUNTRY	AVERAGE EXPOSURE TO WATER STRESS OVER SHALE PLAY AREA
1	Russian Federation	Low
2	United States	Medium to High
3	China	High
4	Argentina	Low to Medium
5	Libya	Arid & Low Water Use
6	Australia	Low
7	Venezuela, RB	Low
8	Mexico	High
9	Pakistan	Extremely High
10	Canada	Low to Medium
11	Indonesia	Low
12	Colombia	Low
13	Algeria	Arid & Low Water Use
14	Brazil	Low
15	Turkey	Medium to High
16	Egypt, Arab Rep.	Arid & Low Water Use
17	India	High
18	Paraguay	Medium to High
19	Mongolia	Extremely High
20	Poland	Low to Medium

a. Based on size of estimated tight oil technically recoverable resources

Sources: Estimates of total technically recoverable shale gas and tight oil resources from the U.S. Energy Information Administration. Estimates of baseline water stress from WRI's Aqueduct Water Risk Atlas.

- Eight of the top 20 countries with the largest tight oil resources[3] face arid conditions or high to extremely high baseline water stress where the shale resources are located; this includes China, Libya, Mexico, Pakistan, Algeria, Egypt, India, and Mongolia.

Hydrological conditions vary spatially and seasonally across shale plays, with variation among plays, within plays, and throughout the year. This variation makes companies' ability to meet the freshwater demands for hydraulic fracturing and drilling highly unpredictable, and estimates based on previous experience not always accurate in new shale formations. This high level of uncertainty can lead to business risks for companies exploring new areas for development. Furthermore, public concern over increased competition and impacts on freshwater availability can threaten a company's social license to operate and lead to changes in government regulations that could impact both short- and long-term investments.

WRI's findings indicate that companies developing shale resources internationally are likely to face serious challenges to accessing freshwater in many parts of the world. These challenges highlight a strong business case for strategic company engagement in sustainable water management at local and regional levels. They also point to a need for companies to work with governments and other sectors to minimize environmental impacts and water resources depletion.

Recommendations

Based on the report's analysis, WRI offers a set of practical recommendations for how governments, businesses, and civil society can continue to evaluate and sustainably manage freshwater availability if shale resources are developed.

1. **Conduct water risk assessments to understand local water availability and reduce business risk.**
   1.1. *Companies can evaluate water-related risks*. Using a combination of publicly available global and asset-level tools, companies should identify water-related business risks and prioritize areas to engage with regulators, communities, and industry to increase water security.
   1.2. *Governments can increase investments in collecting and monitoring water supply and demand information.* Robust baseline information and estimates of future water supply and demand and environmental conditions can help build a strong, shared knowledge base to inform the development of effective water policies and science-based targets and goals.

2. **Increase transparency and engage with local regulators, communities, and industry to minimize uncertainty.**

    2.1. *Companies can increase corporate water disclosure.* By disclosing and communicating their water use and management approach, companies can build trust with financial and river basin stakeholders as they investigate water risks and opportunities. Ongoing disclosure will reduce reputational risks.

    2.2. *Governments and companies can engage with local and regional industry, agriculture, and communities.* Companies should closely collaborate with local government, industry, NGOs, and civil society to understand the hydrological conditions and regulatory frameworks within the river basin. This information allows for more accurate estimates of the cost, technology, and processes required to access water for shale development without displacing other users or degrading the environment.

3. **Ensure adequate water governance to guarantee water security and reduce regulatory and reputational risks.**

    3.1. *Companies can engage in public water policy.* Adequate water governance and environmental protection standards, coupled with predictable implementation and effective enforcement, can minimize environmental degradation and ensure fair water allocation and pricing. A stable regulatory environment allows companies and investors to evaluate long-term opportunities and minimize business risks.

    3.2. *Governments and companies, through collective action, can develop source water protection and management plans.* Governments and businesses in the early stages of developing shale resources have a unique opportunity to work collectively with key river basin stakeholders to develop source water protection and management plans that help reduce business risks; promote a shared water sourcing and recycling infrastructure; and improve the sustainable management of watersheds and aquifers.

4. **Minimize freshwater use and engage in corporate water stewardship to reduce impacts on water availability.**

    4.1. *Companies can minimize freshwater use.* Using publicly available guidelines, companies can evaluate their potential for using non-freshwater sources and build a business case for investing in technology to recycle or reuse water, use brackish water, or otherwise significantly reduce freshwater withdrawals.

    4.2. *Companies can develop a water strategy and engage in corporate water stewardship.* Companies should embed water management at the core of their business strategy to minimize exposure to risks and ensure long-term water availability for other users, the environment, and their own operations. Corporate water stewardship involves a progression of increasing improvements in water use and impact reductions across internal company operations and the rest of the value chain.[4]

INTRODUCTION

Relatively little has been published on how shale development impacts water availability in North America, and even less worldwide. WRI fills this gap with new information describing where in the world freshwater availability is most threatened and may limit extraction of shale resources, should they be developed.

Rapid development of shale resources through hydraulic fracturing and horizontal drilling is significantly increasing the contribution of natural gas, natural gas liquids, and oil to the global energy supply mix. Continued growth could transform the global energy market.[5] While profitable production has yet to spread outside the United States and Canada, governments, investors, and companies have begun to explore the commercial potential of shale resources around the world. China and Argentina recently embarked on joint-venture projects with multinational corporations, and Mexico lifted the government's 75-year-old monopoly on oil and gas production, opening some of the world's largest shale formations for development.[6]

The U.S. Energy Information Administration (EIA) estimates that known shale gas deposits worldwide add 47 percent to the global technically recoverable natural gas resources and that underground stores of tight oil add 11 percent to the world's technically recoverable oil.[7] In 2012, shale resources constituted 40 percent of U.S. natural gas production and 29 percent of U.S. crude oil production.[8] If developed responsibly, this large, abundant, and newly recoverable resource has the potential to catalyze economic growth and reduce emissions from other conventional energy sources. Compared with coal, natural gas results in less carbon dioxide, nitrogen oxides, sulfur dioxide, particulates, and mercury per unit of energy produced.[9] With effective policies and standards in place, natural gas could help displace coal while complementing lower-carbon and renewable energy sources.[10]

It is not sufficient to understand the potential benefits of shale resources relative to other energy sources; it is also necessary to know if the shale resources can actually be extracted. This depends on the economic viability of the resources, that is, the cost and feasibility of extraction, as well as on the onsite environmental and social considerations. These considerations are complex. For shale gas and tight oil to be extracted successfully, governments, companies, and investors must clear a range of economic, technical, environmental, legal, and social hurdles. Poor management of these challenges will, without doubt, impede development, undermine investments, and degrade natural capital.

Much has been written about the key environmental considerations and associated risks of shale development, particularly in the United Sates.[11] All environmental considerations have a strong social component, since natural resources are the foundation of economic opportunity and human wellbeing. A recent U.S. study based on information collected from experts in academia, industry, government, and nongovernmental organizations (NGOs) identified the 15 environmental impacts from shale development most frequently identified and agreed upon as priorities for further regulatory or voluntary action (Table 1).[12] Many are not unique to shale development, particularly those that take place during site preparation or drilling activities, thus countries with mature hydrocarbon industries may already have extensive corporate and government policies to help mitigate them.

Of the 15 impacts identified, 12 relate to surface or groundwater resources. This is because the development of shale resources uses water so extensively, particularly during hydraulic fracturing (Figure 1), and because poor drilling practices, including wastewater management and disposal, can degrade water quality. However, 10 of the identified impacts are linked to concerns over water quality, compared

Table 1 | **Environmental Impacts from Shale Gas Development Seen as Priorities by Government, Industry, Academia, and NGO Experts**

Development Stage	**ACTIVITIES**	**BURDENS**	**IMPACTS**
	Activities associated with the development of shale gas	**Burdens that could be created by a development activity and that would have potential impacts that people care about**	**Aspects of the environment that could be affected by the shale gas development process**
Site preparation	Land clearing and infrastructure construction	Storm water flows	Surface water quality
		Habitat fragmentation	Habitat disruption
Drilling	Venting of methane	Methane	Air quality
	Casing and cementing	Methane	Groundwater quality
	Casing accidents	Methane	Groundwater quality
	Cementing accidents	Drilling fluids/cuttings Fracturing fluids Flowback and produced water	Groundwater quality
Fracturing and completion	Use of surface water and groundwater	Freshwater withdrawals	Surface water availability
			Groundwater availability
	Storage of fracturing fluids	Fracturing fluids	Surface water quality
	Venting of methane	Methane	Air quality
Storage/ disposal of fracturing fluids and flowback	On-site pit/pond storage	Flowback and produced water	Surface water quality
			Groundwater quality
		Fracturing fluids	Surface water quality
	Treatment by municipal wastewater treatment plants	Flowback and produced water	Surface water quality
	Treatment by industrial wastewater treatment plants	Flowback and produced water	Surface water quality

Source: Alan J Krupnick, *Managing the Risks of Shale Gas: Key Findings and Further Research* (Resources for the Future, 2013), http://www.rff.org/rff/documents/RFF-Rpt-ManagingRisksofShaleGas-KeyFindings.pdf.

with only 2 regarding water availability. This might explain why relatively little has been published on how shale development impacts water availability in North America,[13] and even less worldwide.[14]

To fill this gap, the World Resources Institute (WRI) used data from the Aqueduct Water Risk Atlas, West Virginia University, the National Energy Technology Laboratory, and other sources to identify where freshwater availability might be a limiting factor to the development of shale resources. In this report, WRI provides comprehensive color-coded maps that:

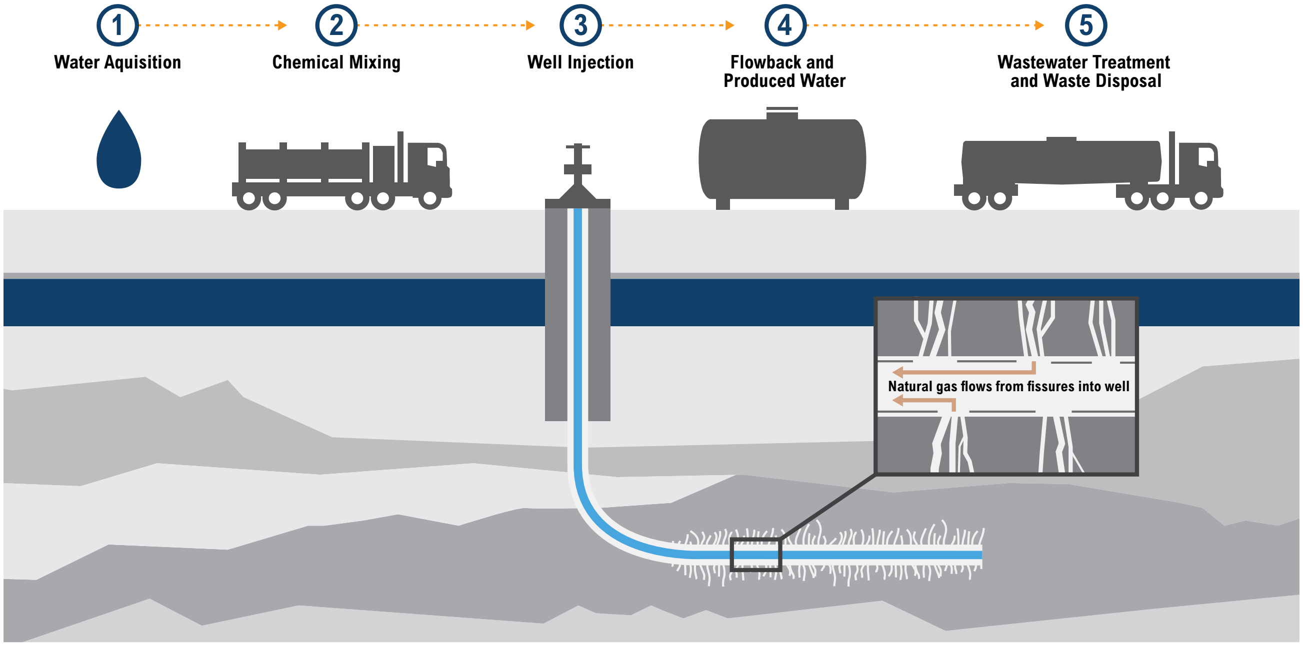
- Identify locations most in need of government oversight and robust corporate policies to ensure freshwater availability for industry, communities, agriculture, and the environment over time, if shale resources are developed, and

- Inform companies developing shale resources of potential business risks associated with freshwater availability, and build the case for increasing water stewardship and early source water assessment in the oil and gas sector.

The results also demonstrate the application of WRI's Aqueduct Water Risk Atlas as a robust decision-support tool to evaluate the water-energy nexus at a global scale and increase public awareness around water-related business risks.

This report is not intended to assess the performance of the oil and gas industry in managing water, but rather to demonstrate the usefulness of global tools like the Aqueduct Water Risk Atlas as a starting point to promote increased dialog among water users across industry, government, and civil society in river basins around the world. The results of this report are published on an interactive online platform (http://www.wri.org/resources/maps/water-for-shale) that provides open access to the data and results, and enables frequent updates of the information as new data are made available.

Figure 1 | **The Hydraulic Fracturing Water Cycle**



Source: Adapted from U.S. Environmental Protection Agency, "The Hydraulic Fracturing Water Cycle," EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources, March 16, 2014, http://www2.epa.gov/hfstudy/hydraulic-fracturing-water-cycle.

SHALE RESOURCES AND WATER

Large water withdrawals during the drilling and hydraulic fracturing stages are necessary to extract shale resources. These withdrawals are concentrated over shale gas and tight oil production areas, making source water availability and the associated risks a critical consideration when evaluating the potential for shale development.

BOX 1 | SHALE RESOURCES TERMINOLOGY

- **Natural gas liquids (NGLs):** naturally occurring hydrocarbons found in natural gas or associated with crude oil that are considered a byproduct in the oil and gas industry and increasingly being targeted for extraction.
- **Shale basin:** large shale formation defined by similar geologic characteristics.
- **Shale gas:** natural gas deposits found in shale reservoirs.
- **Shale play:** the prospective areas of a shale basin where gas and oil could potentially be commercially extracted.
- **Shale resource:** hydrocarbon resources found in shale plays, such as natural gas, natural gas liquids, and tight oil.
- **Tight oil:** oil trapped in fine-grained sedimentary rocks with extremely low permeability, such as shale, sandstone or carbonate.

Sources: E.D. Williams and J.E. Simmons, Water in the Energy Industry. An Introduction (United Kingdom: BP International Ltd, 2013), http://www.bp.com/content/dam/bp/pdf/sustainability/group-reports/BP-ESC-water-handbook-131018.pdf. L. Biewick, G. Gunther, and C. Skinner, “USGS National Oil and Gas Assessment Online (NOGA Online) Using ArcIMS” (Denver, Colorado: U.S. Geological Survey, n.d.), http://proceedings.esri.com/library/userconf/proc02/pap0826/p0826.htm#contact.

Shale is a fine-grained, fissile sedimentary rock composed primarily of clay and silt-sized particles. It is the source rock, reservoir, and seal for shale gas and some tight oil. The shale hydrocarbons considered in this study, referred to as “shale resources,” include: shale gas, natural gas liquids (NGLs), and tight oil (Box 1).

Large shale formations defined by similar geologic characteristics are often referred to as “shale basins.” The prospective areas of the shale basin where gas and oil could potentially be commercially extracted are commonly referred to as “shale plays.” Shale has extremely low permeability, equivalent to about 1 percent of an average conventional reservoir,[15] an even lower permeability than tight gas or coal bed methane reservoirs.[16] Thus gas and fluid pass through shale less easily than through brick, concrete, or even granite.[17] Because of its extremely low permeability, shale must be cracked apart for oil and gas to flow up to the surface at a profitable rate; this is achieved by hydraulic fracturing.

Extraction of Shale Resources

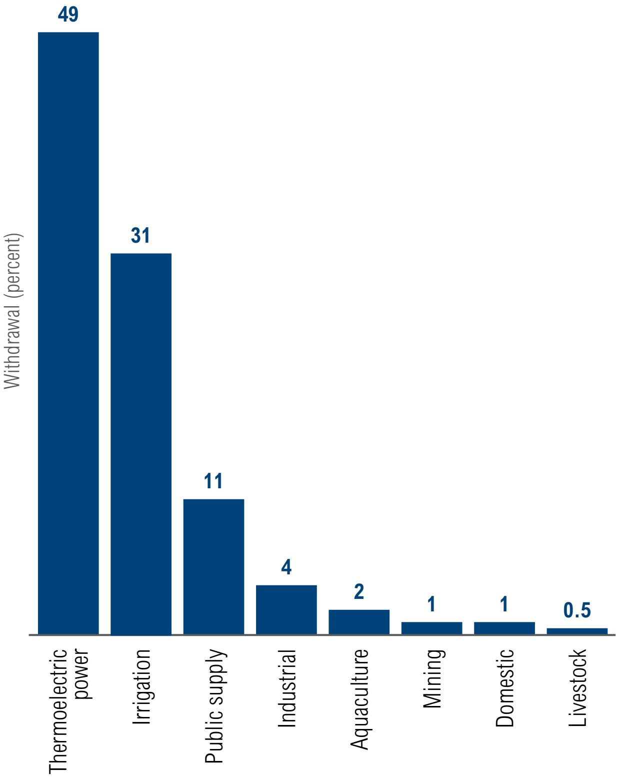
Shale can, in places, be hydraulically fractured to produce large quantities of natural gas, NGLs, and tight oil. Hydraulic fracturing entails pumping fluid composed of water, proppants, and chemicals into the ground at very high pressure. The pressurized water and chemicals create and enlarge cracks in the shale formation, which increases its permeability by 100- to 1,000-fold, allowing the hydrocarbons to flow more easily to the wellbore.[18] Depending on many factors, a well might remain productive for 5 to 40 years.

After the hydraulic fracturing treatment, the water pressure in the well is reduced to allow the fracturing fluid to flow back out of the well followed by the oil and gas. As the fluid flows back to the surface, a process commonly referred to as “flowback,” the sand and other proppants pumped into the formation are left behind—like doorstops—to prop open the new and enlarged cracks. As flowback continues, the composition of the fluid carries higher and higher proportions of hydrocarbons. Within the first few weeks of flowback, some or most of the fracturing fluid returns to the surface as wastewater. In North America, estimates of the volume of flowback vary between 10 to 75 percent of the fracturing fluid originally injected.[19] Because of its chemical content, this wastewater is recycled and treated for reuse, placed into disposal wells, or treated and discharged into surface waters.[20] If not managed properly, flowback water and other wastewater from hydraulic fracturing operations can cause significant degradation to surface water and groundwater that could pose serious risks to the ecosystems and communities that depend on them.[21]

Water Requirements

The life cycle of shale energy requires water during its preproduction, production, and use stages,[22] as well as for refining oil to a grade fit for consumption.[23] The largest water withdrawals for shale resource extraction occur during the drilling and hydraulic fracturing stages. In 2005, water withdrawals for mining (which includes oil and gas extraction) represented only 1 percent of U. S. water withdrawals (Figure 2).[24] In 2010, water withdrawals for hydraulic fracturing represented only 0.5 percent of the withdrawals in Texas.[25] However, water withdrawals for drilling and hydraulic fracturing are unevenly distributed and concentrated over areas where shale resources and tight gas are produced, potentially representing a much higher fraction of the water withdrawn in the drilling area.[26] Additionally, much of the water required for hydraulic fracturing is consumptive, thus it does not all return to the surface or groundwater from which it was abstracted.

Figure 2 | **Percentage of U.S Water Withdrawals by Category, 2005**



Source: J.F. Kenny et al., "Estimated Use of Water in the United States in 2005," U.S. Geological Survey Circular 1344, (2009), http://pubs.usgs.gov/fs/2009/3098/pdf/2009-3098.pdf.

Based on experience in the United States, drilling a single well can require between 0.2 million and 2.5 million liters of water and hydraulic fracturing a well can require between 7 million and 23 million liters of water,[27] 25 percent to 90 percent of which might be consumptive use.[28] The wide range of values for consumptive water use indicates the high levels of uncertainty about possible impacts of hydraulic fracturing on freshwater availability. The water required by a single well can be roughly equal to the water consumed by New York City in 7 minutes, or by a 1,000-megawatt coal-fired power plant in 12 hours.[29] Drilling and fracturing multiple wells, multiple times, in the same area, can rapidly escalate local water consumption. Furthermore, in many areas of the world, the location of shale plays coincides with areas of low availability and high demand for water (Box 2), making access to local water resources a challenge for companies extracting shale resources.

BOX 2 | WATER FOR U.S. HYDRAULIC FRACTURING OPERATIONS IS A SMALL PERCENTAGE OF TOTAL USE, BUT CAN BE LOCALLY SIGNIFICANT

In the United States, water demands for hydraulic fracturing and drilling activities account for only one tenth of 1 percent of all U.S. water withdrawals. This demand, however, is concentrated around active shale plays,[a] 26 percent of which are in areas with high and extremely high water stress. Thus, although the national percentage of water used for fracturing may be low relative to other water demands, the water requirements for shale resources extraction in specific locations can be significant and in competition with other water uses. For example, in Johnson County, Texas, water withdrawals for shale gas development in 2008 were responsible for almost one third of the county's freshwater use.[b] In three contiguous counties in Texas's Eagle Ford shale basin, freshwater demand of hydraulic fracturing is expected to grow by 2020 to exceed the 2008 amount of all other water users combined.[c]

These examples indicate that shale gas development in semiarid regions, such as the southwestern United States, could have a large impact on local surface and groundwater availability and potentially displace other users if the increased demand is not adequately managed.

Sources:

a. U.S. Environmental Protection Agency, "Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources," (Washington, DC: U.S. Environmental Protection Agency, February 7, 2011).

b. Jean-Philippe Nicot and Bridget R. Scanlon, "Water Use for Shale-Gas Production in Texas, U.S.," Environmental Science & Technology 46, no. 6 (March 2012): 3580–86, doi:10.1021/es204602t.

c. Ibid.

The amount of water required to complete a well varies from well to well and play to play, making estimates of water demands for shale development uncertain for most unexplored plays around the world. The variation in water requirements depends on the geology and the well characteristics. For example, the number of horizontal segments hydraulically fractured, as well as the production type, depth and length of the well, determine the amount of water required. In turn, these well characteristics vary based on the formation geology. The shale play's depth, thickness, and porosity can also influence water requirements.[30]

Many companies use freshwater for drilling and fracturing, though brackish and recycled water offer significant opportunities to reduce freshwater demands.[31] Information on the proportion of brackish, recycled, or reused water used as a substitute for freshwater in the United States is scarce.[32] Available data indicates that in 2011 brackish water use by the oil and gas industry in Texas ranged between 0 and 80 percent, and recycled water between 0 and 20 percent of the total water demand, depending on the location.[33] Additionally, although nearly all fracturing treatments use water, alternatives exist including liquefied petroleum gas and carbon dioxide fracture treatments.

One of the limitations to recycling and reusing water is that the amount of flowback returned to the surface varies between and within plays. However, new projects are underway to support increased recycling and reuse to reduce freshwater withdrawals and consumption by the oil and gas sector.[34]

Aside from drilling and hydraulic fracturing (which can occur multiple times in the same well), very little water is needed to prepare the site or maintain the machinery for the well's 5- to 40-year estimated lifespan.[35]

Freshwater Availability Risks

Source water availability is a critical consideration when evaluating the potential for shale development. Shale resources are tied to geographic locations, creating very high location-specific demands for water that must be met in order to successfully extract the resource. Yet, fresh and brackish water are natural resources that must be shared among all users, and that play a critical role in sustaining local ecosystems and socioeconomic development in the areas where shale development takes place.

Limited or unpredictable water availability can jeopardize a project's financial viability. In areas with high demand relative to the available supply, added water withdrawals for drilling and hydraulic fracturing operations can deplete water resources, degrade the environment, and displace other users.

Table 2 | Potential Business Risks Associated with Water Availability

DESCRIPTION	BUSINESS IMPACT	EXAMPLES
FINANCIAL RISKS		
Transportation: Water transportation costs, which can dwarf the purchase price of water, are most often the dominant financial risk.	If not accounted for at the initial stages of the project, additional costs to transport water can significantly threaten profitability.	**United States:** Antero Resources Inc., backed by New York private equity firms, plans to spend more than half a billion dollars on an 80-mile pipeline that will transport water from the Ohio River to extract shale gas in West Virginia and Ohio.[a] The pipeline will reduce water costs, mostly from trucking, by two-thirds, or around US$600,000 per well.[b] This implies that Antero may be spending around US$900,000 per well for water.
Pricing: High water demand and diminishing supplies drive up the price of water.	Increased operating cost to access alternative sources of water.[c]	**United States:** During the 2011 drought, oil and gas companies in parts of Colorado were paying as much as US$1,000 to US$2,000 for the same amount of treated water from city pipes that farmers would pay US$30 for on an average year or US$100 when water was scarce.[d]
REPUTATIONAL RISKS		
Social and environmental concerns: Real or perceived concerns over freshwater availability can threaten a company's social license to operate.	High water stress and other environmental concerns can exacerbate public opposition to hydraulic fracturing,[e] causing a company to lose its social license to operate and/or undergo significant project delays and asset downtime.	**United Kingdom:** Protests in the village of Balcombe concerning a host of hydraulic-fracturing-related environmental risks have caused the energy firm Cuadrilla to delay project development for months.[f] **South Africa:** Shell faced significant social opposition to its plans to seek shale gas in South Africa's semidesert Karoo region. Social concerns over water availability resulted in projected delays and a temporary government ban on hydraulic fracturing.
REGULATORY RISKS		
Regulatory uncertainty: Concerns over environmental degradation, including the depletion of water, can cause governments to limit or even prohibit shale development.	Concerns over water supply availability can be one of many reasons that national and subnational governments ban or place a moratorium on hydraulic fracturing,[g] leading companies to lose their legal license to operate, and/or undergo significant project delays and asset downtime.	**United States:** Severe droughts in 2011 caused restrictions and bans on the use of water for hydraulic fracturing in the Barnett and Permian basins.[h] **Bulgaria:** Environmental concerns led Bulgaria to ban hydraulic fracturing and revoke a shale gas permit granted to Chevron. **France:** France banned hydraulic fracturing and canceled exploration licenses held by companies including Total SA and the U.S. firm Schuepbach Energy.[i]

a. Russell Gold, "Energy Firm Makes Costly Fracking Bet - on Water," Wall Street Journal, August 2013, Online edition, sec. Business, http://online.wsj.com/article/SB10001424127887323420604578652594214383364.html.

b. Ibid.

c. Melissa Stark et al., Water and Shale Gas Development: Leveraging the US Experience in New Shale Developments (Accenture, 2012), http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-Water-And-Shale-Gas-Development.pdf.

d. Jack Healy, "For Farms in the West, Oil Wells Are Thirsty Rivals," The New York Times, September 2012, http://www.nytimes.com/2012/09/06/us/struggle-for-water-in-colorado-with-rise-in-fracking.html?pagewanted=all&_r=2&.

e. Alec Tang and Kristina Ringwood, "Water Sustainability Risk Assessments: Lessons from Water Sensitive Industries," in Offshore Technology Conference (Houston, Texas, USA: Offshore Technology Conference, 2013), 1–6, https://www.onepetro.org/conference-paper/OTC-23903-MS.

f. BBC, "Balcombe Protests: Fracking Row Village Sees Fresh Plan," BBC News Sussex, September 4, 2013, http://www.bbc.co.uk/news/uk-england-sussex-23944344.

g. Matt Steinglass, "Fracking: Netherlands Moves Closer to Shale Gas Exploitation," Financial Times, August 2013, http://www.ft.com/intl/cms/s/0/c20b1e24-0e66-11e3-bfc8-00144feabdc0.html#axzz2eQg9CIST.

h. Mike Lee, "Parched Texans Impose Water-Use Limits for Fracking Gas Wells," Bloomberg Businessweek, September 2011.

i. Tara Patel and Gregory Viscusi, "France's Fracking Ban 'Absolute' After Court Upholds Law," Bloomberg News, October 11, 2013, http://www.bloomberg.com/news/2013-10-11/fracking-ban-upheld-by-french-court-as-constitutional.html.

These externalities can translate into business risks for companies developing shale resources, including: financial risks, reputational risks, and regulatory risks (Table 2).

These risks can translate into business disruptions and impact company profitability, as well as short- and long-term investments in shale development, particularly in arid regions such as those in China's Tarim basin and South Africa's Karoo basin.

The technology exists to procure, treat, and transport water for nearly any shale development operation. The question is: Has the cost of the technology, as well as the social, environmental, and regulatory implications, been adequately addressed in the early stages of the investment and decision-making process? Governments and companies need to answer this question, in part, by assessing source water availability and the associated risks early on. Furthermore, adequate water management policies, plans, and strategies must be in place to allow for long-term sustainable use of local water resources by all sectors, as well as by the environment.

> Source water availability is a critical consideration when evaluating the potential for shale development. Shale resources are tied to geographic locations, creating very high location-specific demands for water that must be met in order to successfully extract the resource.

ASSESSING FRESHWATER AVAILABILITY AND BUSINESS RISK

Companies selecting freshwater to supply shale development projects need to evaluate and understand the availability of local and regional freshwater sources. In this report WRI uses seven indicators to assess freshwater availability and business risks across major shale plays worldwide. The results reveal areas with potential challenges to accessing water, and highlight the associated financial, reputational, and regulatory risks to companies developing shale resources.

BOX 3 | HOW TO IDENTIFY AND ASSESS A WATER SOURCE FOR OIL AND GAS OPERATIONS

The global oil and gas industry association for environmental and social issues (IPIECA) recommends six steps for companies to identify and assess a source of water for oil and gas operations:

- Step 1: Engage stakeholder and regulatory organizations
- Step 2: Understand current and future project water requirements
- Step 3: Identify water sources within the project area
- Step 4: Evaluate the status of water quantity and quality in the area
- Step 5: Assess impacts, risks, and uncertainty
- Step 6: Select the water source

Source: Adapted from IPIECA, Identifying and Assessing Water Sources (London: IPIECA, 2014), http://www.ipieca.org/publication/identifying-and-assessing-water-sources.

Companies that develop shale resources need to access and handle large quantities of water, and thus are likely to be significant users and managers of water at the local and regional levels. As such, they must identify and select their potential water sources within the broader context of local or regional water management considerations.[36] IPIECA, the global oil and gas industry association for environmental and social issues, recommends that in identifying and assessing potential water sources (Box 3), operators work with river basin stakeholders to evaluate the quantity and quality available for use, as well as the associated impacts, risks, and uncertainties before selecting their water sources.

Regulatory frameworks, freshwater constraints, and the economics of water treatment will determine the extent to which brackish water and wastewater are feasible substitutes for freshwater for hydraulic fracturing.[37] In the meantime, companies selecting freshwater to supply their projects need to evaluate and understand the availability of local and regional freshwater. Companies with large portfolios of assets, as well as investors, need location-specific, credible, and comprehensive information that can be compared across regions, countries, and basins, shared publicly, and understood by all stakeholders.

This report offers a set of quantitative indicators and maps to help stakeholders evaluate freshwater availability across major shale plays worldwide. The results reveal areas with potential challenges to accessing freshwater, and the associated financial, reputational, and regulatory risks to companies developing those shale resources. The results also highlight the areas most in need of effective water governance to ensure sustainable management and distribution of water resources to meet the needs of communities, the environment, industry, and agriculture.

Methodology

To create the maps showing areas of high shale resource potential and low water availability, WRI overlaid maps of the world's major shale plays identified at the time this report was written with data for seven water-related indicators: baseline water stress, seasonal variability, drought severity, groundwater stress, dominant water user, population density, and reserve depth interval. The results provide a comprehensive visual resource and quantitative database to help evaluate the spatial variation in water availability and the associated business risks across shale plays.

The indicators and locations of shale plays were combined using geospatial tools. The resulting information is displayed in maps and provides coverage for each indicator, across each shale play, allowing the results to be aggregated and shared at a play, country, region, or global level. In this report, all summary results are calculated by area. For example, a result that shows 38 percent of shale resources are located in areas that are arid or under high to extremely high levels of water stress means that 38 percent of the global shale play area, not 38 percent of the global technically recoverable shale resource volume, is under high or extremely high levels of water stress.

This report summarizes the results at a global level, as well as by shale play for 11 countries. Countries were selected based on the size of their technically recoverable shale resources, according to the U.S. Energy Information Administration, current exploratory and production activity, likelihood of future development, and feedback from industry, academia, and NGO experts. Countries include Algeria, Argentina, Australia, Canada, China, Mexico, Poland, Saudi Arabia, South Africa, United Kingdom, and the United States (Appendix A). All results and underlying data are available for download from the project website (http://www.wri.org/resources/maps/water-for-shale) and will be updated as new data are available.

Geo-Database of Shale Basins and Plays

The West Virginia Geographic Information Systems Technical Center (WVGISTC) and West Virginia University (WVU), in collaboration with the National Energy Technology Laboratory and WRI, compiled a digital GIS geometry and attribute geo-database of major onshore shale formations targeted for unconventional development of gas and liquid hydrocarbon resources.[38] The compilation excludes offshore shale formations.

The geo-database consists of 228 shale basins and 339 shale plays in the public domain in publications by the U.S. Energy Information Administration, Journal of Petroleum Technology, China University of Geosciences, Oil and Gas Journal, national and subnational geological surveys, and other academic, industry, and governmental sources. The geo-database includes a number of attributes for each shale formation, including the basin and play name, geologic age, depth interval, reservoir pressure, thermal maturity, oil and gas in place, and data source, among others. It is available online (https://edx.netl.doe.gov/dataset/unconventional-resources-atlas).

The geo-database is not an all-inclusive collection of unconventional onshore formations, but rather a collection of general information on the location of shale basins and plays publicly available at the time of the analysis.

Water Availability and Business Risk Indicators

Seven indicators are used in this assessment (Table 3). Five were obtained from WRI's Aqueduct Water Risk Atlas, a global database of publicly available water risk indicators and maps. The Aqueduct Water Risk Atlas leverages publicly available data, to provide robust and science-based information for decision makers. The data can be compared globally across political and hydrological boundaries.

This global coverage enables users to consistently evaluate exposure to water-related risks across a portfolio of current or prospective assets, suppliers, commodities, or investments. Because of this, the Aqueduct Water Risk Atlas is not designed to characterize water risks at any particular location; many of the local legal, social, and structural complexities associated with managing water are not included in global models. Instead, the Aqueduct Water Risk Atlas helps provide the context necessary to understand water-related risks at a portfolio-level, which, combined with local information and a deep understanding of a company's management practices, can help evaluate company risks. All indicators in the Aqueduct Water Risk Atlas were developed and published by WRI in 2013, in consultation with an external advisory group of experts from industry, academia, government and NGOs.[39]

One indicator, population density, was obtained from Columbia University and Centro Internacional de Agricultura Tropical. The seventh indicator, the depth interval of the shale formation, was obtained from WVGISTC. The depth of the shale formation has an impact on water requirements because deeper formations require more water for drilling.[40] All indicators were selected based on their relevance for shale exploration and production and feedback from industry, academic, and NGO experts. Indicators make use of the most up-to-date and high resolution global datasets available in the public domain. The definitions, calculations, data sources, and scoring methodology are documented and publicly available for download from the cited sources and available on the project website.

Table 3 | **Indicators and Business Risks**

INDICATOR	LEGEND	BUSINESS RISKS
Baseline water stress The ratio of total water withdrawals from municipal, industrial, and agricultural users to the available renewable surface water. Higher values may indicate more competition among users and greater depletion of water resources. Source: F. Gassert, M. Landis, M. Luck, P. Reig, and T. Shiao, "Aqueduct Global Maps 2.0," Working Paper, (World Resources Institute, Washington, DC, 2013), available at http://www.wri.org/publication/aqueduct-metadata-global.	🟨 Low (<10%) 🟨 Low to medium (10-20%) 🟧 Medium to high (20-40%) 🟥 High (40-80%) 🟥 Extremely high (>80%) ⬜ Arid & low water use ⬛ No data	Higher competition and depletion of water supplies are common triggers for unanticipated changes in water prices and regulations, and often lead to difficulties in accessing water and social concerns over water availability.
Seasonal variability The variation in water supply between months of the year. Higher values indicate more variation in water supply within a given year, leading to situations of temporary depletion or excess of water. Source: F. Gassert, M. Landis, M. Luck, P. Reig, and T. Shiao, "Aqueduct Global Maps 2.0," Working Paper (World Resources Institute, Washington, DC, 2013), available at http://www.wri.org/publication/aqueduct-metadata-global.	🟨 Low (<0.33) 🟨 Low to medium (0.33-0.66) 🟧 Medium to high (0.66-1.0) 🟥 High (1.0-1.33) 🟥 Extremely high (>1.33) ⬜ Arid & low water use ⬛ No data	High levels of seasonal variability indicate potential fluctuations in competition and depletion of water, and challenges in accessing constant supplies of water over a given year. High variability in supplies can require additional transportation and storage, and unanticipated changes in pricing or regulatory requirements.
Drought severity The average length of droughts multiplied by the dryness of the droughts from 1901 to 2008. Higher values indicate areas subject to periods of more severe drought. Source: J. Sheffield and E. F. Wood, "Projected Changes in Drought Occurrence under Future Global Warming from Multi-Model, Multi-Scenario, IPCC AR4 Simulations," Climate Dynamics 31 (2008): 79–105; http://link.springer.com/article/10.1007/s00382-007-0340-z	🟨 Low (<20) 🟨 Low to medium (20-30) 🟧 Medium to high (30-40) 🟥 High (40-50) 🟥 Extremely high (>50) ⬜ Arid & low water use ⬛ No data	Severe droughts often lead to unanticipated changes in water regulation and tariffs, which can make it more costly to access water, and increase social concerns over water availability.

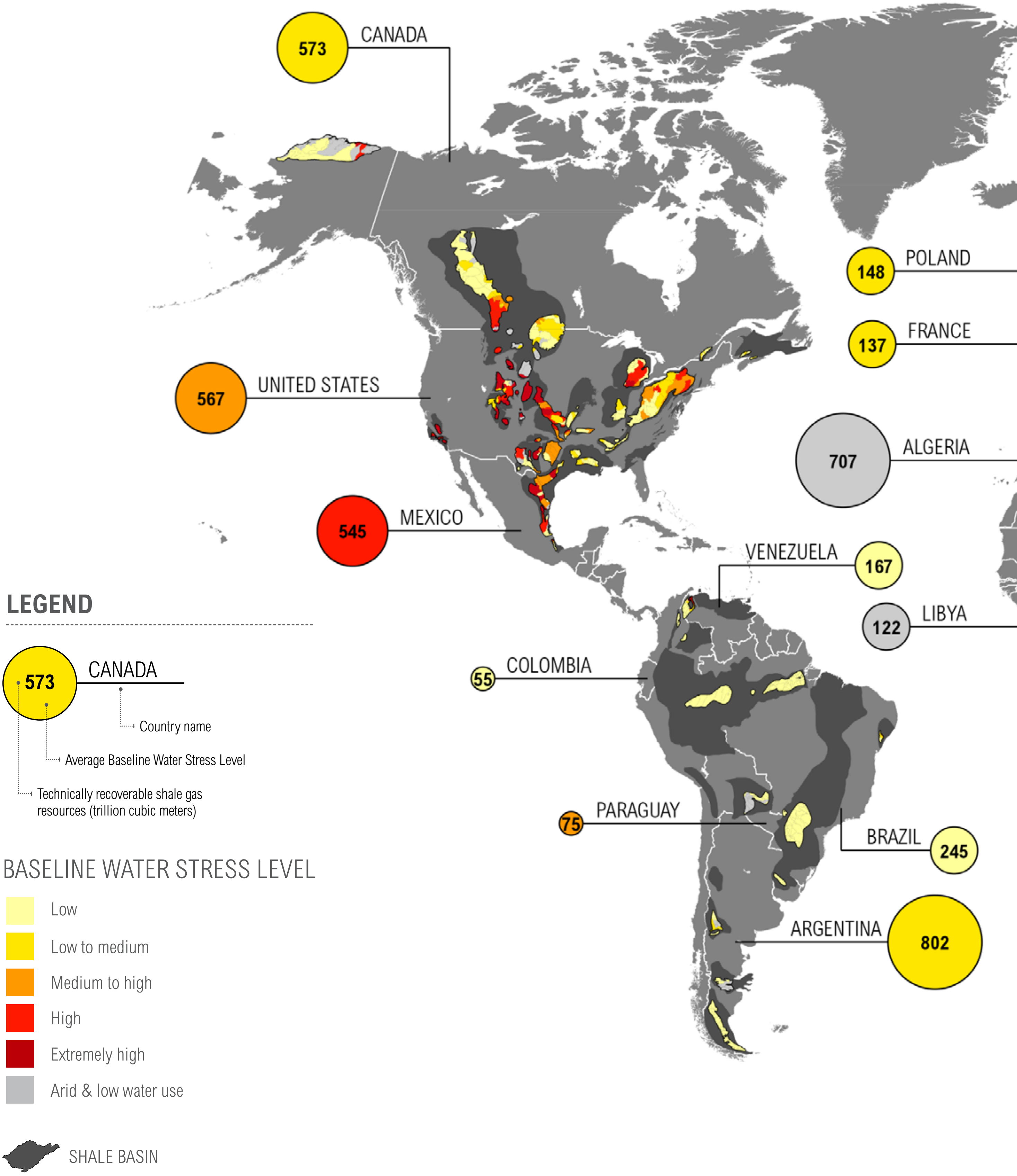
Table 3 | **Indicators and Business Risks (cont.)**

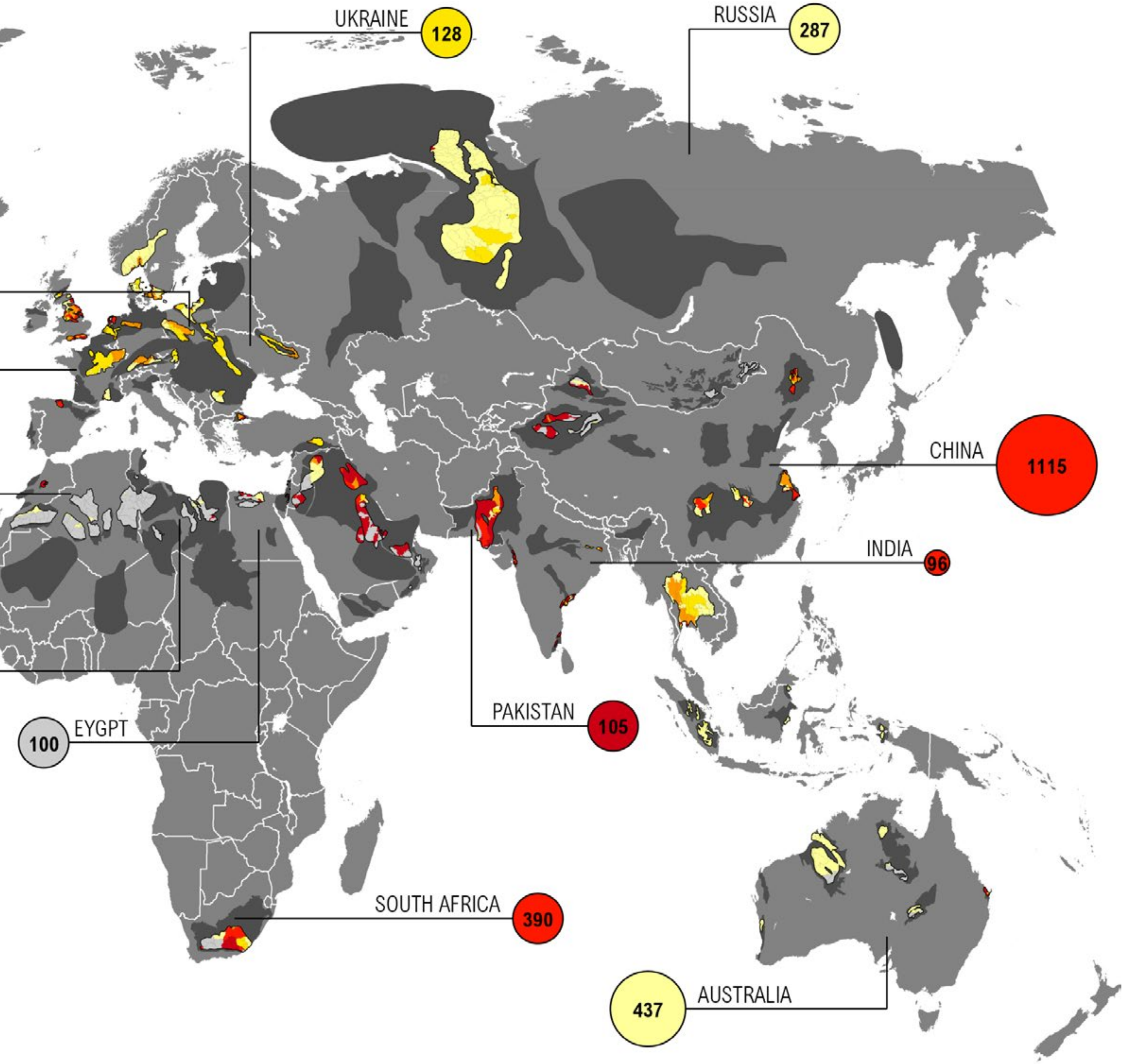
INDICATOR	LEGEND	BUSINESS RISKS
Groundwater stress The ratio of groundwater withdrawal to its recharge rate throughout an aquifer. Values above one indicate where unsustainable groundwater consumption could impact groundwater availability and groundwater-dependent ecosystems. Source: T. Gleeson, Y. Wada, M.F. Bierkens, and L.P. van Beek, "Water Balance of Global Aquifers Revealed by Groundwater Footprint," Nature 488, no. 7410 (2012): 197–200, doi: 10.1038/nature11295.	🟨 Low (<1) 🟨 Low to medium (1-5) 🟧 Medium to high (5-10) 🟥 High (10-20) 🟥 Extremely high (>20) ⬜ Arid & low water use ⬛ No data	Overdrawn aquifers can lead to unanticipated changes in groundwater withdrawal permits, difficulties in accessing groundwater and social concerns over the availability and quality of the resources. Groundwater supplies are often particularly important in developing shale resources because of their close proximity to wells and the potential for contamination.
Dominant water user The sector (agricultural, municipal or industrial) with the largest annual water withdrawals. Source: F. Gassert, M. Landis, M. Luck, P. Reig, and T. Shiao. "Aqueduct Global Maps 2.0." Working Paper. World Resources Institute, Washington DC., 2013), available at http://www.wri.org/publication/aqueduct-metadata-global.	Domestic Agricultural Industrial	Understanding the major water user within a play area helps (a) determine the largest sector competitor for water, and (b) predict the type of conflicts that may arise. For example, in some regions, agricultural water users have strong traditional, political, and social influence.
Population density The average number of people per square kilometer. Source: CIESIN and CIAT, "Gridded Population of the World Version 3 (GPWv3): Population Count Grid," Future Estimates, Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC), 2005, available at http://dx.doi.org/10.7927/H4ST7MRB.	Population Density (people/sqkm) | 0.4	Areas of high population density pose complex barriers to shale development; such as logistical, environmental, and social challenges to accessing water. High population density often indicates high competition for water and significant regulatory and reputational risks.
Reserve depth interval The range of depths (in meters) of the prospective shale area. The black line indicates the global average depth in meters. Source: West Virginia University and The National Energy Technology Laboratory. "Atlas of Unconventional Hydrocarbon Resources." 2014, available at https://edx.netl.doe.gov/dataset/unconventional-resources-atlas.		The range of depths of the prospective shale area indicates if more or less water will be required. Deeper formations generally require more water for drilling.

GLOBAL RESULTS

386 million people live on the land above shale resources, and 38 percent of the world's shale resources are in areas that face high to extremely high water stress or arid conditions. Worldwide, but particularly in these areas, it is necessary to understand freshwater availability, the level of competition for water, and the risks associated with drilling and hydraulic fracturing activities.

Figure 3 | **Location of World's Shale Plays, Volume of Technically Recoverable Shale Gas in the 20 Countries with the Largest Resources, and the Level of Baseline Water Stress**





Notes

1. Colored polygons are areas that have been identified as shale plays: shale deposits that are viable for commercial production.
2. Dark grey polygons are shale basins. While shale plays fall within basins, other shale resources within basins may not be commercially viable.
3. Circle size denotes the country's total technically recoverable shale gas resources (trillion cubic meters).
4. Circle color denotes the area-weighted average of baseline water stress levels over all shale plays within a country. If more than half of the country's shale play area is in arid and low water use regions, the circle is colored in light grey.

Sources: Location of world's shale basins and plays from West Virginia University and The National Energy Technology Laboratory. Estimates of total technically recoverable shale gas resources from the U.S. Energy Information Administration. Estimates of baseline water stress from WRI's Aqueduct Water Risk Atlas.

This section gives the key global findings. It highlights where freshwater availability is most limited, might constrain shale development, and poses business risks to companies extracting the resource. Additionally, it sheds light on the level of water stress across shale formations in the 20 countries with the largest shale gas and tight oil technically recoverable resources (TRR) based on estimates from the U.S. Energy Information Administration.

Key Findings

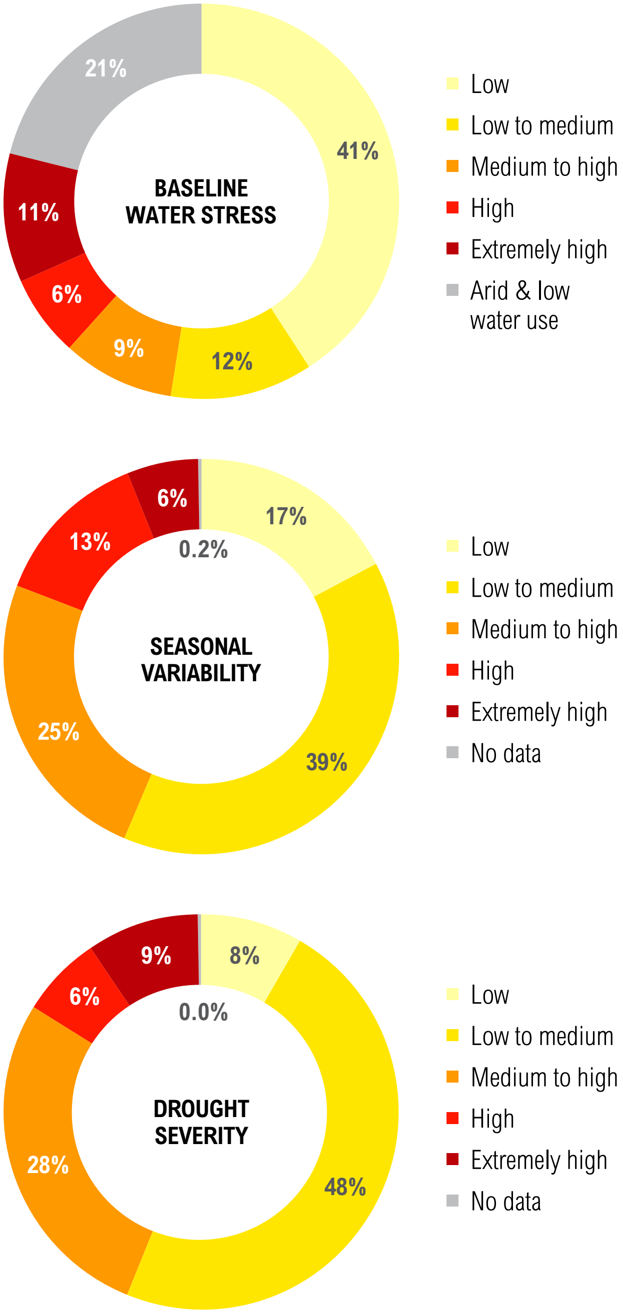
Shale resources are unevenly distributed around the globe, and most are not located where water is abundant (Figure 3). For example, China, Mexico, and South Africa have some of the world's largest technically recoverable shale gas resources and also face high to extremely high levels of water stress in the areas where the shale is located.

The findings (Figure 4) indicate that worldwide:

- 38 percent of shale resources are in areas that are either arid or under high to extremely high levels of water stress
- 19 percent are in areas of high and extremely high seasonal variability, and
- 15 percent are in locations exposed to high and extremely high drought severity.

In areas of high to extremely high baseline water stress, substantial portions of the available freshwater supply (40 to 100 percent) are already being withdrawn by agricultural, municipal, or industrial users. This situation presents significant challenges to ensuring a reliable water supply during drier years while maintaining environmental and human needs. Thus, areas of high stress are overall more vulnerable to droughts or diminishing supplies and increased competition for water.

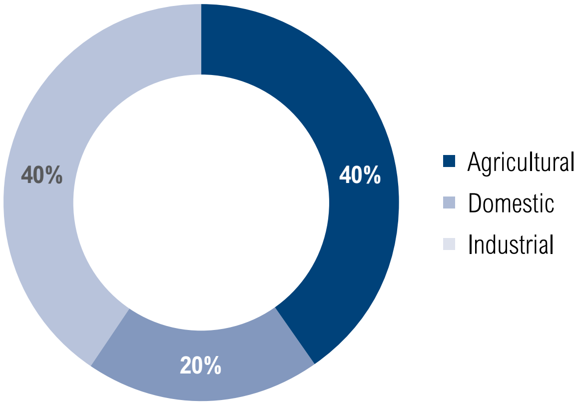
Figure 4 | **Distribution of Baseline Water Stress, Seasonal Variability, and Drought Severity over Shale Plays Worldwide**



Source: Location of world's shale plays from West Virginia University and The National Energy Technology Laboratory. Estimates of baseline water stress, seasonal variability, and drought severity from WRI's Aqueduct Water Risk Atlas.

About 386 million people live on land above the identified shale plays. This estimate was obtained by overlaying population data with the shale plays worldwide. Irrigated agriculture is the largest water user in 40 percent of the shale plays, industry accounts for another 40 percent, and domestic use takes the final 20 percent (Figure 5). Competing water demands from drilling and hydraulic fracturing activities can rapidly escalate and result in conflicts with other water users. Farmers have raised concerns or stood up against the potential for shale development in many parts of the world, including Poland, South Africa, and the United States to name a few. Similar situations may occur when shale development competes for water with domestic users, particularly in areas with ineffective or nonexistent public water policy to protect the environment and ensure water security for all users.

Figure 5 | **Percentage of Shale Plays Worldwide with the Largest Water Withdrawals by Agricultural, Industrial, and Domestic Users**



Source: Location of world's shale plays from West Virginia University and The National Energy Technology Laboratory. Estimates of water withdrawals from WRI's Aqueduct Water Risk Atlas.

Country Comparisons

From the global assessment, we extracted key information by country and combined it with information on the size of each country's technically recoverable resources (TRR), based on U.S. Energy Information Administration estimates. The results shed light on key freshwater availability constraints across shale plays in the 20 countries with the largest technically recoverable resources:

- **Shale gas TRR:** Eight of the top 20 countries with the largest technically recoverable shale gas resources (Table 4) face arid conditions or an average of high to extremely high baseline water stress where the shale is located. China, Mexico and South Africa stand out, ranking very highly based on the size of their resources and exposure to baseline water stress.

- **Tight oil TRR:** Eight of the top 20 countries with the largest technically recoverable tight oil resources (Table 5) face arid conditions or an average of high to extremely high baseline water stress where the shale is located. China, Mexico and Pakistan stand out, ranking very highly based on the size of the resource and exposure to baseline water stress.

In these and other countries exposed to greater water stress than the United States or Canada, companies are likely to face even more serious challenges to accessing freshwater for shale gas and tight oil extraction than they did in North America.

Global results provide useful information on the distribution of water resources across shale plays in each country. For example, the distribution of baseline water stress over shale plays (Figure 6) shows the extent to which national shale resources are exposed to different levels of competition and depletion of water resources. Understanding this type of information can help minimize environmental impacts, evaluate business risks, and develop effective sustainable water sourcing strategies.

Water availability can be limited by two things: arid conditions in areas with limited precipitation and runoff (e.g.regions of Libya, Algeria or Egypt); or high competition for water in areas with demands close to, or exceeding, the available water supplies (e.g. Pakistan, India, Mexico). The social, environmental, and economic implications differ in each case. In arid areas, operators will have difficulty finding water, particularly freshwater. In stressed areas, where users compete for water, there will be greater political and social barriers to allocating already-stressed water resources away from other users. Nevertheless, in both cases, limitations to water availability could pose business risks to companies involved in developing these resources, especially those with unsustainable water management practices.

Worldwide, but particularly in countries with shale formations in areas of high water stress (e.g. China and South Africa), the specific location of the drilling and hydraulic fracturing operations are critical to determining the level of water availability and understanding the associated business risks.

In-depth analyses of water availability over shale plays with high potential for development over the coming decades in 11 countries are given in Appendix A. The information includes background on national energy and shale resources, regulatory environment, and water resources, as well as water availability constraints and business risks.

Table 4 | **Average Exposure to Baseline Water Stress across Shale Plays in the 20 Countries with the Largest Technically Recoverable Shale Gas Resources**

RANK[a]	EIA ESTIMATED SHALE GAS TRR (TRILLION CUBIC FEET)[b]	COUNTRY	AVERAGE EXPOSURE TO BASELINE WATER STRESS OVER SHALE PLAY AREA[c]
1	1,115	China	High
2	802	Argentina	Low to Medium
3	707	Algeria	Arid & Low Water Use
4	573	Canada	Low to Medium
5	567	United States	Medium to High
6	545	Mexico	High
7	437	Australia	Low
8	390	South Africa	High
9	287	Russian Federation	Low
10	245	Brazil	Low
11	167	Venezuela	Low
12	148	Poland	Low to Medium
13	137	France	Low to Medium
14	128	Ukraine	Low to Medium
15	122	Libya	Arid & Low Water Use
16	105	Pakistan	Extremely High
17	100	Egypt, Arab Rep.	Arid & Low Water Use
18	96	India	High
19	75	Paraguay	Medium to High
20	55	Colombia	Low

a. Based on size of estimated shale gas TRR

b. Vello Kuuskraa, Scott Stevens, and Keith Moodhe, Technically Recoverable Shale Oil and Shale Gas Resources : An Assessment of 137 Shale Formations in 41 Countries Outside the United States (Washington, DC: U.S. Energy Information Administration, June 10, 2013), http://www.eia.gov/analysis/studies/worldshalegas/.

c. WRI's Aqueduct Water Risk Atlas.

Table 5 | Average Exposure to Baseline Water Stress across Shale Plays in the 20 Countries with the Largest Technically Recoverable Tight Oil Resources

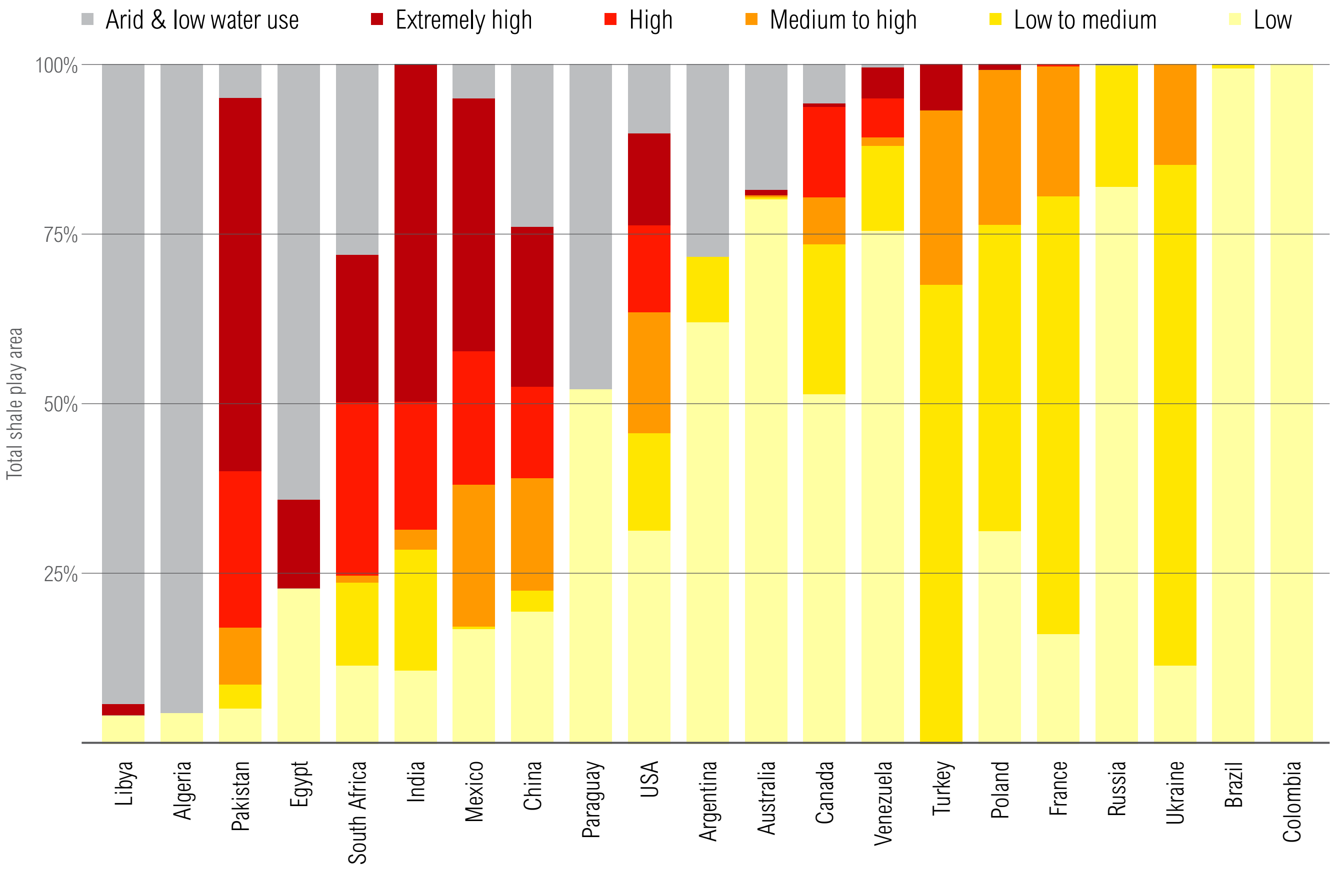
RANK[a]	EIA ESTIMATED TIGHT OIL TRR (MILLION BARRELS)[b]	COUNTRY	AVERAGE EXPOSURE TO BASELINE WATER STRESS OVER SHALE PLAY AREA[c]
1	75,800	Russian Federation	Low
2	58,100	United States	Medium to High
3	32,200	China	High
4	27,000	Argentina	Low to Medium
5	26,100	Libya	Arid & Low Water Use
6	17,500	Australia	Low
7	13,400	Venezuela, RB	Low
8	13,100	Mexico	High
9	9,100	Pakistan	Extremely High
10	8,800	Canada	Low to Medium
11	7,900	Indonesia	Low
12	6,800	Colombia	Low
13	5,700	Algeria	Arid & Low Water Use
14	5,300	Brazil	Low
15	4,700	Turkey	Medium to High
16	4,600	Egypt, Arab Rep.	Arid & Low Water Use
17	3,800	India	High
18	3,700	Paraguay	Medium to High
19	3,400	Mongolia	Extremely High
20	3,300	Poland	Low to Medium

a. Based on size of estimated tight oil TRR

b. Vello Kuuskraa, Scott Stevens, and Keith Moodhe, Technically Recoverable Shale Oil and Shale Gas Resources : An Assessment of 137 Shale Formations in 41 Countries Outside the United States (Washington, DC: U.S. Energy Information Administration, June 10, 2013), http://www.eia.gov/analysis/studies/worldshalegas/.

c. WRI's Aqueduct Water Risk Atlas.

Figure 6 | **Distribution of Baseline Water Stress across Shale Plays in the 20 Countries with the Largest Technically Recoverable Shale Gas Resources**



Note: Countries arranged from most arid or highest water stress on the left, to lowest water stress on the right.
Sources: Location of world's shale plays from West Virginia University and The National Energy Technology Laboratory. Estimates of total technically recoverable shale gas resources from the U.S. Energy Information Administration. Estimates of baseline water stress from WRI's Aqueduct Water Risk Atlas.

For each play, the country analysis includes:

- Name
- Spatial distribution of baseline water stress, seasonal variability, drought severity, and groundwater stress
- Population density
- Dominant water user
- Reserve depth interval

Countries were selected based on the size of their technically recoverable shale resources as disclosed by the U.S. Energy Information Administration, current exploratory and production activity, likelihood of future development, and feedback from industry, academia, and NGO experts. They are:

- Algeria
- Argentina
- Australia
- Canada
- China
- Mexico
- Poland
- Saudi Arabia
- South Africa
- United Kingdom
- United States

CONCLUSIONS AND RECOMMENDATIONS

The preceding sections indicate that freshwater availability could curtail shale development, and that extracting shale resources could have a significant effect on local water availability. Based on these results, WRI makes recommendations for how governments, businesses, and others can evaluate and sustainably manage freshwater availability in any future development of shale resources.

Conclusions

Freshwater availability could curtail shale development in many plays around the world. This finding makes a strong business case for strategic company engagement in sustainable water management at local and regional levels. WRI found that 38 percent of shale resources worldwide are located in areas that are arid or face high to extremely high water stress. Under these conditions, companies developing shale resources internationally are likely to face serious challenges to accessing freshwater in many parts of the world. The analysis also finds that worldwide roughly 386 million people live over the identified shale plays. The ability of companies to work with governments and other river basin stakeholders to identify, assess, and mitigate water availability constraints and the associated business risks will play a key role in determining the extent of shale resource development, and ensuring long-term water availability for all users and the environment.

Global and country assessments reveal large spatial and seasonal variation in hydrological conditions across shale plays, such as between the eastern and western United States, and within plays, like the Karoo in South Africa, Bowland in the United Kingdom, or Sichuan in China. Conditions also vary seasonally, with high to extremely high seasonal variability over close to 20 percent of the world's shale formations, for example in the Beetaloo in Australia or Tampico in Mexico. During drier periods of the year, it may be far more challenging to access freshwater.

The demand for water for hydraulic fracturing and drilling is unpredictable and depends on the formation geology and well characteristics. Because of this, estimates based on previous experience of the environmental impacts, cost, technology, and processes required to access sufficient water for drilling and hydraulic fracturing activities will not always be applicable in new shale formations. This increases uncertainty, and thus business risks for companies exploring new areas for development.

Finally, since much of the water use for shale development can be consumptive, the amount used can have a significant impact on local water availability. In 40 percent of the shale plays—including the Utica play in Canada, Parana play in Argentina, and most plays in China—the largest water user is irrigated agriculture. In all shale resources, but particularly in these, public concern over impacts on the availability and quality of freshwater for other critical human needs may threaten a company's social license to operate and lead to changes in regulations that could impact both short- and long-term investments.

Recommendations

Based on the new information and conclusions provided in this report, WRI makes the following recommendations for how governments, businesses, and other stakeholders can continue to evaluate and sustainably manage freshwater availability in any future development of shale resources:

1. **Conduct water risk assessments to understand local water availability and reduce business risk.**

Arid conditions and high levels of water stress over 38 percent of the world's shale resources indicate that in these areas any additional demands for freshwater will exacerbate an already challenging situation. To minimize impacts on freshwater availability and the associated business risks, the first step is to better understand the local hydrological conditions, risks, and potential impacts prior to investing in or beginning shale development activities. To do so:

1.1. *Companies can evaluate water-related risks*. Using a combination of publicly available global (e.g., WRI Aqueduct Water Risk Atlas[41] or WWF Water Risk Filter[42]) and asset-level tools (e.g. GEMI Local Water Tool[43]) companies can evaluate water constraints and identify business risks. The results help identify priority areas to engage with regulators, communities, and industry in search of solutions to increase water security.

1.2. *Governments can increase investments in collecting and monitoring water supply and demand information*. Sustainably managing water resources for all users requires robust baseline information and future estimates of water supply and demand and environmental conditions in a given surface and ground watershed. Joint research and analysis can help build a strong, shared knowledge base across sectors to inform the development of effective water policies and science-based targets and goals.

2. **Increase transparency and engage with local regulators, communities, and industry to reduce uncertainty.**

The variability in hydrological conditions and uncertainty in competition and demand for water between and within shale formations can create significant business risk. Because of this, it is critically important that financial, government, and river basin stakeholders trust the water management practices of the companies involved. The following actions should be taken to minimize uncertainties and increase stakeholder trust:

2.1. *Companies can increase corporate water disclosure*. Disclosing their water use and management approaches helps companies build trust with financial and river basin stakeholders as they investigate water risks and opportunities. This approach will reduce reputational risks. Disclosure of water use and management can take place through company reports, or publicly available platforms (e.g., the CDP Water program[44]). The scope and content of corporate water disclosure can be determined following guidance in the UN Global Compact CEO Water Mandate Corporate Water Disclosure Guidelines,[45] or Ceres Aqua Gauge.[46]

2.2. *Governments and companies can engage local and regional industry, agriculture, and communities*. Companies engaging in new shale activities should begin or continue to work in close collaboration with local government, industry, farmers, NGOs, and civil society representatives to understand the local agricultural, industrial, and domestic demands for water, as well as the level of depletion of the resource, ecosystem requirements, and regulatory frameworks within the river basin. This information allows for more accurate estimates of the cost, technology, and processes required to access water for shale development without displacing other users or degrading the environment. Engaging local stakeholders before and throughout the project lifecycle also helps limit water-related conflicts and identify opportunities for collective action.

3. **Ensure adequate water governance to guarantee water security and reduce regulatory and reputational risks.**

Roughly 386 million people live on the land over the shale resources identified in this study. Worldwide, but particularly in these areas, public concern over water security and impacts on water availability could escalate quickly. Community opposition or conflicts among industrial, agricultural, and domestic water users can drive changes in regulation that may impact both short- and long-term investments. To ensure water security, governments and companies should take the following actions:

3.1. *Companies can engage in public water policy*. Public concern over water use for shale energy development, in many cases, stems from ineffective or nonexistent public water policy to protect the environment and ensure water security. Thus, adequate water governance and environmental protection standards coupled with predictable implementation and effective enforcement are needed to minimize environmental degradation and ensure fair water allocation and pricing. In a stable regulatory environment, companies and investors can evaluate long-term opportunities and minimize business risks. Companies pursuing shale development should actively engage in public water policy to advance sustainable and responsible water governance that will reduce business risk. This can be done collectively with other industry and non-industry members, through international organizations, or with local NGOs. Guidance is available in the UN Global Compact CEO Water Mandate publications, *Guide to Responsible Business Engagement with Water Policy*,[47] *Framework for Responsible Business Engagement with Water Policy*,[48] and “Shared Water Challenges and Interests: The Case for Private Sector Engagement in Water Policy and Management,”[49] as well as in the World Wildlife Fund (WWF) report, *Investigating Shared Risk in Water: Corporate Engagement with the Public Policy Process*.[50]

3.2. *Governments and companies, through collective action, can develop source water protection and management plans*. Governments and businesses operating in countries at the early stages of shale development have a unique opportunity to work collectively across sectors to develop source water protection and management plans that: help reduce business risks; promote shared water sourcing and recycling infrastructure; improve the sustainable management of watersheds or aquifers; and include participation from key river basin stakeholders. For example, improving agricultural water efficiency can increase water supply reliability for all users and provide a win-win outcome for both industry and agriculture.[51] These types of shared solutions and early engagement through water-related collective action[52] can provide significant advantages to governments and companies involved and attract investor interest.

4. **Minimize freshwater use and engage in corporate water stewardship to reduce impacts on water availability.**

New and increasing demands for water will intensify the level of stress, further limiting the ability of water users to adapt to drought years and threatening the health of ecosystems. To minimize impacts on water availability:

4.1. *Companies can minimize freshwater use.* Companies can use guidelines, such as the IPIECA guide, *Identifying and Assessing Water Sources*,[53] and work with local governments to evaluate potential non-freshwater sources and build the business case for increased investments in technology to recycle or reuse wastewater, use brackish water, or otherwise significantly reduce water withdrawals. For example, operators in the Horn River basin in British Columbia, Canada, reduced their dependence on freshwater by identifying an opportunity to use saltwater and investing in a closed-looped system.[54]

4.2. *Companies can develop a water strategy and engage in corporate water stewardship.* Oil and gas companies are significant users and managers of water at local and regional levels.[55] As such, they should have water management embedded at the core of their business strategy to minimize exposure to risks and ensure long-term water availability for other users, the environment, and their own operations. This can be done by engaging in corporate water stewardship, a progression of improvements in water use and impact reductions across internal company and value chain operations.[56] Through water stewardship, any company can publicly commit to the sustainable management of water resources in the public interest through collective action. A water stewardship approach helps all major operational, investment, and strategic decisions take water risk into account, including the future impacts of water use on business, local communities, and the environment.[57] Guidance on how to strategically manage water and engage in corporate water stewardship is available through programs such as the UN Global Compact CEO Water Mandate, IPIECA Water Working Group, Alliance for Water Stewardship, European Water Stewardship, or WWF's Water Stewardship Program, to name a few.

Sustainably managing water resources for all users requires robust baseline information and future estimates of water supply and demand and environmental conditions in a given watershed.

APPENDIX A: COUNTRY ANALYSES

Algeria

Background

Energy and shale resources: Fossil fuels are the backbone of the Algerian economy; they accounted for 70 percent of government revenues and 98 percent of export revenues in 2011.[58] Algeria is the largest natural gas producer and second largest oil producer in Africa,[59] and holds the third largest shale gas resource in the world.[60]

Regulatory environment: In January 2013, the Algerian parliament approved amendments to hydrocarbon laws that introduced strong fiscal incentives to attract foreign companies to explore the country's shale resources.[61] In May 2014, the Algerian cabinet announced it will move forward with the exploitation of the country's large shale reserves.[62]

National water resources: More than 80 percent of the country is in the Sahara desert, and shale plays are located in areas of very low rainfall and extremely dry land. Desalination and wastewater reuse are both government priorities. Agriculture accounts for more than 60 percent of the nation's total water withdrawal. A tripled natural gas production and a two-fold increase in oil production over the past 30 years[63] has likely driven significant increases in the demand for water by the oil and gas sector. The Algerian Ministry of Water Resources is in charge of managing the country's water resources.

Water Availability Constraints

- More than 95 percent of Algeria's shale plays are covered by the Sahara desert.
- The Ghadames play holds 40 percent of Algeria's total shale resources and is located in an area that is almost entirely arid, with extremely low levels of surface water availability. Similar conditions are present over the rest of Algeria's plays.
- Industry is the dominant water user in four of the seven shale plays in Algeria.

Business Risks

- The most prominent risk to companies developing shale resources in Algeria is the limited surface water availability and associated challenges in securing freshwater sources.
- High seasonal variability in freshwater supplies will make the timing of drilling and hydraulic fracturing operations critical when evaluating access to water.

Figure A1 | **Shale Plays and Baseline Water Stress in Algeria**

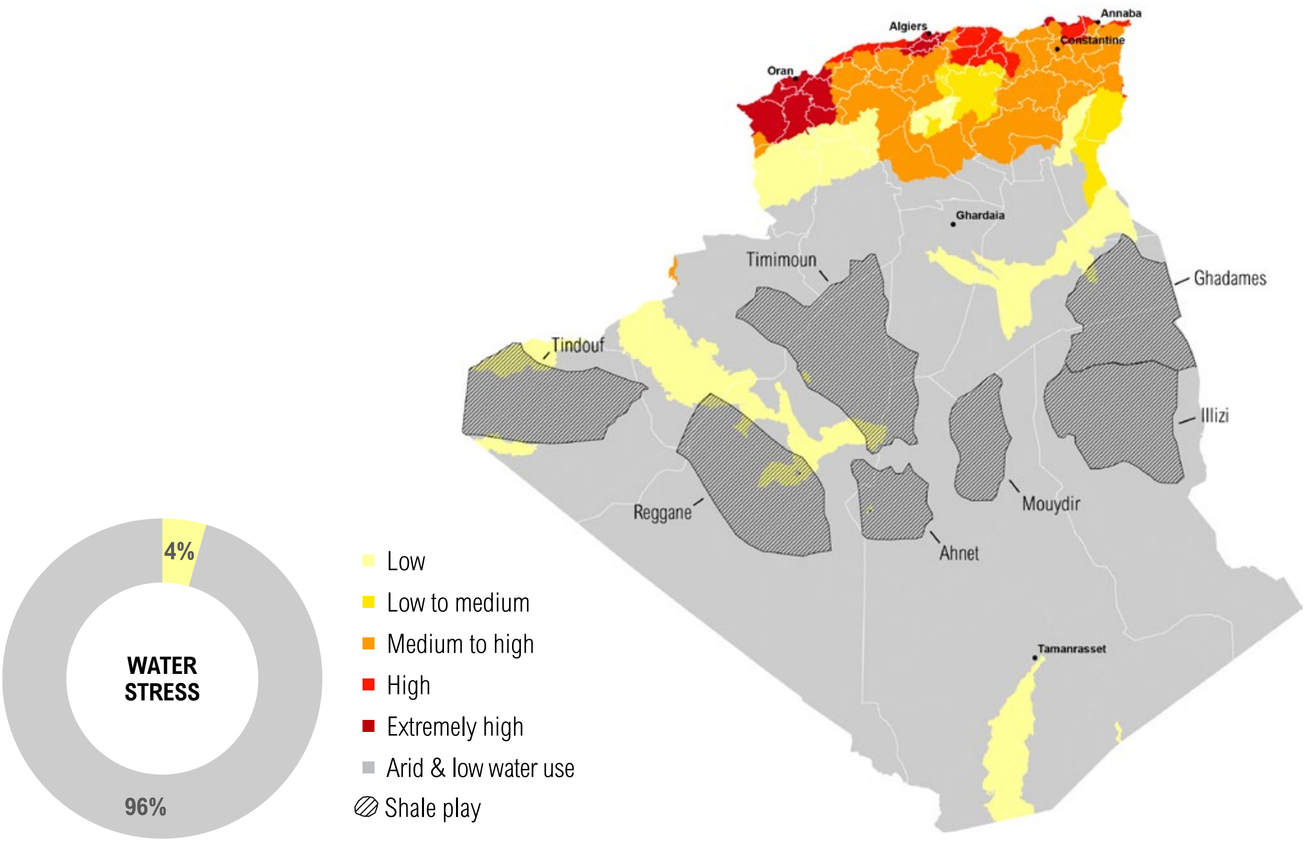
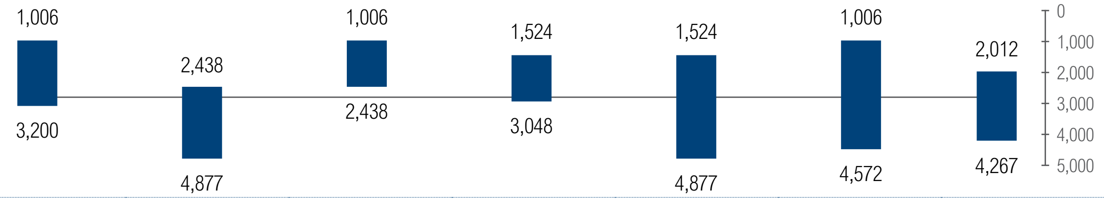


Table A1 | **Water Availability Indicators for Shale Plays in Algeria**

SHALE PLAYS	Ahnet	Ghadames	Illizi	Mouydir	Reggane	Timimoun	Tindouf
Baseline Water Stress							
Seasonal Variability							
Drought Severity							
Groundwater Stress							
Population Density (people/sqkm)	0.4	3.0	0.5	0.7	0.9	1.3	0.3
Dominant Water User	🌾	⚙	👥	🌾	⚙	⚙	⚙
Reserve Depth Interval (meters)	1,006 3,200	2,438 4,877	1,006 2,438	1,524 3,048	1,524 4,877	1,006 4,572	2,012 4,267



Argentina

Background

Energy and shale resources: Argentina is the largest natural gas producer and consumer in South America, and a regionally significant producer and exporter of oil.[64] It possesses the world's second largest technically recoverable shale gas resources and fourth largest technical recoverable tight oil resources based on estimates from the U.S. Energy Information Administration.[65] Over two thirds of the country's resources are located in the Neuquén play, where most of the development is taking place.[66]

Regulatory environment: Price controls on gas caused Argentina to begin importing natural gas in 2008, and weakened the economic incentive for unconventional gas development. To encourage unconventional gas development, the Argentine government passed the "gas and oil plus programs" in 2008, and slackened tariffs in July 2013 to allow 20 percent of produced crude and natural gas to be exported tax free. These, as well as other provincial government interventions in licenses, pricing, and regulation from early 2012 indicate high regulatory uncertainty.[67]

National water resources: Most of the plays in Argentina are located in areas with semiarid or arid climates, except for the Parana, which has more abundant water resources feeding from the Parana River. While agriculture is still the dominant water user, accounting for more than 60 percent of the total water use, industrial withdrawals have recently increased in both absolute value and percentage share of the national total.[68] Multiple institutions operating at the national, provincial, and river basin levels manage water resources.

Water Availability Constraints

- The Neuquén is arguably the most prospective play in Latin America because of its favorable geologic characteristics[69] and pipeline infrastructure.[70] Although, similar to the national average, the Neuquén has medium to low baseline water stress over nearly 70 percent of its area, parts of the play do suffer from medium to high levels of groundwater stress.
- In the San Jorge play, 74 percent of the area faces high to extremely high drought severity, and most of the play is located in arid areas with very low water use and limited supplies.
- Population density in the Parana play is an order of magnitude higher than in the other plays, causing domestic water use to be the highest user of all sectors.

Business Risks

- High drought severity and arid conditions in the San Jorge play could lead to increased costs and competition with other users to access and secure limited freshwater supplies; this could result in financial and regulatory risks to companies developing shale resources.
- Stressed aquifers in the Neuquén could indicate limited access to groundwater should these underground resources not be managed adequately to ensure long-term availability for all users.
- In the Parana play, higher population density could translate to higher regulatory and reputational risks.

Figure A2 | **Shale Plays and Baseline Water Stress in Argentina**

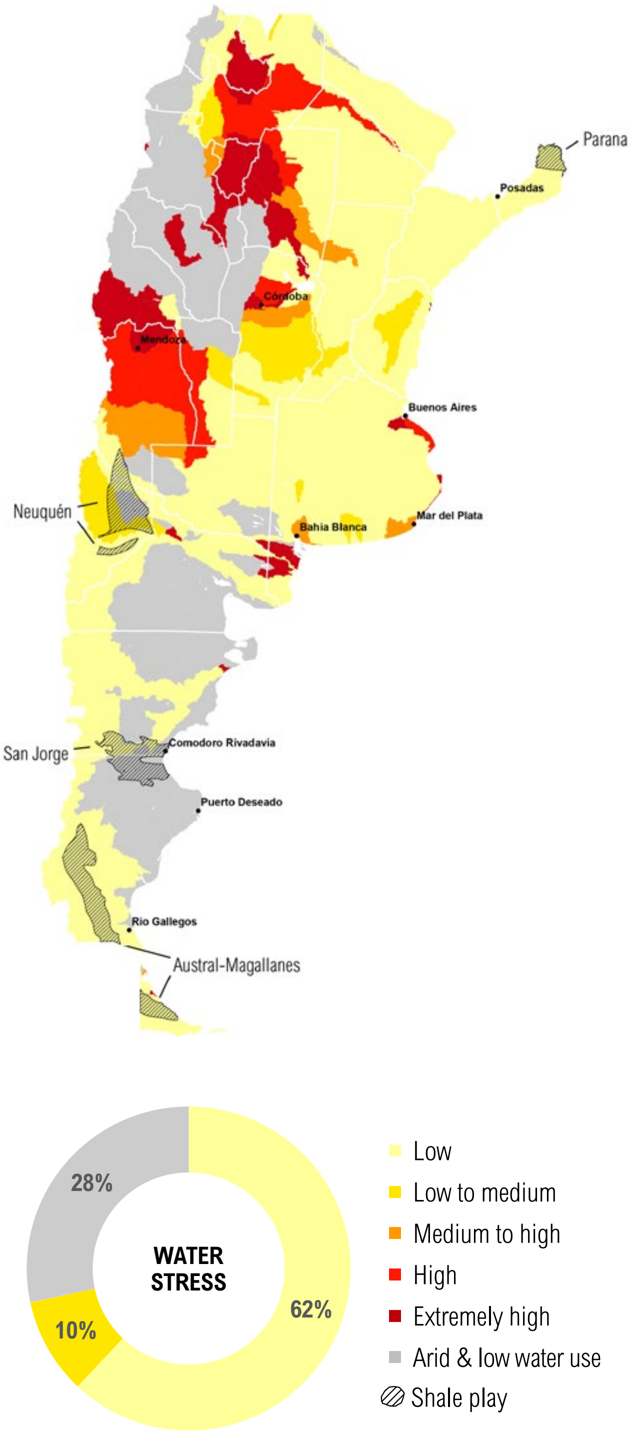
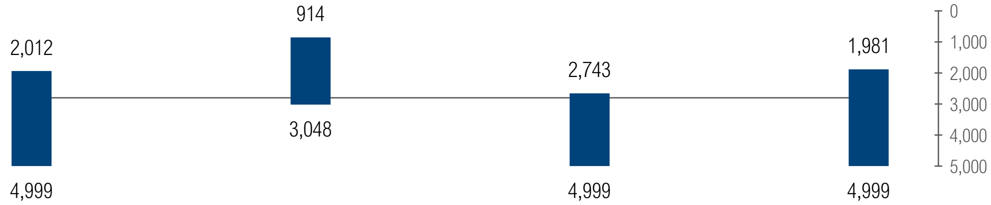


Table A2 | Water Availability Indicators for Shale Plays in Argentina

SHALE PLAYS	Austral - Magallanes	Neuquén	San Jorge	Parana
Baseline Water Stress				
Seasonal Variability				
Drought Severity				
Groundwater Stress				
Population Density (people/sqkm)	2.3	6.3	2.4	37
Dominant Water User	👥	🌾	⚙	👥
Reserve Depth Interval (meters)	2,012 4,999	914 3,048	2,743 4,999	1,981 4,999



Australia

Background

Energy and shale resources: Australia exports over 70 percent of its energy production. It is the second largest coal exporter and the third largest liquefied natural gas exporter worldwide.[71] With the world's seventh largest technically recoverable shale gas resources and similar geologic and industry infrastructure conditions to the United States and Canada, Australia has the potential to be one of the next countries with commercially viable shale gas and tight oil production.[72] The country's electricity price hikes of 70 percent over the past four years are likely to increase the demand for cheaper natural gas that could help displace more-polluting energy sources such as coal.[73]

Regulatory environment: In 2011, the first successful shale gas production test was announced in the Cooper play,[74] with more exploration under way in the western and Northern provinces.[75] Current international exploration interest could result in widespread shale development in Australia.[76]

National water resources: Australia is the world's second driest continent, with much of its shale in extremely remote and very arid locations. The distribution of water withdrawals is highly uneven across the country. At a national level, the country uses 5 percent of its renewable freshwater; however, some regions extract more than half of the locally available water.[77] The Australia Water Act of 2007 was established to achieve sustainable and integrated management of water resources across the country.[78]

Water Availability Constraints

- Most shale resources in Australia are in areas of medium to high drought severity and medium to high seasonal variability in water supplies.
- The Cooper play is most likely to host Australia's first commercial shale well,[79] and is located in an arid region with low levels of water use, limited freshwater supplies, and medium to high seasonal variability.
- The Maryborough play is located in an area of high to extremely high baseline water stress and much higher population density than the rest of the plays in Australia.

Business Risks

- Arid conditions in the Georgina, Cooper, and Canning plays could represent significant challenges for companies seeking to access surface water, leading to potential financial, regulatory, and reputational risks.
- Similarly, high levels of competition for water, and population density in the Maryborough play pose risks to securing freshwater, particularly during dry periods, which could drive increased reputational and regulatory risks for companies competing with local agricultural and domestic water users.
- The Beetaloo play's very high levels of both seasonal variability and drought demonstrate a strong seasonality in water availability. Situations of this type pose financial and reputational risks to shale development during times of increased competition for limited water resources.

Figure A3 | **Shale Plays and Baseline Water Stress in Australia**

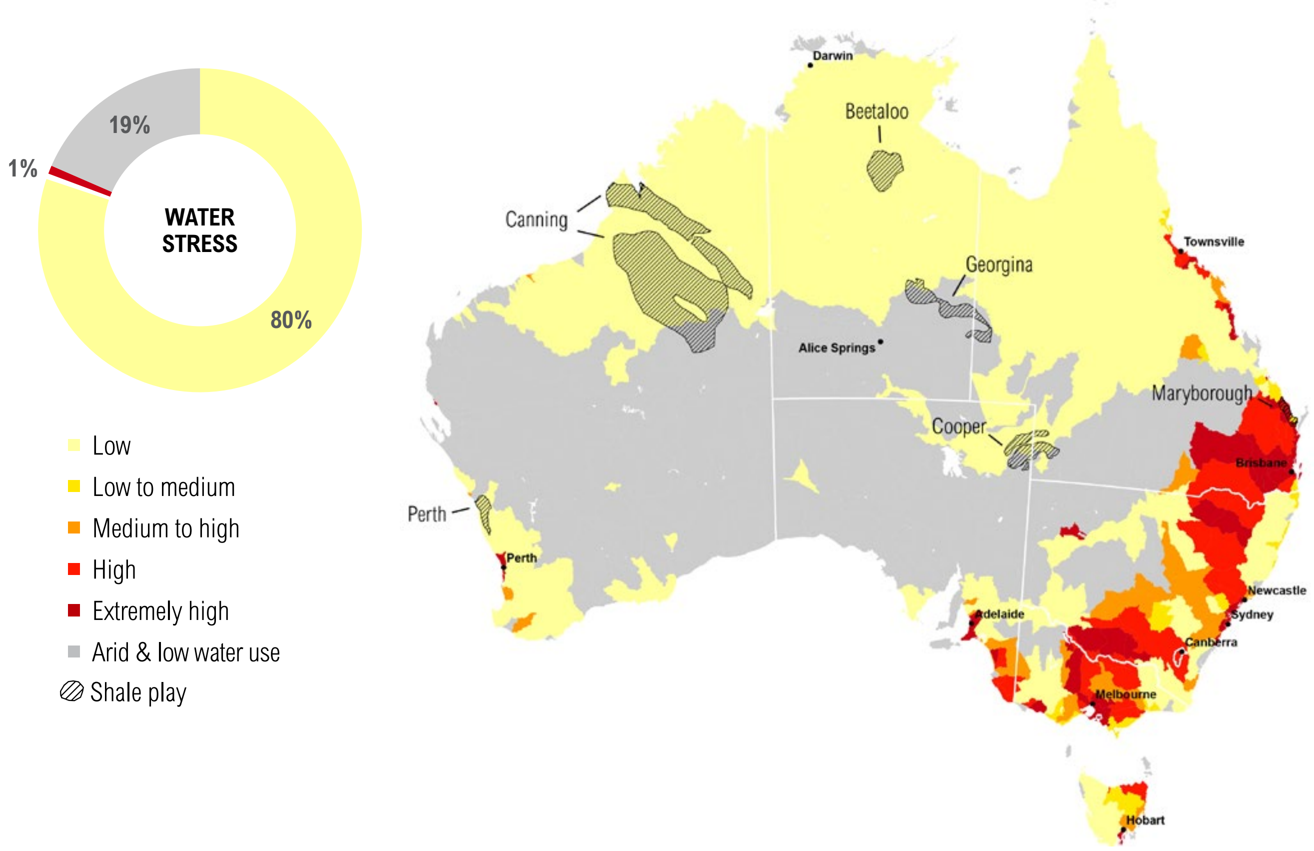
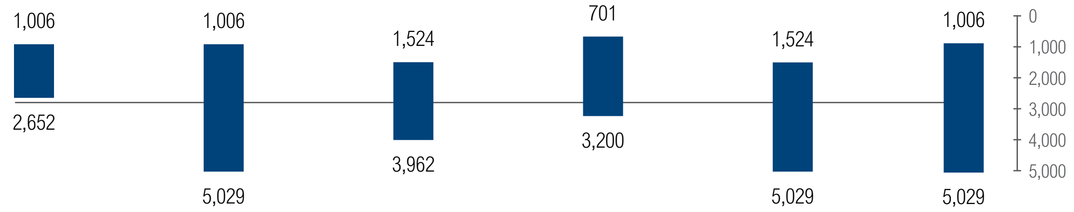


Table A3 | **Water Availability Indicators for Shale Plays in Australia**

SHALE PLAYS	Beetaloo	Canning	Cooper	Georgina	Maryborough	Perth
Baseline Water Stress						
Seasonal Variability						
Drought Severity						
Groundwater Stress						
Population Density (people/sqkm)	0.1	0.1	0.1	0.1	26.0	0.7
Dominant Water User	🌾	👥	⚙	🌾	🌾	⚙
Reserve Depth Interval (meters)	1,006 2,652	1,006 5,029	1,524 3,962	701 3,200	1,524 5,029	1,006 5,029



Canada

Background

Energy and shale resources: Canada is the world's fourth largest producer of natural gas, the primary supplier of U.S. gas imports, and a net exporter of oil, natural gas, and coal.[80] It has the fourth largest technical recoverable shale gas resources and tenth largest technically recoverable tight oil resources worldwide.

Regulatory environment: Canada is the only country other than the United States that is developing shale resources commercially. Hydraulic fracturing is legal in all provinces except Quebec and Newfoundland,[81] and significant development is under way in the western provinces. In Quebec, home to the St. Lawrence Lowlands and Utica shale play, a de facto moratorium on hydraulic fracturing for gas exploitation is in effect until a strategic environmental assessment is completed. Furthermore, the Utica shale play is home to most of Quebec's population and agricultural productivity. Quebec's national assembly is reviewing a bill that, if passed, would formalize the current moratorium on hydraulic fracturing in the Utica shale play.[82]

National water resources: Canada's abundant freshwater resources and low population density make it the country with the most water per capita worldwide.[83] Nevertheless, because of heavy industrialization, many areas of Canada suffer from water stress caused by increased demand for overdrawn water resources. The energy industry in Canada accounts for nearly 70 percent of the country's total water withdrawals.[84]

Water Availability Constraints

- The Colorado Group play, sometimes referred to as the Cardium play, is in the province of Alberta, which has the nation's highest level of competition for freshwater, with nearly 40 percent of the play area under high or extremely high baseline water stress.
- The Cordova Embayment play stands out for its high levels of seasonal variability in freshwater supplies.
- The Utica play, between Montreal and Quebec City along the St. Lawrence River, has the highest population density of all Canadian plays.

Business Risks

- The Cordova Embayment and Colorado Group plays have high seasonal variability and baseline water stress indicating potential challenges for companies to access freshwater. Situations of this type could translate to higher costs and regulatory uncertainty when accessing water for hydraulic fracturing and drilling activities.
- If the moratorium in the Utica play was lifted, high population density and local government opposition could translate into significant social opposition and reputational risks to companies and investors engaged in shale resources development.

Figure A4 | **Shale Plays and Baseline Water Stress in Canada**

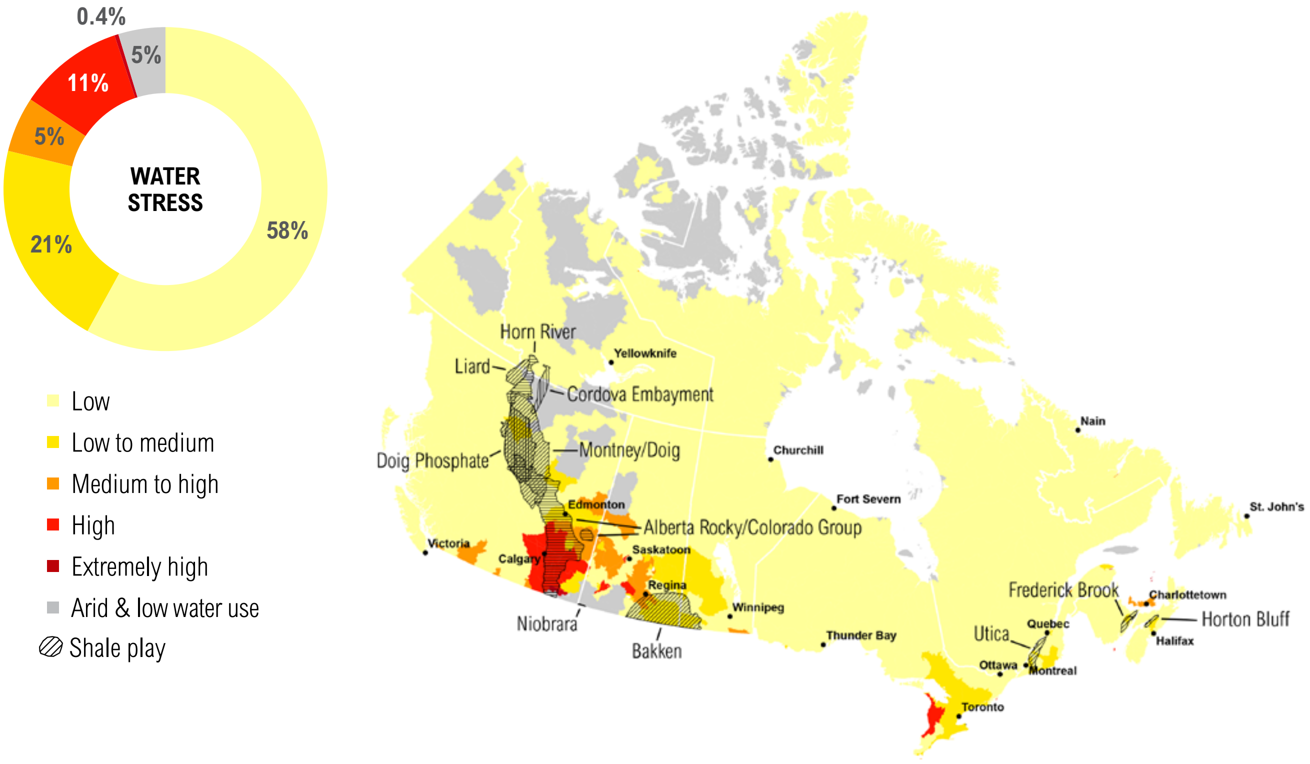


Table A4 | **Water Availability Indicators for Shale Plays in Canada**

SHALE PLAYS	Alberta Rocky (Colorado Group)	Bakken	Cordova Embayment	Doig Phosphate	Frederick Brook	Horn River	Horton Bluff	Liard	Montney (Doig)	Utica
Baseline Water Stress										
Seasonal Variability										
Drought Severity										
Groundwater Stress										
Population Density (people/sqkm)	15.7	1.6	0.1	1.3	11.8	0.3	17.9	0.1	0.3	49.6
Dominant Water User	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙	⚙
Reserve Depth Interval (meters)	3,048 5,000	1,676 2,438	1,676 1,890	2,073 3,322	Unknown	1,920 3,109	914 1,524	2,012 3,962	2,073 3,322	1,219 3,353

China

Background

Energy and shale resources: China is the world's largest energy producer and consumer.[85] The International Energy Agency projects China's energy demand will grow by 60 percent and natural gas consumption by over 400 percent by 2035.[86] Based on EIA information, China possesses the largest technically recoverable shale gas resources and the third largest technically recoverable tight oil resources worldwide.

Regulatory environment: The Chinese government supports shale gas as an enticing alternative to both imported gas and coal, because of its domestic availability and lower greenhouse gas and particulate emissions.[87] Exploration, including the drilling of about 100 wells over the past few years, has focused on the Sichuan basin, which, along with the Tarim, holds the majority of China's shale resources.[88] The government is seeking technology and experience through strategic alliances with foreign operators and, as of September 2012, has been encouraging foreign participation in domestic shale development through a public tender process.[89]

National water resources: China is the second largest water user in the world, responsible for 14 percent of water withdrawals globally, almost a quarter of which are for industrial use.[90] Water is more abundant in the south of China than the north. However, the north holds most of the fossil reserves and industrial activity. In response, the South-North Water Transfer Project is underway, which is designed to transfer more than 44 billion cubic meters of water from the south to the north every year.[91]

Water Availability Constraints

- Over 60 percent of China's shale resources are in areas of high to extremely high baseline water stress or arid conditions.
- The Sichuan play, China's most important shale play, combines areas of low and very high baseline water stress driven by pockets of high demand for water relative to the available supply.
- Over 95 percent of the Tarim play is subject to extremely high baseline water stress or arid conditions, including areas with extremely high groundwater stress and seasonal variability. Collectively, these conditions will pose major challenges for companies to access water.
- All shale resources across China are located in areas of high population density, except for the Tarim and the Junngar plays.

Business Risks

- Companies operating in arid areas and in areas of high or extremely high baseline water stress (60 percent of China's shale play area) will have to compete with other users for what is already a very scarce resource. High levels of competition among agricultural, domestic, and industrial water users could represent higher costs, reputational risks, and increased regulatory uncertainty for operators trying to access water for hydraulic fracturing and drilling operations.
- The Tarim and Junngar plays are dominated by arid and low water use conditions, and very high surface and groundwater stress, leading oil and gas operators to potentially face significant financial risks associated with the additional costs of accessing and transporting water.
- Developers in areas with extremely high population density and medium to high seasonal variability, such as the Sichuan and most other Chinese plays, may face significant regulatory and reputational risks if water-intensive activities are conducted irresponsibly during drier periods.

Figure A5 | **Shale Plays and Baseline Water Stress in China**

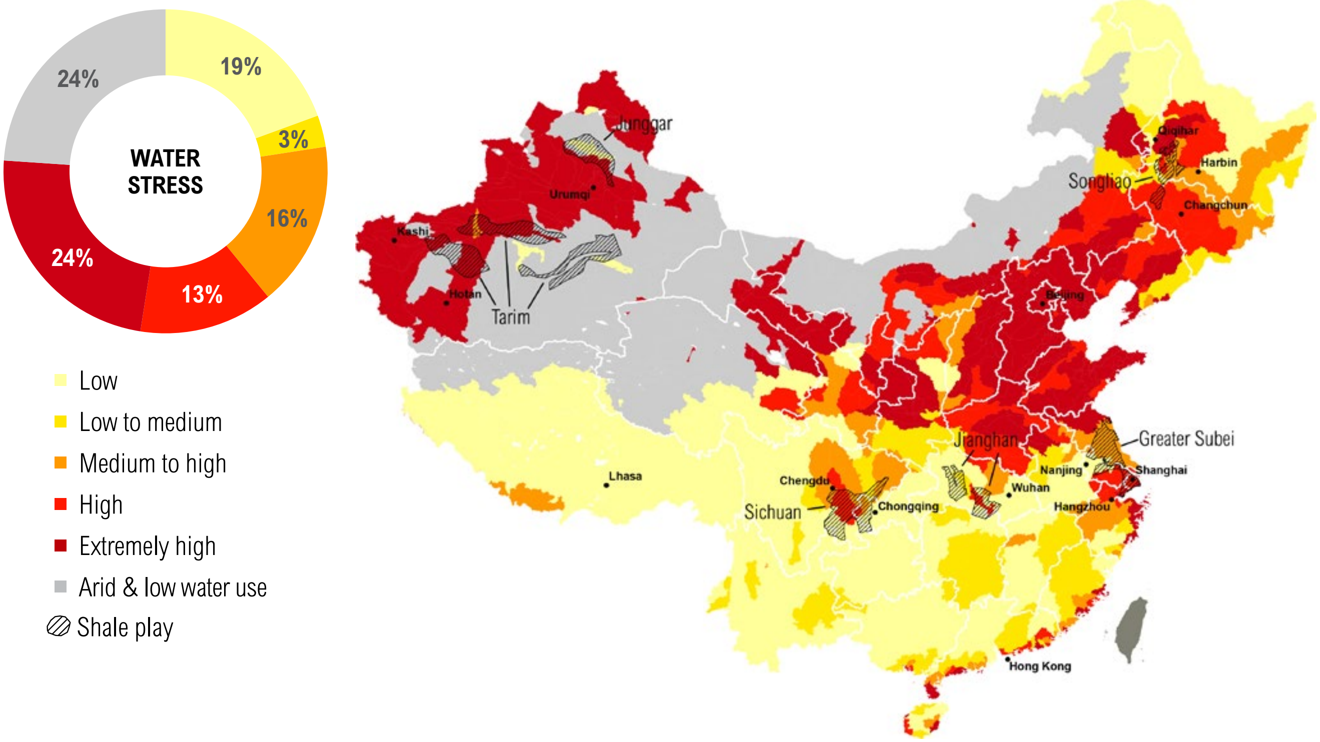


Table A5 | **Water Availability Indicators for Shale Plays in China**

SHALE PLAYS	Greater Subei	Jianghan	Junggar	Sichuan	Songliao	Tarim
Baseline Water Stress						
Seasonal Variability						
Drought Severity						
Groundwater Stress						
Population Density (people/sqkm)	1091.0	323.0	19.0	539.0	135.0	13.0
Dominant Water User	🌾	🌾	🌾	🌾	🌾	🌾
Reserve Depth Interval (meters)	1,006 4,999	1,006 4,999	1,524 4,999	1,000 4,999	1,006 2,499	2,624 4,999

0 1,000 2,000 3,000 4,000 5,000

Mexico

Background

Energy and shale resources: Mexico remains the world's eighth largest oil producer despite recent declines in production and exports; U.S. Energy Information Administration estimates that Mexico possesses the sixth largest technically recoverable shale gas resources and the eighth largest technically recoverable tight oil resources worldwide.

Regulatory environment: Mexico recently introduced a bill to change the constitution and allow private companies to partner with the government to find and produce oil and gas, ending the country's 75-year-old monopoly on oil and gas production, potentially opening up some of the world's biggest remaining untapped oil reserves to private companies.[92]

National water resources: Rainfall is scarce in the north of the country where a large portion of the country's shale is located. Overall, 50 percent of Mexico's annual runoff is generated in the southeast, compared with only 4 percent generated in the north.[93] Rapid urbanization and increasing demands for food and energy in Mexico have driven national water withdrawals to steadily increase over the past few decades, making water management a challenge in Mexico and imposing a significant cost to the country's economy.

Water Availability Constraints

- In Mexico, 61 percent of the technically recoverable shale resources are located in areas that are arid or under high to extremely high baseline water stress. Specifically, the Tampico and Sabinas plays are located almost entirely in areas of very high water stress.
- The Burgos play, which forms part of the high-potential and well-explored Eagle Ford shale formation,[94] has several pockets of extremely high water stress, and sits over a major aquifer already subject to depletion because of unsustainable withdrawals.
- The Tampico play, in which PEMEX plans to drill up to 80 exploratory wells by 2015,[95] is mostly in areas of high to extremely high water stress and seasonal variability in freshwater supplies, similar to the conditions in the Tuxpan play.
- The Veracruz play, which will likely see up to 10 exploratory wells in place by 2015,[96] is located in an area of high seasonal variability in water supplies, has higher population density than other Mexican plays, and includes locations of high competition for water.

Business Risks

- Most of Mexico's technically recoverable shale resources are in areas already subject to high competition for limited surface and groundwater resources. Because of this, competing with agricultural, domestic, and industrial demands for limited supplies of water could pose significant financial, regulatory, and reputational risks to companies engaged in shale development.
- Strong seasonal variability in water supplies is common across the Tampico, Tuxpan, and Veracruz plays, posing additional challenges to securing constant supplies of freshwater throughout the year. Strong temporal variability in water supplies, especially in areas of high population, creates additional uncertainties and reputational risks to companies extracting shale resources.

Figure A6 | **Shale Plays and Baseline Water Stress in Mexico**

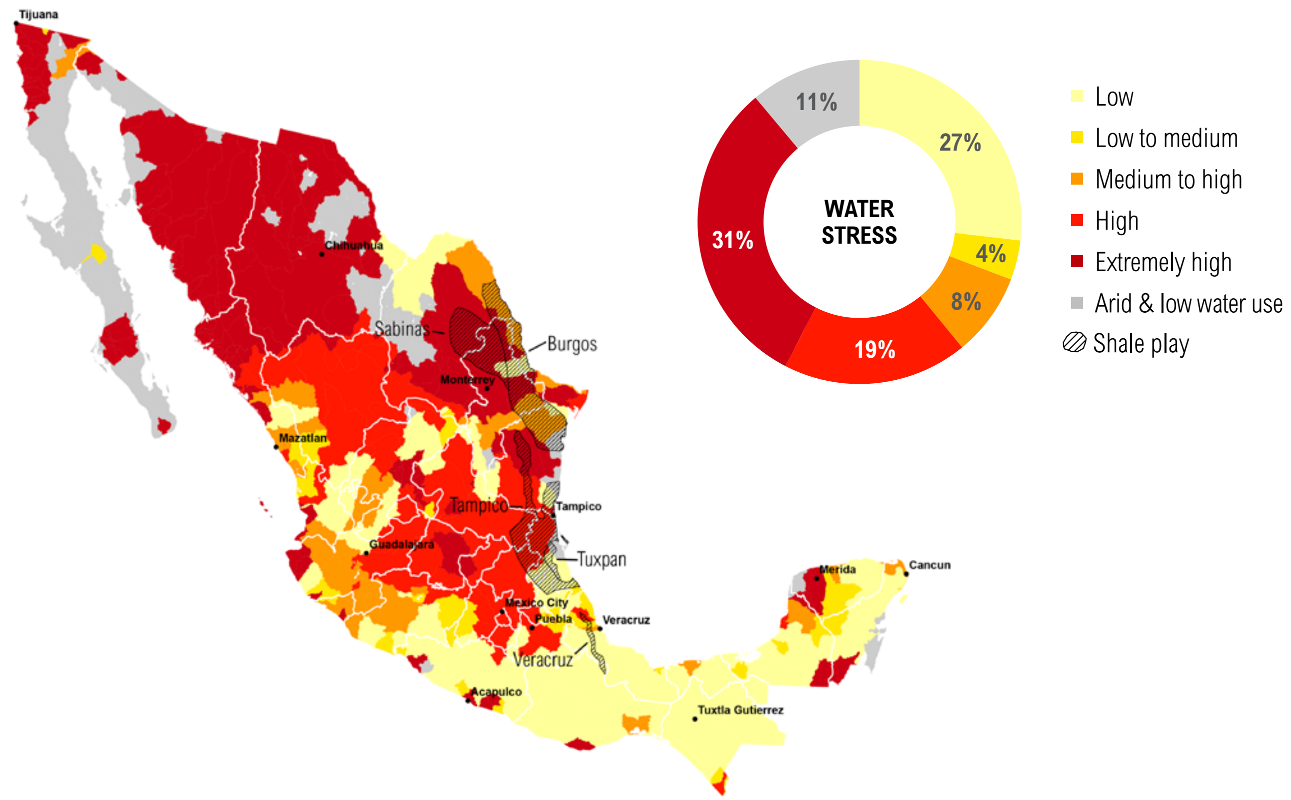
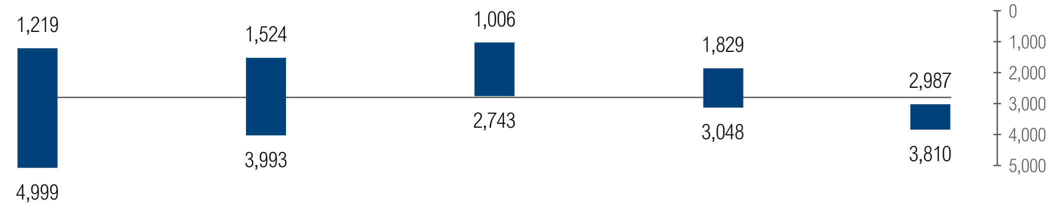


Table A6 | **Water Availability Indicators for Shale Plays in Mexico**

SHALE PLAYS	Burgos	Sabinas	Tampico	Tuxpan	Veracruz
Baseline Water Stress					
Seasonal Variability					
Drought Severity					
Groundwater Stress					
Population Density (people/sqkm)	18.0	15.0	75.0	68.0	96.0
Dominant Water User	🌾	🌾	🌾	⚙	🌾
Reserve Depth Interval (meters)	1,219 4,999	1,524 3,993	1,006 2,743	1,829 3,048	2,987 3,810



Poland

Background

Energy and shale resources: Poland's economic revival over the past decade continues to bolster energy demand. The country imports 95 percent of its crude oil and around two thirds of its natural gas.[97] The development of shale resources could potentially contribute to the waning dominance of coal in Poland's energy supply mix and help achieve the country's commitment to a 14 percent reduction in carbon emissions by 2020. Additionally, it could increase its energy security by reducing dependence on Russian gas imports.

Regulatory environment: To encourage the development of shale resources, the government adopted new legislation in October 2012 to streamline environmental review, facilitate state participation, incentivize investment, and deregulate the labor market in the oil and gas industry. However, significant regulatory, technological, and infrastructural challenges remain. Only 50 wells have been drilled so far, despite Poland's standing as one of the more promising exploration sites for shale development in Europe.[98]

National water resources: Poland's average water resources per capita are among the lowest in Europe, with only 1,500 cubic meters per year per capita–36 percent of the European average. High domestic and industrial water withdrawals combined with natural conditions cause water deficits, particularly in certain areas of the north. There is also considerable variation in river flow, and limited capacity in artificial reservoirs to help mitigate excesses and deficits of surface water.[99]

Water Availability Constraints

- Water availability could pose challenges in accessing water in a few areas of high and extremely high baseline water stress along the coast of the Baltic Sea.
- High population density is common across most plays, indicating potentially high domestic demands for freshwater.
- The Baltic play, Poland's most prospective region,[100] has the highest population density of all Polish plays, as well as the only two areas with extremely high levels of baseline water stress.

Business Risks

- High levels of population density throughout most of the country indicate the potential for social concerns over freshwater availability that could quickly escalate to regulatory and reputational risks to companies engaged in shale development.
- Companies could face challenges to accessing water for drilling and hydraulic fracturing activities in a few areas along the Baltic play because of high competition with other users; this could represent financial, regulatory, and reputational risks to companies not managing water sustainably or engaging with key regulators and river basin stakeholders.

Figure A7 | **Shale Plays and Baseline Water Stress in Poland**

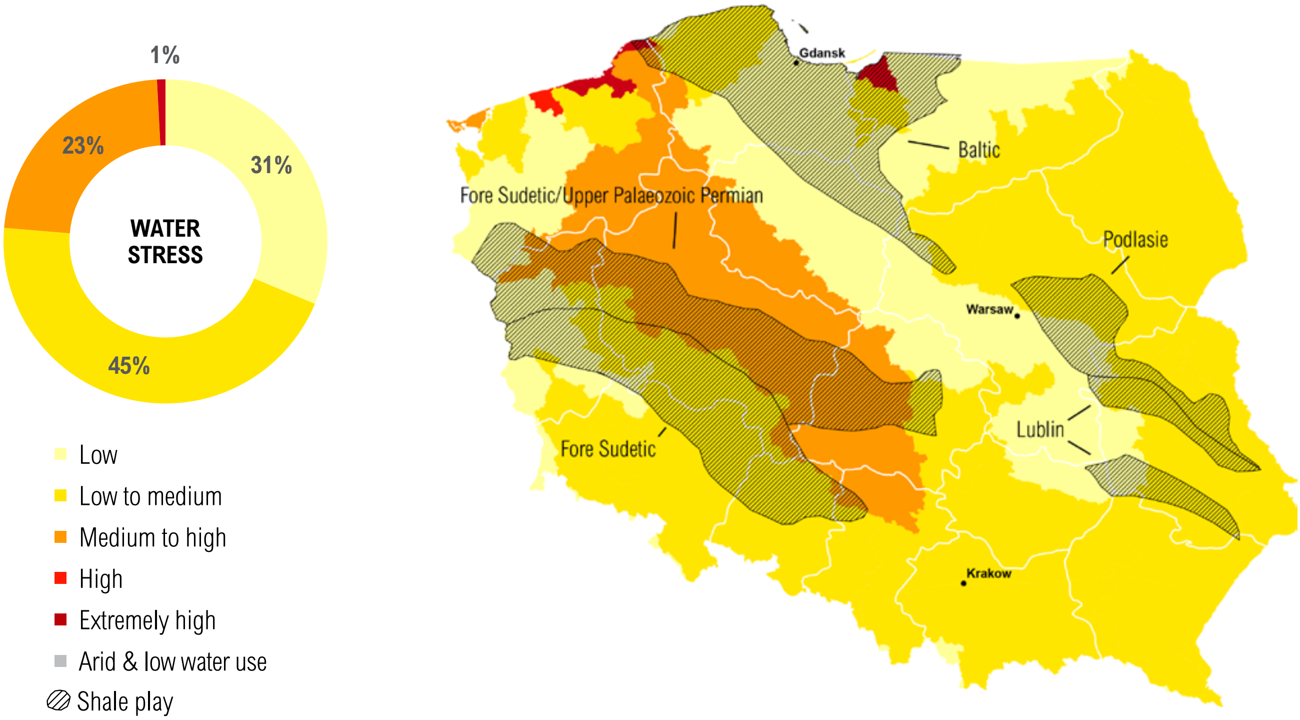
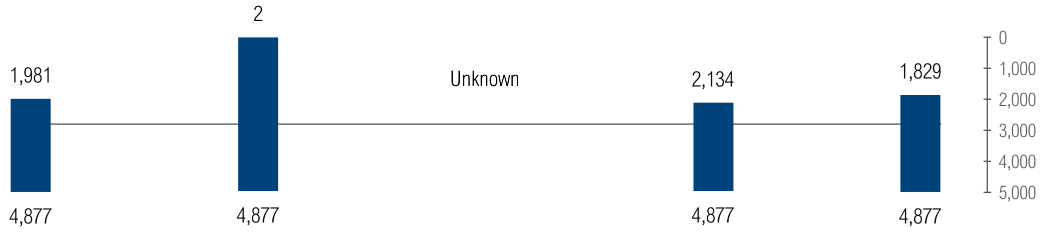


Table A7 | **Water Availability Indicators for Shale Plays in Poland**

SHALE PLAYS	Baltic	Fore Sudetic	Fore Sudetic (Upper Palaeozoic Permian)	Lublin	Podlasie
Baseline Water Stress					
Seasonal Variability					
Drought Severity					
Groundwater Stress					
Population Density (people/sqkm)	116.0	113.0	79.0	71.0	98.0
Dominant Water User	⚙	⚙	⚙	⚙	⚙
Reserve Depth Interval (meters)	1,981 4,877	2 4,877	Unknown	2,134 4,877	1,829 4,877



Saudi Arabia

Background

Energy and shale resources: Oil is the backbone of the Saudi Arabian economy. Saudi Arabia (officially known as the Kingdom of Saudi Arabia) has the world's largest crude oil reserves, is the second largest oil producer and holds the fifth largest conventional gas reserves in the world (mostly associated with petroleum deposits). In Saudi Arabia, domestic natural gas demand is projected to almost double by 2030.[101] The country banned natural gas imports, so domestic supplies will be required to meet any additional demand.[102] The Kingdom's massive conventional reserves could supply its growing demand; however, given the Organization of the Petroleum Exporting Countries' (OPEC's) limits on oil production, the majority of this production growth will likely come from nonassociated reserves.

Regulatory environment: Saudi Arabia's oil use in relation to its economic output is twice the global average, indicating possible interest in exploration and development of shale gas as an alternative fuel type. However, the Kingdom's plans to explore its vast shale reserves are likely to take years to develop. There are no political barriers at this point; instead, the success will depend on the economic feasibility, especially in regard to limited water supplies.[103]

National water resources: Saudi Arabia lies in a region of tropical and subtropical desert, and for the most part is arid and dry. It is the world's largest producer of water from desalination; in 2006, more than 1 billion cubic meters of desalinated water were produced, equivalent to almost half of the country's total annual renewable surface water resources. However, water supplied from desalination meets only a small fraction of the total demand; the remainder is sourced from deep groundwater aquifers posing significant risks to the depletion of these resources.

Water Availability Constraints

- Saudi Arabia shale plays are located in the Arabian Desert, in areas of extremely high surface and groundwater stress, as well as naturally occurring arid conditions.

Business Risks

- High costs associated with accessing water and developing robust desalination capacity expansion to meet the water demands for hydraulic fracturing and drilling will be one of the largest challenges in developing shale resources in Saudi Arabia.
- High surface and groundwater stress and arid conditions also indicate the potential for competition with local users for scarce water resources. Conflicts with other users because of reallocation or depletion of water resources can rapidly escalate into reputational and regulatory risks for companies developing shale resources.

Figure A8 | **Shale Plays and Baseline Water Stress in Saudi Arabia**

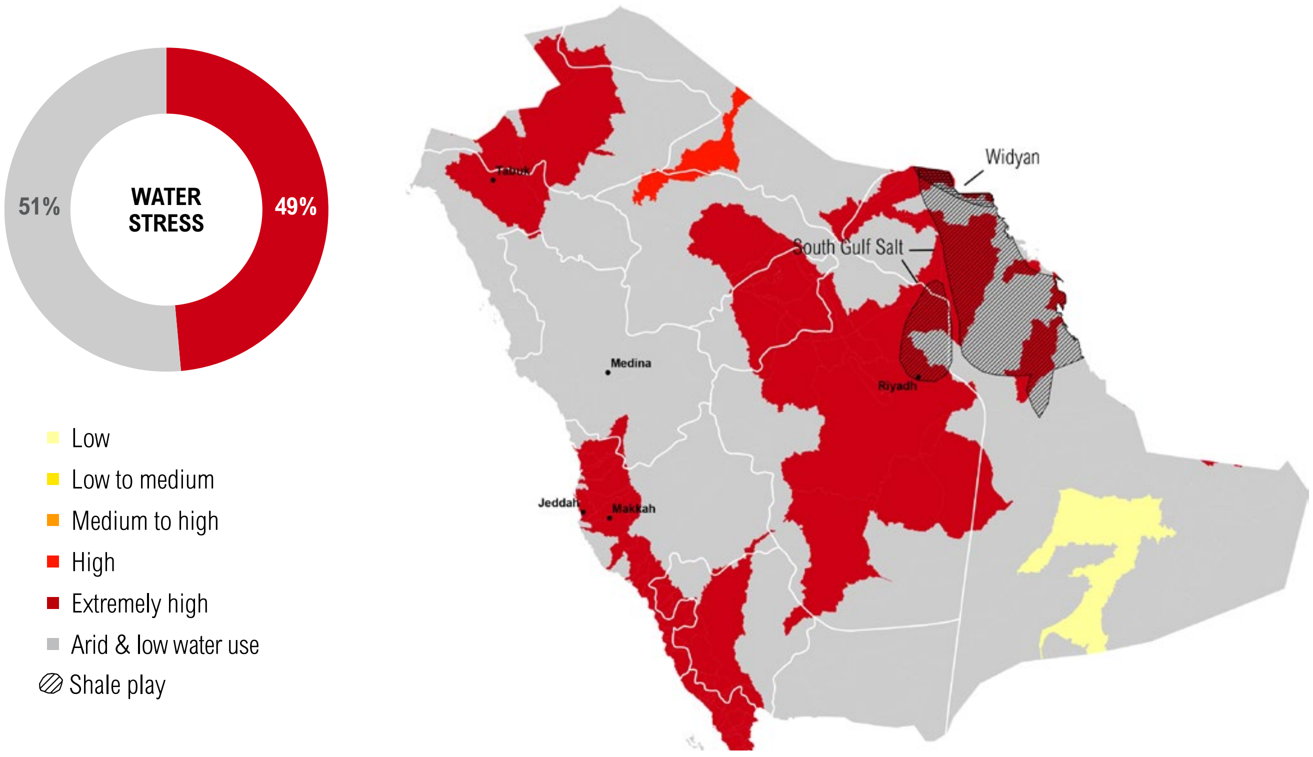


Table A8 | Water Availability Indicators for Shale Plays in Saudi Arabia

SHALE PLAYS	South Gulf Salt	Widyan
Baseline Water Stress		
Seasonal Variability		
Drought Severity		
Groundwater Stress		
Population Density (people/sqkm)	0.4	3.0
Dominant Water User	🌾	⚙
Reserve Depth Interval (meters)	Unknown	Unknown

South Africa

Background

Energy and shale resources: Coal fuels South Africa's economy and energy exports.[104] The country's small and dwindling conventional natural gas and oil reserves have required South Africa to rely heavily on imported fuels, thereby threatening the country's energy security. Based on estimates by the U.S. Energy Information Administration, South Africa has the world's eighth largest technically recoverable shale gas resources which, if developed, could boost the country's economy and temper its high and increasing unemployment rate.[105] In addition to financial incentives for shale development—including a high natural gas price, low corporation tax, and favorable royalty terms[106]—South Africa's rapidly growing demand for electricity (spotlighted by rolling blackouts and coupled with a commitment to reduce carbon emissions by 34 percent by 2020) increases the demand for a less carbon-intensive fuel than coal for power generation.[107]

Regulatory environment: The government instituted a moratorium on shale development in April, 2011 which was lifted in September 2012 after a government-funded study on the environmental and water-use impacts of hydraulic fracturing found shale gas extraction to be adequately safe.[108] While various international oil companies have obtained "technical cooperation permits," none have been granted exploration permits to begin drilling. There has been some confusion on when development might start. Some argue that it will take a few years,[109] and that no exploratory licenses will be granted until an appropriate law is in place.[110] Others say that it could start as early as 2015, after the South African cabinet announced that exploration licenses will be granted before the elections of 2014.[111]

National water resources: South Africa is a semiarid country characterized by low rainfall and limited groundwater resources. Almost half the country is supplied by water from the Orange River which flows through four countries—Namibia, Botswana, South Africa, and Lesotho—requiring international cooperation to manage the watershed. More than 90 percent of the nation's total water withdrawals are from agricultural and domestic users, and the country has a national water resources strategy to help meet the growing demands for limited freshwater resources.

Water Availability Constraints

- South Africa has just one large shale play, located in the Karoo desert. The word Karoo derives from the Khoisan word for "land of great thirst."[112] Approximately 75 percent of the Karoo play is located in arid areas with high or extremely high baseline water stress.
- The Karoo play is over an aquifer that is already under stress, and that is being withdrawn at rates that far exceed its natural recharge rates.

Business Risks

- In most of the play, the demand for surface and groundwater is close to or exceeds the available supply. In these areas, competition for water with agriculture or domestic users can pose significant regulatory and reputational risks to companies involved in shale development.
- Accessing water in areas that are arid or with high levels of surface and groundwater stress can be costly and translate into financial risks if not accounted for at the early stages of decision making.

Figure A9 | **Shale Plays and Baseline Water Stress in South Africa**

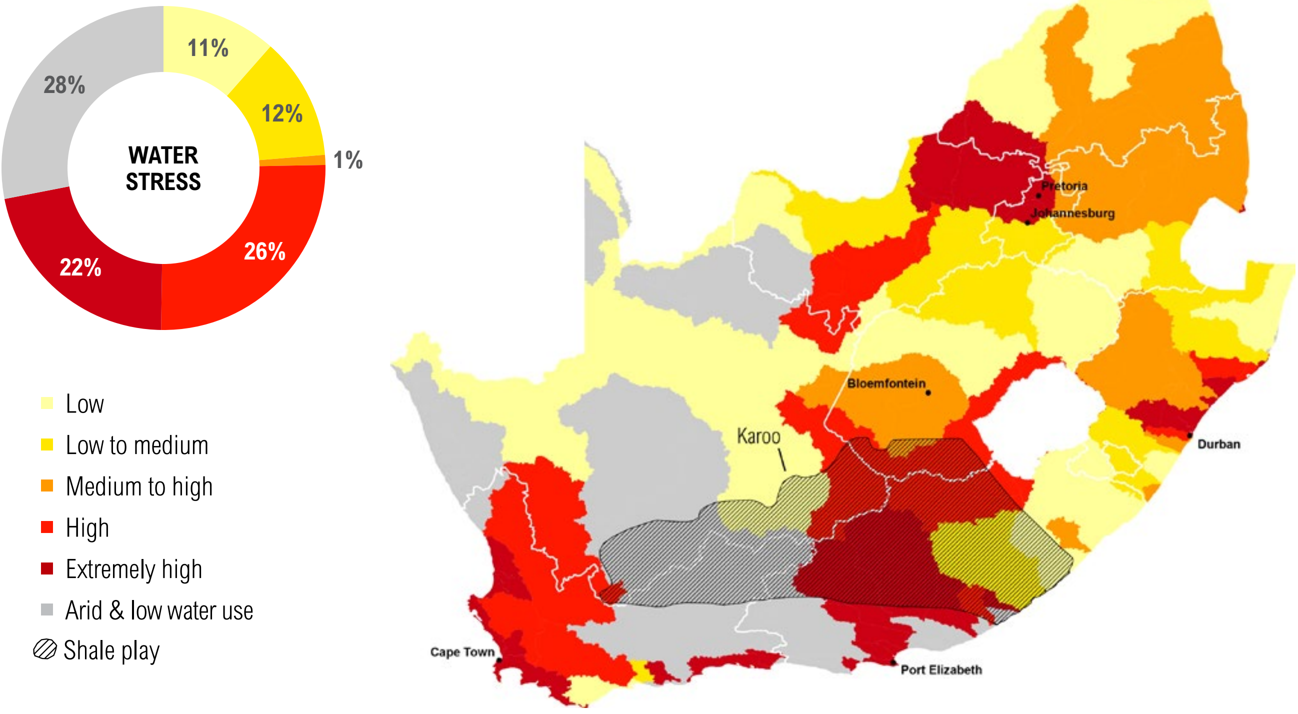
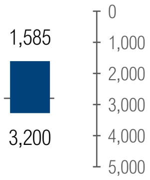


Table A9 | Water Availability Indicators for Shale Plays in South Africa

SHALE PLAYS	Karoo
Baseline Water Stress	
Seasonal Variability	
Drought Severity	
Groundwater Stress	
Population Density (people/sqkm)	13.0
Dominant Water User	🌾
Reserve Depth Interval (meters)	

United Kingdom

Background

Energy and shale resources: The United Kingdom is the second largest oil producer and the third largest natural gas producer in Europe.[113] It switched from exporting to importing natural gas and oil in 2004 and 2005 respectively, as production from major mature conventional gas and oil fields declined.[114]

Regulatory environment: The government has set high natural gas prices and plans to create strong financial incentives for shale development by cutting taxes on shale production and requiring shale developers to pay local communities £100,000 per well plus 1 percent of revenue, to mimic the benefits U.S. mineral rights owners receive.[115] The government enacted a moratorium on shale operations in May 2011 after the country's first hydraulically fractured well was associated with a series of small earthquakes. It lifted the moratorium 18 months later after enacting more stringent regulations aimed at reducing seismic risks. Despite local opposition, the national government remains broadly supportive of shale gas development.[116]

National water resources: The United Kingdom's freshwater resources per capita are slightly below the European average,[117] and water resources are not evenly distributed, with more water in the west than in the east of the country. Industrial water withdrawals in the United Kingdom have been declining gradually for the past 10 years as the country's natural gas and oil production shrinks. However, industrial water use still accounts for more than 30 percent of the nation's total water demand.[118]

Water Availability Constraints

- High population density and domestic water demands are common across most shale plays in the United Kingdom.
- The Northern Petroleum System, Bowland, and Wessex-Weald plays contain the most active shale exploration in the United Kingdom, and are located in areas of medium to extremely high baseline water stress.

Business Risks

- High population density and high levels of domestic water withdrawals across most plays in the United Kingdom indicate that companies developing shale resources could potentially face regulatory and reputational risks if they don't actively engage with local stakeholders and undertake water stewardship efforts to ensure water security.
- In areas with high and extremely high levels of water stress, companies could face challenges in accessing water because of competition and increasing costs that could pose financial risks if not planned for in advance.

Figure A10 | **Shale Plays and Baseline Water Stress in United Kingdom**

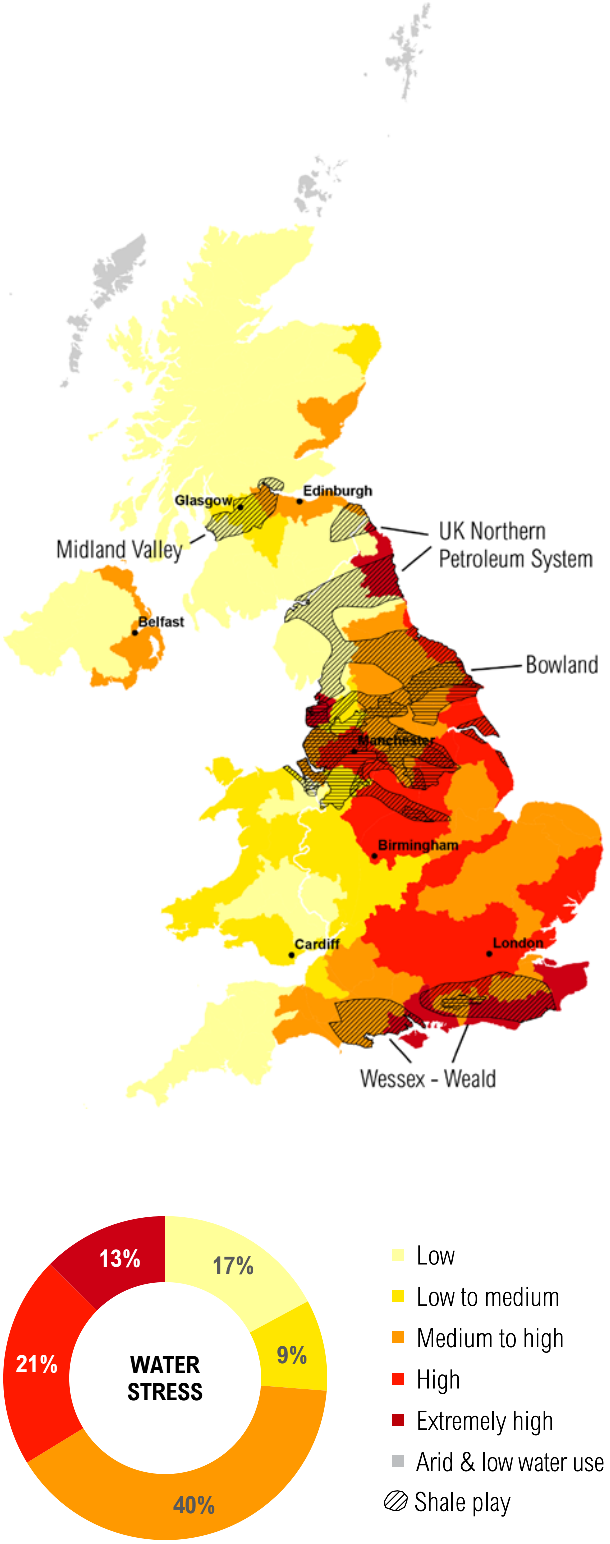


Table A10 | Water Availability Indicators for Shale Plays in United Kingdom

SHALE PLAYS	Bowland	Midland Valley	UK Northern Petroleum System	Wessex - Weald
Baseline Water Stress				
Seasonal Variability				
Drought Severity				
Groundwater Stress				
Population Density (people/sqkm)	609.0	677.0	170.0	181.0
Dominant Water User	👥	🌾	⚙	👥
Reserve Depth Interval (meters)	Unkno wn	1,524 3,962	1,524 3,962	1,219 3,505 0 1,000 2,000 3,000 4,000 5,000

United States

Background

Energy and shale resources: The United States is the world's largest natural gas producer and the largest consumer of natural gas and oil. The United States possesses the world's second largest tight oil and the fifth largest technically recoverable shale gas resources. Under conditions favorable to development, shale gas could contribute significantly to the United States becoming an exporter of natural gas by 2019 and an exporter of liquid fuels by the mid-2030s.[119]

Regulatory environment: The U.S. federal government and many state governments broadly support continued development of shale resources,[120] but eight local and three state moratoriums are in place, as well as one statewide ban.[121] Environmental regulation is being introduced at federal[122] and state levels (e.g. 14 states require disclosure of fracturing fluids; 5 require a permit, registration, and reporting for water withdrawals over 1,000 gallons a day; and 11 require a permit or approval and recordkeeping for wastewater transportation).[123]

National water resources: The United States possesses 7 percent of the world's total freshwater resources[124] and is the world's third largest water user. However, with a spectrum of different geography and climates, the availability of water resources varies significantly across the country, from the water-abundant northeast and northwest to the water-scarce west and southwest. The industrial sector is the dominant water user in the United States using almost half of national water withdrawals.[125] Oil and gas companies have spent approximately US$1 billion on pipelines to secure freshwater sources,[126] and stressed water supplies have driven local governments to ban the use of city water for hydraulic fracturing,[127] causing operators to truck water from up to 75 miles away.[128]

Water Availability Constraints

- Over 35 percent of U.S. shale resources are located in areas that are either arid or under high or extremely high baseline water stress.
- For the most part, shale plays in the west (Texas, Colorado, and California) are located in areas of higher competition for water than those located in the more water-abundant east.
- For the western plays, agriculture is the dominant water user across 80 percent of the area. In the east, the dominant water user is industry.
- Most U.S. plays are in areas at least partially subject to high or extremely high baseline water stress and arid and low water use.
- Ten plays (for example the Monterey, Niobrara, Avalon-Bone Spring, and Eagle Ford) sit atop aquifers that are being withdrawn at rates that far exceed their natural recharge rate.

Business Risks

- The largest business risk to companies developing shale in the United States is the increasing demand and competition for freshwater, which could potentially lead to uncertainty in regulatory changes that could cause financial, regulatory, and reputational risks to companies.
- In plays with very high levels of competition for freshwater (such as the Monterey, Lombard, Mowry, Niobrara, Lewis, Avalon-Bone Spring, Barnett-Woodford, Antrim, or Pierre-Niobrara plays) accessing water might represent additional costs to operators and financial risks, particularly in areas where depleted groundwater resources are already facing high demand from irrigated agriculture (for example the Monterey or Avalon-Bone Spring plays).

Figure A11 | **Shale Plays and Baseline Water Stress in the United States**

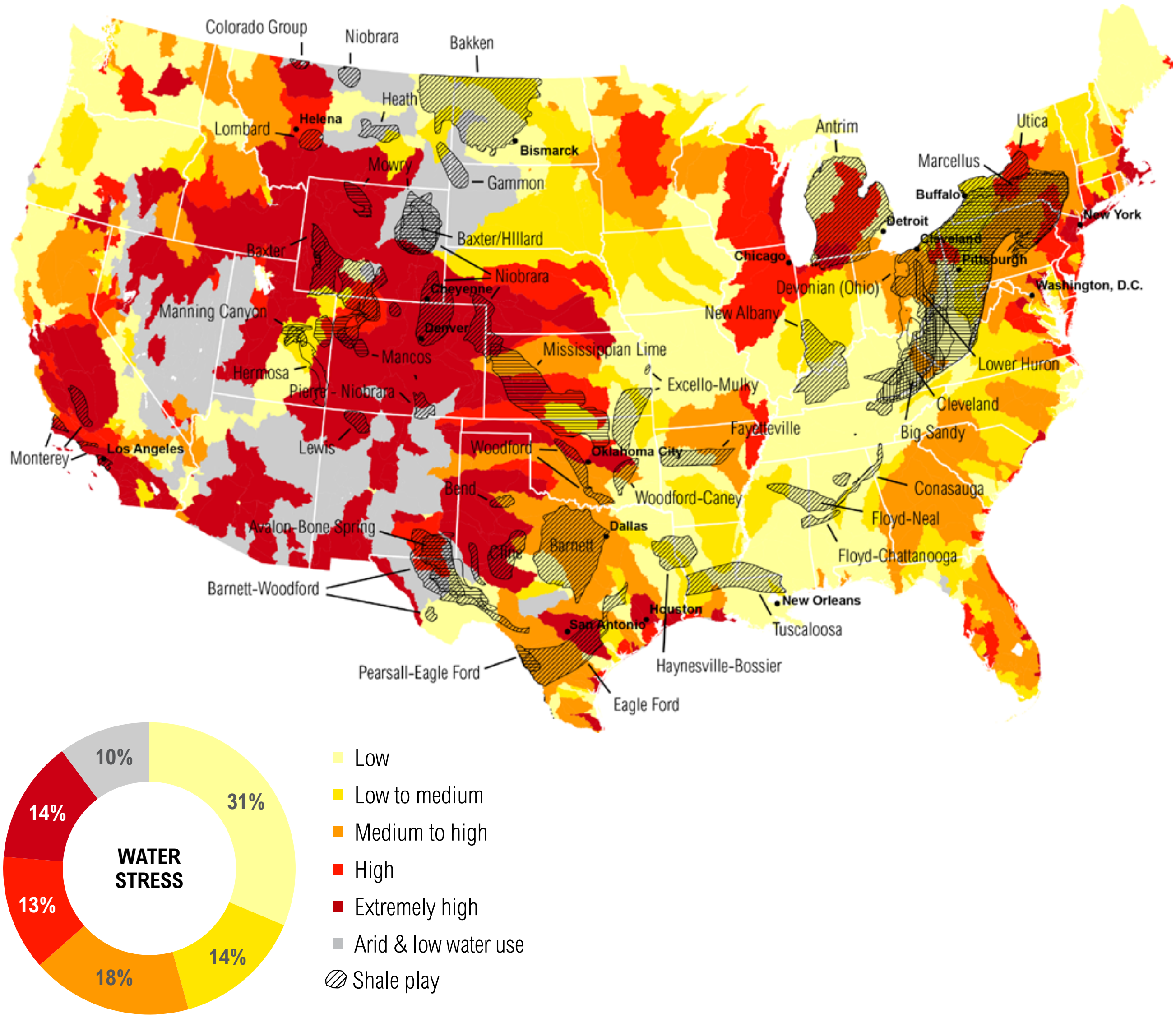


Table A11 | Water Availability Indicators for Shale Plays in the United States

SHALE PLAYS	Antrim	Avalon - Bone Spring	Bakken	Barnett	Barnett - Woodford	Baxter	Baxter/Hillard	Bend	Big Sandy	Brookian
Baseline Water Stress										
Seasonal Variability										
Drought Severity										
Groundwater Stress										
Population Density (people/sqkm)	72	3.1	3.0	60	0.6	1.2	1.2	3.1	32	0.1
Dominant Water User	⚙	🌾	⚙	⚙	🌾	🌾	⚙	🌾	⚙	⚙
Reserve Depth Interval (meters)	366 1,006	1,676 4,572	1,676 2,438	2,073 2,591	Unknown	2,438 3,658	Unknown	2,134 3,200	Unknown	Unknown 0 1,000 2,000 3,000 4,000 5,000

Table A11 | Water Availability Indicators for Shale Plays in the United States (cont.)

SHALE PLAYS	Chattanooga	Cleveland	Cline	Conasauga	Devonian (Ohio)	Eagle Ford	Excello - Mulky	Fayetteville	Floyd - Chattanooga	Floyd - Neal
Baseline Water Stress										
Seasonal Variability										
Drought Severity										
Groundwater Stress										
Population Density (people/sqkm)	24	15	5.5	119	61	11	44	23	8.5	28
Dominant Water User	⚙	⚙	⚙	⚙	⚙	🌾	⚙	⚙	⚙	⚙
Reserve Depth Interval (meters)	Unknown	Unknown	Unknown	400 640	Unknown	1,006 3,658	Unknown	1,200 2,316	Unknown	Unknown

Table A11 | Water Availability Indicators for Shale Plays in the United States (cont.)

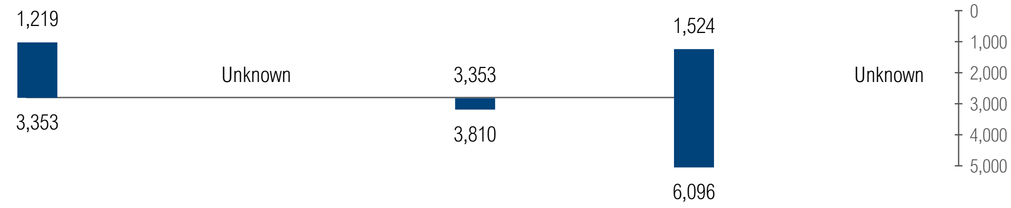
SHALE PLAYS	Gammon	Haynesville - Bossier	Heath	Hermosa	Kingak	Lewis	Lombard	Lower Huron	Mancos	Manning Canyon
Baseline Water Stress										
Seasonal Variability										
Drought Severity										
Groundwater Stress										
Population Density (people/sqkm)	0.4	40	0.2	1.1	0.1	8.1	2.4	0.7	2.4	0.7
Dominant Water User	⚙	⚙	🌾	🌾	⚙	🌾	🌾	⚙	🌾	🌾
Reserve Depth Interval (meters)	Unknown	3,505 4,267	Unknown	Unknown	Unknown	914 1,829	Unknown	Unknown	Unknown	Unknown 0 1,000 2,000 3,000 4,000 5,000

Table A11 | Water Availability Indicators for Shale Plays in the United States (cont.)

SHALE PLAYS	Marcellus	Mississippian Lime	Monterey	Mowry	New Albany	Niobrara	Pearsall - Eagle Ford	Pierre - Niobrara	Shublik	Tuscaloosa
Baseline Water Stress										
Seasonal Variability										
Drought Severity										
Groundwater Stress										
Population Density (people/sqkm)	34	5.8	703	1.8	27	29	2.6	3.5	0.1	23
Dominant Water User	⚙	🌾	🌾	🌾	⚙	🌾	🌾	🌾	⚙	⚙
Reserve Depth Interval (meters)	610 2,743	Unknown	Unknown	Unknown	152 152	914 1,829	Unknown	Unknown	Unknown	3,048 4,572 0 1,000 2,000 3,000 4,000 5,000

Table A11 | Water Availability Indicators for Shale Plays in the United States (cont.)

SHALE PLAYS	Utica	Wolfberry	Wolfcamp (Wolfbone)	Woodford	Woodford - Caney
Baseline Water Stress					
Seasonal Variability					
Drought Severity					
Groundwater Stress					
Population Density (people/sqkm)	14	32	0.9	18	11
Dominant Water User	⚙	⚙	⚙	⚙	⚙
Reserve Depth Interval (meters)	1,219 3,353	Unknown	3,353 3,810	1,524 6,096	Unknown



ABBREVIATIONS AND ACRONYMS

EIA	U.S. Energy Information Administration
GDP	Gross domestic product
GHG	Greenhouse gas
GIS	Geographic information system
IEA	International Energy Agency
IPIECA	The global oil and gas industry association for environmental and social issues
NGLs	Natural gas liquids
NGO	Nongovernmental organization
OPEC	Organization of the Petroleum Exporting Countries
PEMEX	Petróleos Mexicanos
TRR	Technically recoverable resource
UK	United Kingdom
U.S.	United States
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UN	United Nations
WRI	World Resources Institute
WVGISTC	West Virginia Geographic Information Systems Technical Center
WVU	West Virginia University

DEFINITIONS

Brackish water: water that is generally saltier than freshwater, but not as salty as seawater.[129]

Conventional oil and gas resources: reservoirs of natural gas or oil that typically permit the oil and natural gas to flow readily into wellbores.

Flowback: water that returns to the surface directly after hydraulic fracturing. Flowback contains a mix of fracturing fluid and water originally found in the formation.

Hydraulic fracturing: treatment by which a fluid is pumped at high pressure down a wellbore to initiate and propagate cracks in low-permeability geological formations.

Natural gas liquids (NGLs): natural gas liquids are naturally occurring hydrocarbons found in natural gas or associated with crude oil that are considered a byproduct in the oil and gas industry but are increasingly being targeted for extraction.

Produced water: water that returns to the surface along with the oil or gas pumped from the well; produced water returns to the surface after the flowback and is mostly water originally found in the formation.

Recycled Water: water used a second time after undergoing treatment.

Reused Water: water used a second time with minimal treatment.

Shale basin: large shale formations defined by similar geologic characteristics.

Shale gas: natural gas deposits found in shale reservoirs, with even lower permeability than tight gas reservoirs.

Shale play: area of a shale basin where gas and oil could be commercially extracted. Oil and gas deposits within a play usually share similar geologic and geographic properties such as source rock, migration pathways, trapping mechanisms, and hydrocarbon type.[130]

Shale resource: hydrocarbon resources found in shale plays, such as natural gas, natural gas liquids, and tight oil.

Technically recoverable resource (TRR): resources that can be produced using current technology without reference to the economic viability.[131]

Tight gas: natural gas trapped in reservoir rock with a permeability that is a factor of 10 to thousands of times less permeable than conventional natural gas reservoirs.

Tight oil: oil trapped in fine-grained sedimentary rocks with extremely low permeability, such as shale, sandstone, or carbonate.

Unconventional oil or gas resources: reservoirs of natural gas or oil, in geological formations with often extremely low permeability, which are unable to flow readily to the wellbores. Examples include: heavy oil, oil sands or tar sands, tight oil, oil shales, tight gas, shale gas, and coalbed methane.

Water consumption: volume of surface or groundwater withdrawn that is not returned to the original water source and therefore is no longer available for reuse.

Water withdrawal: volume of water that is taken from a surface or groundwater source

Water stress: the ratio of total water withdrawals relative to the available renewable surface water

ENDNOTES

1. In this report, shale resources (or more technically, shale hydrocarbons) include shale gas, natural gas liquids, and tight oil.

2. Technically recoverable resources based on estimates by the U.S. Energy Information Administration.

3. Technically recoverable resources based on estimates by the U.S. Energy Information Administration.

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ABOUT WRI

WRI is a global research organization that works closely with leaders to turn big ideas into action to sustain a healthy environment—the foundation of economic opportunity and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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