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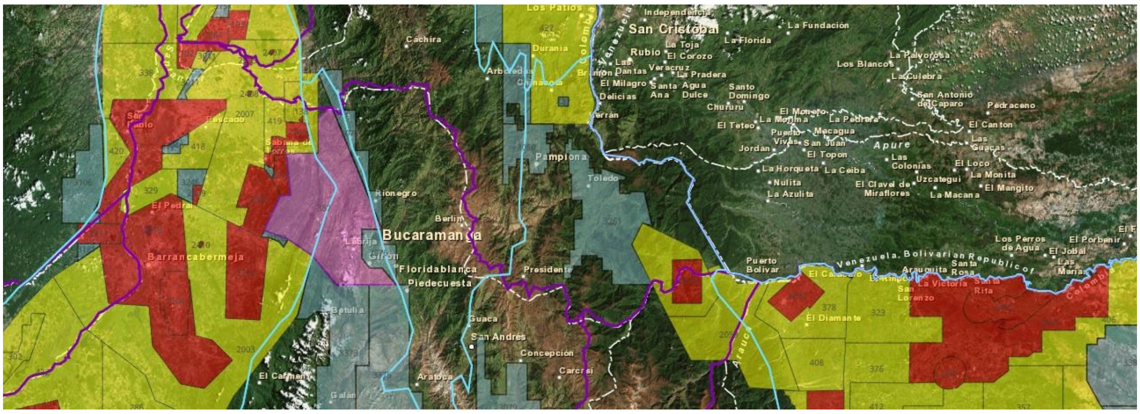

Adaptation to climate change in Colombia's oil and gas industry
Recommendations to promote risk management

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Contents

Summary

This report has been prepared by the UNEP DTU Partnership on behalf of the Latin American Energy Organization (OLADE). The report identifies key elements for risk planning in Colombia's oil and gas sector, and provides recommendations about public policy initiatives to promote risk management by key actors in the industry. It focuses on industry operations in the entire country.

Table S.1 lists the main climate change-related risks faced by the oil and gas industry in Colombia. At present information on the consequences of climate change-related extreme-weather events is not systematically collected in Colombia.

Table S.1: Potential climate change-related risks faced by the oil and gas industry

Industry segment	Potential primary risks
Exploration	Subsidence, wave loading and loss of access to surface water
Production	Disruption of working seasons, wellbore damage, loss of access to surface water, and interruptions
Transport and terminals	Damage to coastal facilities, shipment interruptions, and improved or reduced shipping lanes or seasons
Pipelines	Landslides induced by heavy rains, thaw subsidence and frost jacking, and wildfires
Refining and processing	Loss of access to water, flooding, and loss of peak cooling capacity
Nearby communities	Competition for water, local opposition to new sites, storm impacts on key infrastructure, and loss of species and habitats, or loss of human lives

Risk treatment typically involves an iterative process, by which a risk reduction measure is selected and assessed against the relevant impacts, the residual impacts are estimated and, if they are deemed too high, the measure is revised, with a view to identifying a new measure that reduces residual impacts further. Table S.2 lists potential risk management measures that the oil and gas industry in Colombia may want to consider with a view to reducing the risks associated with climate change-related extreme-weather events.

Table S.2: Possible risk management measures

Corrective measures	Potential sources of incidents						
	Operation under extreme conditions	Faulty valves, faulty pumps and leakages	Corrosion	Overflows and spills	Accidents involving motor vehicles	Influxes and overpressure	New sites in locations prone to impacts
Tailored staff training programmes	✓	✓		✓	✓	✓	
Expanded quality assurance protocols	✓				✓		
Stricter and more frequent inspections		✓	✓			✓	
Immediate repairs of damaged assets		✓	✓			✓	
Upgraded technologies and infrastructure		✓	✓	✓	✓		
Improved rainwater collection systems				✓			
Enhanced water capture capacities				✓			
Comprehensive ex-ante assessments							✓

The responsibility for preparing a climate change risk management plan for oil and gas operations is with industry. Nonetheless, government can and, arguably, should promote the development and implementation of such plans. To this end we recommend that the Colombian government takes the following steps:

- facilitate a dialogue among industry actors (possibly through the Colombian Petroleum Association) and a multi-stakeholder forum (possibly through the national planning authority), with a view to defining the main tenets of climate change risk management in the country;
- introduce minimum monitoring and reporting requirements on the part of industry (possibly as a precondition for awarding concessions), with a view to collecting information on climate change-related incidents, technology standards, and preparedness and response capacities;
- set up an insurance scheme for the oil and gas industry (to cover losses attributable to the impacts of climate change), which is designed in such a way as to be accessible only to

companies that develop a climate change management plan that meets certain minimum requirements).

1. Introduction

This is the UNEP DTU Partnership's report for the Latin American Energy Organization (OLADE) under contract 82272. This is a draft final report, which incorporates comments received on an interim version of the text.

Context

In September 2014, OLADE commissioned the UNEP DTU Partnership (UDP) to conduct an analysis of climate change-related risks that may affect Colombia's oil and gas industry. The analysis is presented in this report, which is complemented by a number of data files submitted to OLADE.

Box 1: UNEP DTU Partnership

The UNEP DTU Partnership (UDP) is a leading international research and advisory institution on energy, climate change and sustainable development. UDP is a so-called collaborating centre of the United Nations Environment Programme (UNEP). In this capacity it supports the delivery of UNEP's climate change activities. In addition UDP works with other multilateral and bilateral agencies. In July 2014, coinciding with a change in office location, UDP changed its name (from the UNEP Risø Centre to UNEP DTU Partnership).

This work falls within a larger bilateral project to support climate change adaptation in Latin American countries, funded by the Canadian International Development Agency. UDP provided in-kind staff time to conduct some of the work described in this report.

Goal of the project

We identify key elements for risk planning in Colombia's oil and gas sector. In addition, we provide recommendations about public policy initiatives to promote risk management by key actors in the industry. Box 2 presents the key risk analysis terminology that will be used in the remainder of this report.

Our premise is that, to introduce policy in this area, government needs two complementary but distinct types of evidence: an understanding of what specifically risk management means for the industry and an overview of the mechanisms government could use to advance its goals in this area. Therefore, this report does not constitute a fully-fledged risk management plan for any one sector or sub-sector, neither is it a governmental strategy for the oil and gas sector.[1] Instead,

[1] The data and the consensus needed to produce either of these documents are not yet available. Besides, the work required to produce them is outside of what is possible to do given or budgetary and calendar constraints.

the report gives elements for the preparation of both risk management plans for industry and a governmental strategy document.

Box 2: Risk analysis terminology

Risk: Effect of uncertainty on objectives.

Risk management: Coordinated activities to direct and control an organization with regard to risk.

Risk management framework: Set of components that provide the foundations and organizational arrangements for designing, implementing, monitoring, reviewing and continually improving risk management throughout the organization.

Risk management policy: Statement of the overall intentions and direction of and organization related to risk management.

Risk management plan: Scheme within the risk management framework specifying the approach, the management components and resources to be applied to the management of risk.

Source: ISO 2009b

Beneficiaries

Colombia's Ministry of Energy and Mines has acted as our main interlocutor on oil and gas industry issues at the national level. It has further played a critical convening role vis-à-vis all other relevant actors in the country. Therefore, the ministry, representing all other oil and gas industry stakeholders in Colombia, is the direct beneficiary of this work.

Approach

We have considered four types of short- to mid-terms determinants of risk: socio-economic developments, climate change impacts, availability of technologies and preparedness and response capabilities. Figure 1 illustrates our conceptual model, which assumes that the level of risk to the oil and gas industry is a function of future developments in these four determinants.

Expected growth in primary energy consumption is the key socio-economic parameter examined. Increased consumption is expected, both in absolute and per capita terms, which may exacerbate risks related to storage and supply capacities. We did not consider likely future trends in the incidence of terrorist attacks or developments in international trade of oil and gas products.

We were unable to obtain an overview of technologies in the oil and gas sector in Colombia, which would have allowed us to compare the country's portfolio of technologies with the global state-of-the-art. Lacking this, our assessment of technology capabilities is qualitative and, therefore, indicative.

Similarly, it has not been possible to obtain an overview of preparedness and response capabilities. We have assumed that these capabilities are low, compared to 'good practices' in other countries.[2] The implication for the analysis is that, with regard to risk reduction, we assume that improvements in preparedness and response capabilities can play a relatively significant role with regard to risk reduction.

Finally, we have characterised the impacts of global warming through high-resolution projections of likely changes in temperature, precipitation and wind speed. Data shortcomings prevented us from using measurement data to validate model outputs (we had to use re-analysis data, which is nonetheless considered to be effective in removing key biases).

Figure 1: Short- to mid-term determinants of risks related to climate change

Methodology

Our analysis relies on existing evidence, obtained through a review of the literature and interviews with key specialists. High-resolution projections of likely changes in temperature,

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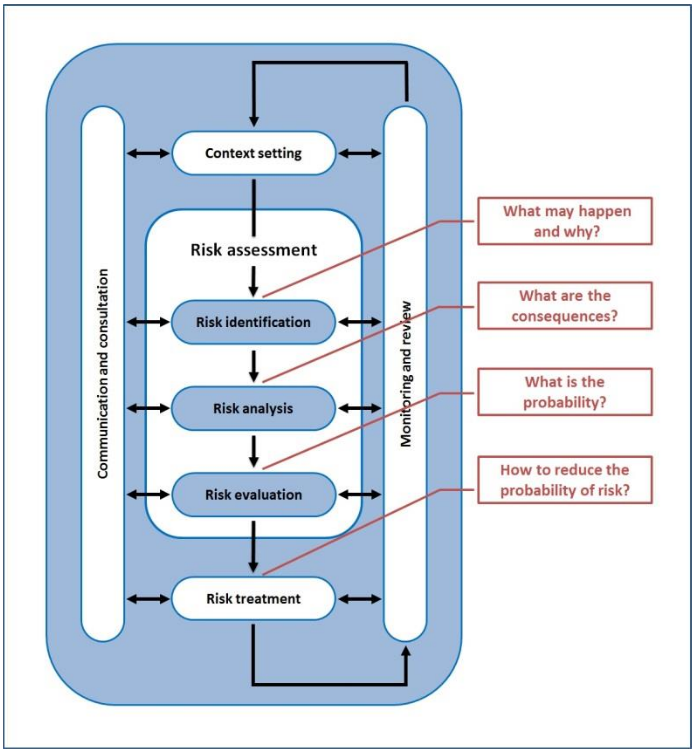
[2] The reason for this is that, had preparedness and response protocols been in place, it would have presumably been easy to identify them and share them with us. Since this was not the case, we assume that those protocols do not exist and, therefore, that capabilities in this area are low.

precipitation and wind speed are an exception to this, in that they have been prepared specifically to support our analysis.

The International Standards Organization (ISO) has developed a generic risk management framework. Figure 2 outlines the key elements of this framework and shows the interactions among them. We have added the text boxes on the right hand-side of the figure, to help the reader understand the figure.

We have structured our analysis around that generic risk management framework, which includes the various elements depicted in Figure 2. Our goal with this approach is simply to illustrate as closely as possible the type of issues industry would have to include in a risk management plan. Note that certain elements (in particular 'communication and consultation' and 'monitoring and review') cannot be described fully ex-ante (that is, in the absence of an actual risk management plan).

Figure 2: ISO 31000 risk management framework



Source: adapted from ISO, 2009a

In addition, we have made suggestions regarding the steps that government could take to promote better risk management practices by industry. Rather than outlining a specific sequence of actions by government, we have described a few key initiatives that we believe are relevant and can be undertaken in different order, depending on the preferences of the Colombian administration.

Limitations of the analysis

In addition to budget and time restrictions, data shortcomings constrained the level of analytical detail. Specifically, it was not possible to obtain disaggregated information by region, industry segment and issue.[3] Instead, the information that could be obtained was rather aggregated, leading, inevitably, to aggregated findings. Nonetheless, our analysis does highlight the key issues that a fully-fledged risk management plan would have to take into account, which in turn allows us to make recommendations for steps government may want to take to promote better risk management in the sector.

Outline

Chapter 2 sets the context for the risk management analysis. Chapters 3 to 6 present our findings concerning, respectively, risk identification, risk analysis, risk evaluation and risk treatment. Chapters 7 and 8 outline our suggested provisions with regard to, respectively, monitoring and review, and communication and consultation. Chapter 9 provides concluding remarks concerning the steps government may want to take in this area. Appendix A contains a summary of the climate projections prepared to support the analysis. Appendix B lists key references we have consulted. Appendix C lists the individuals we have interviewed. Appendix D contains an overview of the location of present and future industry sites.

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[3] Industry segment refers to, for example, oil exploration, pipelines, or storage facilities. Issue refers to, for example, preparedness and response capabilities or technology standards and availability.

2. Context setting

The impacts of climate change are potentially devastating. They are already being felt and are expected to intensify over the coming decades (IPCC, 2014). As a result, public and private sector actors alike have begun to take climate change impacts into account in their risk management strategies. Specifically, in most countries, government agencies are increasingly preparing sector-specific plans for reducing climate change vulnerabilities (UNFCCC, 2014).

Legislation passed in Colombia in 2014 requires that each sector of the economy draws up a climate change adaptation plan. To facilitate this work, a blueprint was prepared that sectors are expected to follow (DNP, 2013). The National Hydrocarbons Agency has begun work in this area.

During 2011 Colombia's oil and gas industry was affected by three climate change-related extreme-weather events (two pipeline damage incidents caused by landslides following intense rains, and flooding of the refinery at Barrancabermeja). In the wake of these incidents Ecopetrol appointed one member of staff to monitor climate change-related risks. The company has since taken steps to monitor climate risks and identify risk management strategies.

Ranking risks

Risk management plans are most useful when they rank risks in an unambiguous manner. Rankings can be static if risks are believed to remain unaltered over time. However, in most instances risk management plans will not be based on static rankings: instead, they will outline the tools that are needed and the methods that have to be applied to determine which risks will be more important to consider at any given future time.

Ranking risk is challenging for three main reasons: firstly, in the majority of situations a very large number of potential risks could in principle be considered; secondly, the definition of risk is far from trivial[4]; and thirdly, different stakeholders are likely to have different views concerning which issues matter most.

[4] Different variables can be used to measure risk, with each variable yielding different risk rankings. Similarly, the scope of the definition can be narrow (including mortality and morbidity or insured losses only) or broad (including also equity and temporal issues, for example).

Next steps

To prepare an effective risk management plan all relevant stakeholders have to have a shared understanding of the plan's intended goals and scope. Specifically, the 'problem owner' (individual companies with concessions in Colombia) has to build consensus around the following issues:

- how many and which impacts the plan will consider;[5]
- the type of evidence that stakeholders are willing to consider, given prevailing knowledge gaps;
- the extent to which society should dread any one type of impact.

Typically, reaching consensus on all these issues represents the hardest stage in the elaboration of the risk management plan.

In addition, the 'problem owner' has to collect a rather large amount of information, which is seldom readily available. Compared to the information base available in Colombia when we began our analysis, the results of our work supplement that information base in two ways:

- We provide better projections of key climatic variables, compared to the projections available in Colombia at the time when we began our analysis. These higher-quality projections allow for a more precise attribution of likely climate change impacts both across regions and in time.
- Our analysis represents the first attempt at collecting and analysing industry and climate data within a risk management framework. In doing so, our analysis highlights both trends and gaps in knowledge, thus providing signposts for the development of a risk management strategy for the sector.

Nonetheless, critical pieces of information are still missing. The most important are:

- Data on technology standards by region and industry segment. Understanding what technologies are in which industry segment and location, and the extent to which they differ from state-of-the-art technologies, is critical for judging the role that technology upgrades can play in reducing vulnerability.
- Data on preparedness and response capacities by region and/or industry segment, as relevant. We define preparedness and response in a broad sense, to comprise both monitoring and early warning capacities, as well as trained staff. Likely developments in preparedness and response capacities are particularly challenging to estimate, in that monitoring and early warning systems rely on critical threshold levels for the industry which are difficult to assess today (in Colombia and elsewhere), due to limited experience. Similarly, estimating how many staff will be trained in the future, and how well, is at least just as difficult.
- Historical meteorological observation data for key climatic variables (temperature and precipitation in particular), spanning at least thirty years and covering, if not the entire country, at least all locations with current or planned industry assets. This information would allow for a more thorough elimination of the biases introduced by climate models. A

[5] For example, impacts on people, on ecosystems or on economic assets.

better bias-corrected set of projections would allow for a better attribution of climate change impacts at the local level.

Key points

Legislation passed in Colombia in 2014 requires that each sector of the economy draws up a climate change adaptation plan. To facilitate this work, a blueprint was prepared that sectors are expected to follow.

Risk management plans are most useful when they rank risks in an unambiguous manner. However, ranking risk is challenging because many risks could in principle be considered, definitions vary across stakeholder groups, and so do priorities.

Against this background, it is important that, in the process of elaborating a risk management plan for its operations, an industry seeks consensus around the risk ranking factors mentioned above. In addition, information has to be collected with regards to, in particular, technology standards and preparedness and response capacities.

3. Risk identification

The debate about risk management for climate change in the oil and gas industry is still incipient in Colombia. For this reason we have taken an inclusive approach, covering more rather than less. Table 1 illustrates the types of risks we have considered, by industry segment (also including a 'neighbouring communities' element, to capture social issues such as local oppositions to a given project or actual losses in private assets and lives).

Table 1: Potential climate change-related risks faced by the oil and gas industry

Changes in climate	Potential primary risks
- Changes in temperature - Changes in precipitation - Sea-level rise	**Exploration** - subsidence - wave loading[6] - loss of access to surface water **Production** - disruption of working seasons - wellbore damage - loss of access to surface water - interruptions **Transport and terminals** - damage to coastal facilities - shipment interruptions - improved or reduced shipping lanes or seasons **Pipelines** - landslides induced by heavy rains - thaw subsidence and frost jacking - wildfires **Refining and processing** - loss of access to water - flooding - loss of peak cooling capacity **Neighbouring communities** - competition for water - local opposition to new sites - storm impacts on key infrastructure - loss of species and habitats, or loss of human lives

Source: adapted from IPIECA, 2013

Further to the definition given in Box 2, risk can be characterised as a function of hazards, exposure and vulnerability. These concepts are defined in the following paragraphs. In addition, the reminder of this section provides a crude estimate of the climate change-related hazards to

[6] Wave loading refers to the difference in pressure caused by waves. This has structural design implications for off-shore platforms and shallowly buried pipes.

which the oil and gas industry in Colombia is exposed, as well as qualitative descriptions of the levels of exposure and vulnerability that the industry may face in connection with those hazards.

Hazards

Hazards have been defined as “the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources” (IPCC, 2012). In the context of our analysis the focus is on natural events, and the likelihood that an event of a given magnitude occurs within the time period of interest.

Further to the summary on Table 1 (refer to the left hand-side column), to estimate those likelihoods we have obtained projections of temperature and precipitation for the period to 2050 (Appendix A).[7] With regard to local sea-level rise we have relied on existing projections.

Consistent with existing studies, our projections show an increase in average temperatures, most marked in the Caribbean coast and the interior. Rainfall would follow the reverse pattern, with a most marked increase in the Pacific coast. The reader is referred to Appendix A for additional details on the results of our projections.

Colombia’s second ‘national communication’ to the United Nations Framework Convention on Climate Change states that, on the basis of forty-year time series, sea level appears to have raised by about 3.5 mm per year on the Caribbean coast, and about 2.2 mm per year on the Pacific coast (MAVDT, 2010). These values are consistent with, albeit slightly lower than, the estimates reported in the latest assessment report by the Intergovernmental Panel on Climate Change (IPCC, 2014) and the more recent literature. For our analysis we use an average of 3 mm per year (Box 3).

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[7] Our analysis also includes projections of wind speed. We have not placed much emphasis on them, as potential future changes in wind speed are notoriously difficult to model.

Box 3: Impacts of sea-level rise

Analyses of sea-level rise show that risk of marine flooding is high on both the Caribbean and Pacific coasts (IPCC, 2014 and MAVDT, 2010). Specific areas at risk include:

- Caribbean: Turbo, Lorica and Tolú, Cartagena, Barranquilla and Santa Marta;
- Pacific: the coastal strip stretching from Tumaco to Arusi and Nuquí.

On the Caribbean coast, industry assets at highest risk in the mid-term include those close to Puerto Colombia.[8] In the longer term the sites around Turbo and Ponedera are likely to be affected.[9]

On the Pacific coast, the area at risk contains no active sites – only areas that are 'reserved' for potential future exploitation.[10] Any future developments in this area are likely to be affected by sea-level rise.

Box 4 presents a generic overview (tailored to Colombia's oil and gas industry) of the potential impacts associated with changes in precipitation, temperature and wind speed. It is important to note that impacts only occur when a hazard does occur **and** industry assets are actually exposed and vulnerable. The following paragraphs introduce the concepts of exposure and vulnerability, which are central to understanding how hazards may or may not become actual risks for the industry.

[8] There is a well in operation south of this area (named Arroyo Cocamba-1) and a reserved area (labelled 3180) off the coast of the city, both of which could be at risk in the mid-term.

[9] In the long-term risk may be highest in one active concession in Turbo (labelled 389) and one active concession in the southern part of Ponedera (labelled 3).

[10] An exception to this is a platform off the coast of Buenaventura. Since sea-level is expected to rise gradually, no significant impacts can be expected on this site due to sea-level rise.

Box 4: Overview of impacts by climatic variable

Precipitation

- Increased precipitation can provoke floods and landslides. Landslides can affect transport of oil and gas by road and through pipelines. Floods can affect production sites, road transport and transport through pipelines (where they cross river basins), as well as refineries.
- Decreased precipitation can affect production and refining operations where these depend upon reliable supplies of fresh water.

Temperature

- High temperatures can increase the incidence of certain diseases. Specifically, malaria or Chagas disease could become more common.
- Indirect impacts through power losses.

Wind speed

- Gales will disrupt offshore operations (in most instances operations will be brought to a complete halt). Infrastructure may suffer damages and staff working on offshore platforms will be at risk.
- Wind storms can result in reduced access to onshore facilities. Severe storms can disrupt onshore operations.

Exposure

Exposure has been defined as “the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected” (IPCC, 2012). The location of the assets of Colombia’s oil and gas industry is known and therefore a simple mapping of the likely geographical distribution of hazard occurrences would highlight which assets are exposed.

However, today’s location of assets is not the only factor at play: current sites may close and new sites may open in areas where there are none today. Therefore, in addition to present-day data, the assessment of exposure has to consider the industry’s plans for the future.

Appendix D contains a summary of the geographical distribution of industry assets, by industry segment. For each province and industry segment, information is given concerning the presence of a site, plans to establish one in the future and the relative importance of that site in comparison with similar sites in other locations.

Tables 2.a to 2.c summarise anticipated trends in precipitation and maximum temperature. Trends are given for the locations of the two largest refineries in the country, Barrancabermeja and Mamonal. Further details are provided in Appendix D.

Table 2.a: Precipitation (mm annually)

Site	Historical	Projections to 2025		Projections to 2050	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Barrancabermeja	2257	2271 (2143-2398)	2259 (1948-2497)	2293 (2062-2569)	2222 (1891-2437)
Mamonal	1200	1140 (1040-1214)	1152 (947-1236)	1112 (979-1241)	1060 (930-1209)

Notes:

- Data labelled 'Historical' correspond to the average of the period 1976-2005.
- Estimates labelled 'Projections 2025' correspond to the average of the projections obtained for the period 2011-2040.
- Estimates labelled 'Projections 2050' correspond to the average of the projections obtained for the period 2036-2065.
- The figures under the columns 'Projections' correspond to the average of all ten models (figures in brackets correspond to the maximum and minimum numbers in the ten-model set of estimates).
- The reader is referred to Appendix A for a definition of RCP 4.5 and RCP 8.5.

Table 2.b: Extreme rain (number of days annually)

Site	Historical	RCP 4.5	RCP 8.5
Barrancabermeja	1.8	2.3 (1.7-3.2)	2.5 (1.4-3.7)
Mamonal	0.8	0.9 (0.5-1.3)	0.8 (0.5-1.5)

Notes:

- Extreme rain is defined as daily precipitation levels exceeding the highest daily levels registered in the top 1 percent wettest days in the period 1976-2005.
- Data labelled 'Historical' correspond to the average of the period 1976-2005.
- Estimates labelled 'RCP 4.5' and 'RCP 8.5' correspond to the average of the projections obtained for the period 2006-2100.
- The figures under the columns 'RCP 4.5' and 'RCP 8.5' correspond to the average of all ten models (figures in brackets correspond to the maximum and minimum numbers in the ten-model set of estimates).
- The reader is referred to Appendix A for a definition of RCP 4.5 and RCP 8.5.

Table 2.c: Maximum temperature (annual maximum, in degrees centigrade)

Site	Historical	Projections to 2025		Projections to 2050	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Barrancabermeja	34.1	36.4 (36.1-36.7)	36.5 (36.2-36.8)	37.1 (36.6-37.8)	37.9 (37.3-38.5)
Mamonal	37.3	39.5 (39.0-40.1)	39.5 (39.1-40.0)	39.9 (39.5-41.1)	40.3 (39.8-41.6)

Notes:

- Data labelled 'Historical' correspond to the average of the period 1976-2005.
- Estimates labelled 'Projections 2025' correspond to the average of the projections obtained for the period 2011-2040.
- Estimates labelled 'Projections 2050' correspond to the average of the projections obtained for the period 2036-2065.
- The figures under the columns 'Projections' correspond to the average of all ten models (figures in brackets correspond to the maximum and minimum numbers in the ten-model set of estimates).
- The reader is referred to Appendix A for a definition of RCP 4.5 and RCP 8.5.

Vulnerability

Vulnerability has been defined as "the propensity or predisposition to be adversely affected" (IPCC, 2012). Vulnerability is determined by the extent to which a given industry asset that is exposed to a certain hazard can withstand the adverse impacts associated with that hazard. An asset that can withstand a certain climate change-related hazard is often referred to as 'climate proof' (for that hazard and the associated severity threshold).

In the context of the oil and gas industry, both physical and human factors play a role in 'climate proofing' an asset:

- Physical factors can be characterised in terms of the quality of the infrastructure and the quality of the technology involved.[11] For most climate change-related extreme-weather events, infrastructures can be built and technologies exist that withstand most hazards. If the physical factors associated with an exposed industry asset are 'climate proof', the asset is not vulnerable (even though it is exposed). Conversely, an exposed asset whose physical factors are not 'climate proof' will be vulnerable. Note that investing in the most 'climate proof' infrastructures and technologies will not be efficient in all cases (from an economic point of view): in some instances paying for remediation costs may be more economically advantageous.
- Human factors can be characterised in terms of the preparedness and response capacities of industry staff. As mentioned above, preparedness and response is defined in a broad, sense, to include both monitoring and early warning capacities, as well as trained staff. The

[11] Infrastructure refers to, for example, a storage site, whereas technology refers to, for example, a water pump.

impact associated with a given hazard will be reduced if monitoring and early warning mechanisms are in place to warn staff about an impending threat. Similarly, impacts will also be reduced if staff has been trained to manage the consequences of the threat.

As indicated above (Chapter 2), we have not been able to obtain information on technology standards or preparedness and response capacities. Without this information, industry cannot prepare a proper climate change risk management plan. We thus recommend that industry starts collecting these data (Chapter 9).

Vulnerability is also determined by factors external to the industry. In the context of the oil and gas sector, increased competition for water resources and increased demand for energy are the main such factors. This is because the same industry asset exposed to the same hazard will be more vulnerable if it has less water at its disposal or has to deliver more output, compared to a 'reference situation'.[12]

The most recent projections of water use exclude the oil and gas industry (IDEAM, 2010). Nonetheless, these projections are useful for the purposes of this work, in that they highlight that water demand is expected to increase dramatically (from 35,877 million m^3 per year in 2008 to 70,551 million m^3 per year in 2019).[13] In sum, these projections highlight that competition for water is expected to increase. Since precipitation levels are expected to decrease in certain parts of the country (Appendix A), and given that the oil and gas industry is unlikely to be granted preferential access to the resource over agricultural uses, water availability could effectively become a limiting factor and, therefore, an important climate change-related risk for the industry.

In 2012 oil was the primary energy source used to generate 0.6 percent of the electricity consumed in Colombia, whereas natural gas supplied 14 percent (IEA, 2014). Expected annual growth rates (national-level averages) of electricity demand in Colombia are 3.6 percent in the period 2010-2020 and 3.5 percent in the period 2021-2030 (UPME, 2013).[14]

In 2012 about 73 percent of all oil products were used for domestic transport (IEA, 2014). In the period 2015-2030 the expected annual growth rate of demand for gasoline and diesel oil is just above 1 percent (Arango, 2015).

In 2012 about 52 percent of the production of natural gas was used by industry in Colombia (IEA, 2014). In the period 2015.2030 the expected annual growth rate of demand for natural gas by industry is just above 1 percent (Arango, 2015). This includes consumption by the gas industry itself, the pulp and paper sector, the chemical industry, the cement industry, the iron and steel industries, and other manufacturing industries.

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[12] 'Reference situation' refers to a situation in which water availability and output requirements do not represent significant constraints.

[13] Agriculture is expected to remain the main user of water, accounting for just over half of the total water demand in Colombia, both in 2008 and in 2019.

[14] This growth will be rather unevenly distributed, with rates in the period 2014-2024 ranging from 25 percent in the Centro region to just below 3 percent in the Sur region (UPME, 2014).

In short, domestic demand for oil and gas products is expected to increase, albeit at moderate rates. If these projections come to pass, the industry will play an even bigger role in Colombia's economy. For this reason the need for proper risk management procedures becomes all the more important.

Key points

Consistent with existing studies, our projections show an increase in average temperatures across the country, most marked in the Caribbean coast and the interior. Rainfall would follow the reverse pattern, with a most marked increase in the Pacific coast.

Barrancabermeja and Mamonal are likely to be exposed to increased average temperatures. Mamonal is likely to be exposed to reduced precipitation levels (the evidence is inconclusive regarding Barrancabermeja). The number of days of extreme rain is likely to increase in Barrancabermeja (there is no conclusive evidence about Mamonal, as the projections of the different models show a wide spread).

Vulnerability levels are a function of several factors: exposure (see the previous paragraph), preparedness and response capacities, technology standards, and socio-economic developments (notably increased competition for water resources and increased demand for energy). Projecting current trends into the future, vulnerability is likely to increase.

4. Risk analysis

In addition to characterising vulnerability, risk management plans ought to describe the implications of it – that is, they have to outline the range of possible consequences associated with all possible ‘vulnerable states’. Only when the consequences of the impacts are known, can those impacts be managed.

Ideally, such characterisation should distinguish between industry segments, types and magnitude of the impact, and geo-climatic regions. In practice, however, most plans will simply outline two or three progressively more damaging levels of impacts by industry segment. On that basis, the risk management plan will lay down the actions to be taken if and when an impact occurs in a given industry segment, irrespective of the type and magnitude of the event associated with the impact, and irrespective of the location of the vulnerable asset.

The illustrative cases in Box 4 outline in general terms the impacts of climate change-related extreme-weather events on oil and gas industry operations. Evidence from companies working in the sector in Colombia provides insights on some of those impacts and illustrates their consequences.

In 2012 Ecopetrol registered 25 incidents (45 in 2009, 58 in 2010 and 58 in 2011). In that same year the costs associated with crude oil losses (through spills) amounted to about USD 1,000, whereas environmental restoration costs amounted to just over USD 100,000. Flooding associated with heavy rains represents the main cause of the incidents: it causes leakages, corrosion, malfunctioning of valves and pumps, overflow of oil products, and accidents, among other problems.

New Horizon Exploration, a company exploiting the Bloque La Maye concession, faced more important losses. These losses were caused by flooding associated with the climatic phenomenon dubbed La Niña.[15] Specifically, water rose by up to two meters and remained high even after the rainy season, effectively making access impossible for months, after the Hatillo levee gave way. At contract signature, the Bloque La Maye concession was valued at USD 11 million.

The examples above illustrate a subset of all possible consequences of climate-change related extreme-weather events. We cannot tell if this subset is large or small and, similarly, we cannot tell how representative the cases are. For obvious reasons, proper risk management requires a description of all possible consequences, also including information on incidence levels (Chapter 5).

We recommend the Ministry of Energy and Mines that data concerning all relevant incidents is customarily recorded across all industry segments. Relevant data includes information about

[15] La Niña is a climatic phenomenon characterised by lower-than-average temperature of Equatorial surface water layers in the Pacific Ocean. Although not fully conclusive, most evidence points towards climate change exacerbating the occurrence of La Niña.

the threat (for example, the magnitude of a flooding), details about the technologies required to limit the damage (for example, water pumps or flooding-proof storage tanks), estimates of the costs associated with the incident (including material losses, foregone revenue, staff time and other resources invested) and information about the duration of the incident.

Businesses are obviously driven by the goal of maximising profitability on a given concession. For this reason, their timeframes are relatively short (at least from the point of view of adaptation to climate change). As a result, businesses are unlikely to adopt data collection mechanisms concerning the impacts of climate change.[16] Arguably, this is a short-sighted approach, in that the information is as useful to them as it is useful to energy sector regulators.

When monitoring systems are set up and information is collected and eventually centralised, concerns over data confidentiality typically arise. Examples exist across several types of industries that show how information technology and appropriate governance mechanisms help overcome those concerns.[17] Not least, experience is also available to show how the data collected can be used to measure the performance of businesses, which in turn may be used as a criterion for attributing concessions.[18]

Key points

In addition to characterising vulnerability, risk management plans ought to outline the range of possible consequences associated with all possible 'vulnerable states'. It is clear that economic impacts of a single incident run in the hundreds of thousands of US dollars. In some instances, the human and environmental toll adds to this.

At present information on the consequences of climate change-related extreme-weather events is not systematically collected in Colombia. We recommend that data concerning all relevant incidents is customarily recorded across all industry segments. Relevant data includes information about the threat, details about the technologies required to limit the damage, estimates of the costs associated with the incident and information about the duration of the incident.

[16] Making concession allocation contingent on those mechanisms being established could help reverse this trend.
[17] The pharmaceutical industry is a case in point: information disclosure procedures have been implemented (in certain jurisdictions) which have proven to be compatible with confidentiality requirements.
[18] In the construction sector, for example, contractors that can prove superior practices with regard to construction waste management and disposal will receive - in some countries - more favourable treatment in competitive bidding processes.

5. Risk evaluation

Once vulnerability has been characterised and the consequences of it have been described, a risk management plan has to outline the likelihood that an impact of a certain magnitude actually occurs. This likelihood is a function of two parameters: the expected future incidence of different types of climate change-related extreme-weather events and the level of 'climate proofing' of a given industry asset. Therefore, risk evaluation effectively amounts to determining, for each relevant impact, the degree of vulnerability of an industry asset that has been identified as being 'vulnerable'.

The above relationship can be difficult to quantify. For this reason, risk management plans often take a simplified approach: they assign probabilities (by industry segment) to a small number of 'typical' likely impacts. To the extent possible, these probabilities should be adapted to the reality of the industry asset concerned, to reflect technology standards, location and preparedness and response capabilities.

We provide estimates of likely trends in selected climatic variables (Appendix A). They give an indication of the expected future incidence of different types of climate change-related extreme-weather events.

Estimates of the level of 'climate proofing' of a given industrial asset can be determined empirically, on the basis of observed impacts – in Colombia or elsewhere. For example, pipeline technicians are best placed to judge the levels of 'climate proofing' of a particular pipeline, on the basis of (i) the quality of the infrastructure, compared to industry standards; (ii) the specific conditions (terrain, setup, etc.) of the pipeline being considered; and (iii) incidents experienced in the recent past.

It is important to note that risk evaluation requires regular updates, as new knowledge emerges and experience with risk management in general increases. While annual revisions of projections of likely developments in climatic variables are not warranted, annual revisions of estimates of 'climate proofing' levels certainly are (Chapter 7).

Key points

Risk evaluation entails assessing the likelihood that an impact of a certain magnitude actually occurs. This likelihood is a function of two parameters: the expected future incidence of different types of climate change-related extreme-weather events and the level of 'climate proofing' of a given industry asset.

We provide estimates of likely trends in selected climatic variables, which give an indication of the expected future incidence of different types of climate change-related extreme-weather events. Estimates of the level of 'climate proofing' of a given industrial asset can be determined empirically, on the basis of observed impacts – in Colombia or elsewhere.

6. Risk treatment

Risk treatment refers to actions undertaken to reduce the probability of a certain impact, thus mitigating risk. Risk treatment typically involves an iterative process, by which a risk reduction measure is selected and assessed against the relevant impacts, the residual impacts are estimated and, if they are deemed too high, the measure is revised, with a view to identifying a new measure that reduces residual impacts further.

Measures typically seek to reduce the vulnerability of the industry asset concerned (for example, by upgrading technologies). They may also seek to limit the probability of a certain impact (for example, by improving early warning systems). Finally, in some instances, measures entail risk sharing mechanisms (typically through insurance schemes).

In certain situations, a company may choose to ignore a certain type of risk and, therefore, it may choose to implement no corrective measure against it. For example, in the light of the high uncertainty surrounding projections of wind speed, a company may elect to ignore the potential adverse impacts arising from developments in wind speed, until uncertainty in the projections can be reduced.

A company may choose to keep, or even increase, its exposure to a certain risk, to pursue a business opportunity. For example, off-shore exploration in a particular region may be subject to low-probability, high-impact risks associated with climate change-related extreme-weather events. In these circumstances, if the anticipated profits are large enough, a company may elect to ignore the risk.

Selecting the appropriate risk treatment measure involves non-trivial technical and financial decisions. These decisions have to be consistent with prevailing regulatory requirements, which are likely to vary from one jurisdiction to another. Not least, the risk treatment process requires that all stakeholders are consulted (Chapter 8).

Finally, it is worth noting that risk treatment may be unsuccessful: in spite of all efforts, risk treatment measures may in practice fail to reduce risk. This may be caused by mistakes in the risk assessment process (Figure 2), by changes in the level of hazards (Chapter 3), or by a combination of both. In some cases, inadequate risk assessment may even increase risk, compared to a ‘reference situation’.[19]

Table 3 lists potential risk management measures, building extensively on a set identified by Ecopetrol. This is a rather generic list, which should be expanded and adapted for each industry segment.

[19] Reference situation refers to a situation in which no risk management is conducted and no risk-reduction measures are implemented.

Table 3: Possible risk management measures

Corrective measures	Potential sources of incidents						
	Operation under extreme conditions	Faulty valves, faulty pumps and leakages	Corrosion	Overflows and spills	Accidents involving motor vehicles	Influxes and overpressure	New sites in locations prone to impacts
Tailored staff training programmes	✓	✓		✓	✓	✓	
Expanded quality assurance protocols	✓				✓		
Stricter and more frequent inspections		✓	✓			✓	
Immediate repairs of damaged assets		✓	✓			✓	
Upgraded technologies and infrastructure		✓	✓	✓	✓		
Improved rainwater collection systems				✓			
Enhanced water capture capacities				✓			
Comprehensive ex-ante assessments							✓

Source: adapted from Ecopetrol

Risk management plans can be static or dynamic. A static plan will identify a set of risk-reduction measures which will be implemented (in parallel or in steps), irrespective of future developments. A dynamic plan outlines the measures that will have to be implemented when a certain critical threshold is crossed. Dynamic plans are more challenging to set up (Chapter 7), but are more cost-effective.

In addition to identifying risk management measures, a risk management plan has to outline how each measure will be implemented, notably with regard to other company procedures. Specifically, the plan has to include information on the following aspects:

- rationale for the selection of measures and expected benefits resulting from each;
- allocation of responsibilities with regards to implementation;
- anticipated financial and human needs;
- performance requirements, including a calendar for implementation;
- and monitoring and reporting requirements.

It is crucial that regular company operation procedures are revised, to ensure that risk management plans can be made consistent with, and supportive of, those procedures. Not least, care has to be taken to make stakeholders aware of residual risks.

Key points

Risk treatment typically involves an iterative process, by which a risk reduction measure is selected and assessed against the relevant impacts, the residual impacts are estimated and, if they are deemed too high, the measure is revised, with a view to identifying a new measure that reduces residual impacts further.

We provide a generic list of risk management measures, which should be expanded and adapted for each industry segment. In addition to identifying risk management measures, a risk management plan has to outline how each measure will be implemented, notably with regard to other company procedures. If necessary, regular company operation procedures should be revised, to ensure that risk management plans can be made consistent with, and supportive of, those procedures.

7. Monitoring and review

A risk management plan requires regular revisions, to integrate new knowledge, fine-tune goals and risk-reduction measures, and revise implementation mechanisms. Such regular revisions rely entirely on monitoring and review programmes, and consultation with stakeholders (Chapter 8).

A good monitoring and review programme should achieve the following:

- ensure that the risk management plan performs according to its targets;
- provide additional information relevant to risk management;
- identify lessons learnt, as experience builds up with the implementation of the risk management plan;
- identify changes in the context to the risk analysis (for example, legislation introducing more stringent planning and reporting requirements on the oil and gas industry would call for a revision of the risk management plan);
- identify emerging risks.

Monitoring and review programmes often deliver against a pre-determined schedule. Nonetheless, it is important that the programme is flexible enough to deliver upon demand (typically, when a threat emerges).

In light of this we recommend that a multi-stakeholder committee is set up (Chapter 8), possibly convened by the National Hydrocarbons Agency, to prepare monitoring and review recommendations for key industry actors. Such recommendations could be seen as illustrative and non-binding, paving the way for additional industry engagement with regard to risk management for climate change.

Key points

To continually improve risk management plans, monitoring and review programmes are required. Such programmes help integrate new knowledge, fine-tune goals and risk-reduction measures, and revise implementation mechanisms.

We recommend that a multi-stakeholder committee is set up, to prepare monitoring and review recommendations for key industry actors. Such recommendations could be seen as illustrative and non-binding, paving the way for additional industry engagement with regard to risk management for climate change.

8. Communication and consultation

Communication and consultation with stakeholders, both external and internal, is necessary throughout the risk management process. This is because, among other factors, perceptions about risk and differences in values are likely to vary among stakeholder groups (Chapter 2). Simply stated, a risk management plan that neglects certain stakeholders and thus overlooks issues of concern to them will effectively be an incomplete plan, in that those overlooked concerns in themselves represent a risk.

Against this background, in its risk management principles and guidelines, ISO advises that the 'problem owner' develops a specific communication and consultation plan as a part of his risk management strategy. Further, ISO suggests that the plan covers "the risk itself, its causes, its consequences (if known), and the measures being taken to treat it".

This chapter outlines our recommendations in terms of the preparation of a communication and consultation plan developed in support of a risk management strategy for the oil and gas industry. In addition, the chapter summarises exchanges between UDP and selected oil and gas industry stakeholders. These exchanges were used to inform the preparation of this document. We refer to them in this chapter because similar exchanges would sprobably have to be undertaken for the preparation of a proper communication and consultation plan.

Recommendations for the preparation of a communication and consultation plan

The oil and gas industry in Colombia is somewhat fragmented, with various companies operating in the different industry segments. Therefore, there is no single interlocutor that represents industry as a group. Besides, levels of interest in risk management for climate change vary across all industry actors: some actors may want to engage in risk analysis for climate change, and some may not. In light of this we recommend that a committee is set up, bringing together representatives from all industries. This committee could act as a forum for exchanging experiences about these issues, to the benefit of all participating companies.[20]

In addition to oil and gas industry stakeholders, other stakeholders should be involved in the consultations. These include interest groups (focusing on environmental issues, labour rights issues, or some other relevant topic), government agencies, local communities and other industries (notably industries with large water demands). We recommend that Colombia's planning authority (not the Ministry of Energy and Mines) acts as convener of these different stakeholders, to ensure that its facilitating role is seen as unbiased and independent. An alternative to this approach could entail leaving the convening role to a committee that is composed of a small number of well-respected and independent individuals, each representing one stakeholder group.

[20] Given its mandate and membership, the Colombian Petroleum Association might be in a position to take on a task like this.

We can offer three recommendations with regard to the content of the consultations:

- begin by establishing the context (refer to the Chapter 2 discussion on ‘ranking risks’);
- define in an unambiguous manner the subset of risks targeted;
- ensure that the views of all stakeholders are treated equally and that different areas of expertise are brought together for the analysis of risks.

In this context, it is worth recalling that the ability of stakeholders to engage in consultations depends on a range of factors:

- **Information**. Industry understands its processes in ways that no other stakeholder does, which limits the ability of those other stakeholders to engage in technical discussions. Nonetheless, it is often non-industry stakeholders who can provide evidence of the implications of industry processes (with regard to environmental quality, land-use management, or any other issue). For this reason, the various stakeholder groups have to ‘educate’ one another along the way, if the consultation is to be of any use.
- **Time**. Because industry stakeholders have a bigger stake in the outcome of the discussions, time is not likely to be a major constraint for them. However, for a non-industry stakeholder a consultation comes over and above his or her regular tasks and, because of this, time is effectively a limiting factor. To overcome this problem, in similar settings funds have been set aside (by government, or by industry through government) to fund an independent expert who represents a given stakeholder group.
- **Skill**. Typically, industry stakeholders are more competent at bargaining and communicating, compared to other stakeholders. This is simply because negotiation and communication often represents a larger part of their jobs, compared to non-industry stakeholders. If funds are available, non-industry stakeholders lacking such skills can procure them in the form of an independent external expert (see above).

In the current context of low oil prices, allocating funding for ‘non-core’ industry activities such as the consultations described above becomes particularly challenging. On the other hand, starting a consultation process in times of economic bonanza, only to abandon it when oil prices fall, can be particularly damaging, in that stakeholders are unlikely to reengage if and when industry sets out to restart the process. For this reason it is important that, before starting the process, commitment has been secured to see the process through, irrespective of the economic climate.

Exchanges between UDP and selected oil and gas industry stakeholders

Building upon the scope of work agreed with OLADE in late 2014, UDP conducted desk research to identify the key issues for further investigation. This included a list of questions for stakeholders and industry experts, divided into the following categories: industry segments, climate zones, technologies, impacts, and preparedness levels.

It was possible to gather some detailed information within the above-listed categories in advance of the primary research conducted in Bogota, on 23-25 February 2015. For example, the National Hydrocarbons Agency publishes detailed information on oil and gas installations, including location, type and size of the operation. However, more detailed information regarding the specific technologies used and the impacts of extreme weather events, as well as the levels of preparedness could only be gathered during the country visit. Therefore, meetings were set up by the project counterpart at the Ministry of Mines and Energy, who identified the most relevant actors. In total, we interviewed thirteen individuals from five organisations in Colombia, all based in Bogota (Appendix C).

In terms of gathering primary data for technologies, impacts and preparedness levels, it was agreed (between UDP and the Ministry of Mines and Energy) that it would be necessary to consult directly with the oil and gas industry, since the questions concerned more operational issues. Despite various attempts to engage with private oil and gas companies, the Ministry was only able to set up meetings with Ecopetrol, the country's largest oil and gas operator that is majority-owned by the Colombian government. The consultations with Ecopetrol were positive to the extent that they viewed the study as relevant and timely. However, the individuals were unable to provide the detailed information required regarding the impact of historical extreme weather events on the various industry installations and operations. Equally, detailed information regarding the types of technologies used in the Colombian oil and gas industry, how they compare to international benchmarks, and the extent to which this increases or decreases the industry's overall exposure to climate risks was lacking. Indeed, it soon became apparent, during the meeting with Ecopetrol, that the required information was simply not available within the company and that an aggregate picture of impacts, technologies and levels of preparedness could only be gathered by conducting in-depth consultations with operations managers.

Key points

Communication and consultation with stakeholders, both external and internal, is necessary throughout the risk management process: a risk management plan that neglects certain stakeholders and thus overlooks issues of concern to them will effectively be an incomplete plan, in that those overlooked concerns in themselves represent a risk.

Since the oil and gas industry is rather fragmented in Colombia, we recommend that a committee is set up, bringing together representatives from all industries and stakeholders. This committee would oversee the preparation of a communication and consultation plan for risk management in the industry.

it is worth recalling that the ability of stakeholders to engage in consultations depends on (i) the level of information they have, (ii) the time they can devote to it, and (iii) the negotiating skills they poses. Typically, industry is at an advantage, compared to other stakeholders. Therefore, if consultations are to be meaningful, those other stakeholders will need support.

9. Recommendations

Science is conclusive about the fundamentals concerning the overall nature and magnitude of climate change. In light of this, managing the impacts of climate change should arguably be seen as an extension of regular quality assurance procedures and practices, much like health and safety standards have increasingly been adopted as core organisational goals.

Managing climate change-related impacts in the oil and gas industry is a complex task. Chapters 2 to 8 in this report illustrate the scope of the challenge and the main steps involved in the preparation of a climate change risk management plan for the oil and gas industry.

The responsibility for preparing a risk management plan is with industry, not with government. The reason for this is twofold: critical pieces of knowledge reside with industry and it is industry's assets that face the primary impacts of climate change. Notwithstanding, government is not without responsibility in this area: firstly, in its capacity as regulator of the sector, Colombia's Ministry of Mines and Energy is a key stakeholder in risk management; secondly, given the sector's contribution to the Colombian economy, it is arguably a matter of national interest that the industry reduces its exposure to risk (by developing and adopting sound risk management practices). In sum, government arguably has the responsibility to promote, and contribute to the development of, such sound practices.

This chapter makes recommendations concerning the steps that the Colombian government could take to foster climate change risk management in the oil and gas industry. The chapter complements the information provided in chapters 2 to 8, which touch upon issues on which industry has the main responsibility for acting. It is worth noting that understanding the information provided in chapters 2 to 8, and appreciating the magnitude of the challenge faced by industry arguably constitutes the first step that government should take in this area.

Our recommendations can be grouped under three different headings: non-regulatory action, regulatory action and inter-ministerial collaboration. They are outlined in the following paragraphs.

Non-regulatory action

Colombia's oil and gas industry is relatively new to risk management for climate change. Some actors, notably Ecopetrol, are already taking steps toward assessing and managing the risks associated with climate change (Chapter 2). Nonetheless, other businesses in the industry have yet to engage in a serious debate about this issue. Experience from other countries (and industries) shows that, as impacts increase, companies begin to take a more pro-active approach.

We suggest that, to spur and accompany this gradual engagement process, the Colombian government facilitates a dialogue among industry actors. The Colombian Petroleum Association is arguably well placed to lead such a dialogue, which would most likely have to be voluntary.

Experience from other industries shows that, to increase the appeal of the dialogue among, in particular, industries that may be reluctant to engage, it is useful to articulate the initial phases of it in terms of experience-sharing by leading companies in this area. At a later stage, as reporting and disclosure become more central topics in the dialogue, government has to be ready to offer technical solutions that ensure non-disclosure and confidentiality.[21]

In addition to the above forum for industry, it is important that government sets-up a multi-stakeholder dialogue through which the concerns of all stakeholders can be taken into consideration (Chapter 8). Decisions concerning definitions and scope with regard to risk management for climate change (Chapter 2) have to be made in this forum, not in the industry-only forum (Chapter 8).

It is important that the entity convening the multi-stakeholder dialogue is perceived as unbiased and independent (for example, Colombia's planning authority would arguably be more suitable than a line ministry). In addition, it is essential that non-industry actors receive support (in the form of both information and funding, when required). The reader is referred to Chapter 8 for additional details on these issues.

Regulatory action

Our analysis shows that industry (and, by extension, government) has precious little information relevant to risk management for climate change. This report highlights the extent of the shortfall. In addition to being useful in the context of risk management, most of this information could also constitute beneficial input to core-business decisions. Simply stated, one cannot manage what one cannot measure – and right now it appears clear that the oil and gas industry in Colombia is measuring and reporting very little with regard to the issues highlighted in this report.

In light of the above, we suggest that industry extends its quality assurance procedures (including record-keeping and simple data collection routines) to cover information that is relevant to risk management for climate change. At a minimum, this information should cover key aspects of climate change-related incidents (Chapter 4) as well as an inventory of technology standards and preparedness and response mechanisms (Chapter 2).

We recommend that the Ministry of Energy and Mines introduces minimum monitoring and reporting requirements on the part of industry, possibly as a precondition for awarding concessions. These requirements could be seen as a part of a broader (mandatory) monitoring and review programme (Chapter 7). Requirements should be tailored to each industry segment and defined through a multi-stakeholder process (see above).

The rationale for this recommendation is twofold: firstly, individual industries require this kind of dataset if they are to take any steps toward managing climate change risks; secondly, to

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[21] In the absence of non-disclosure and confidentiality mechanisms, industry is unlikely to agree to releasing data about its operations and the way climate change may have impacted them.

determine the magnitude of the problem country-wide and, on this basis, plan policy in this area, government requires the summation of all individual industry datasets.

The above recommendations support actions that bear fruit only in the long-term. As a result, after an initial period of engagement, the momentum for climate change risk management might wane. For this reason, it is important to undertake one or several additional activities with more immediate and tangible results.

In this context, we recommend that the Ministry of Energy and Mines, with other relevant actors, sets up an insurance scheme for the oil and gas industry. The scheme would cover certain losses attributable to the impacts of climate change and could be funded by industry itself (possibly including all industries with an active concession).[22] However, only industries having developed a climate change risk management plan (that meets certain minimum requirements) could benefit from the scheme. This would have the dual effect of fostering more pro-active action on the part of industry, as well as providing a safety net in the case of impacts.[23]

Inter-ministerial collaboration

Our projections of climatic variables appear to be more comprehensive, robust and up-to-date than any other existing projections in the country (prepared domestically, or through regional or multi-lateral organisations). These projections are directly relevant to risk management for climate change in the oil and gas industry – but not exclusively: they are also relevant to most, if not all, planning exercises for adaptation to climate change, whether they have a sectorial or national scope. We encourage the Ministry of Energy and Mines to make the projections available to fellow government agencies, most notably the Ministry of Environment and any technical agencies attached to it.

[22] For example, contributions to the scheme by each individual company could be calculated as a very small share of the company's profits over one year.
[23] Pro-active action refers to the incentive of developing risk management plans, without which a company (has to make annual payments to the scheme but) cannot benefit from the scheme.

Appendix A 'Downscaled' climate projections

This appendix provides a summary of the projections of key climatic variables prepared to support our analysis. Preceding this summary is an overview of the approach used to develop these projections.

A.1. Background

We have modelled four variables: temperature (maximum and minimum), precipitation and wind speed. To quantify some of the uncertainties associated with the projections, we have used ten models. Model outputs consist of daily estimates up to 2100 at a resolution of 0.5 degrees of latitude by 0.5 degrees of longitude.

To obtain these estimates we have 'downscaled' global climate model outputs consistent with the so-called representative concentration pathways (Box A.1). Of the four 'representative concentration pathways', we have chosen the second and fourth highest pathways (so-called RCP 4.5 and RCP 8.5).

Box A.1: Representative Concentration Pathways

The 'representative concentration pathways' (RCP for short) are greenhouse gas concentration trajectories that describe plausible ranges of climate change. They represent a departure from previous climate change scenarios in that they are articulated around concentrations (earlier scenarios had been articulated around emission levels). This makes it easier to explore the role of different technological developments and socio-economic trends in mitigating climate change and adapting to it (Moss *et al.*, 2010).

Four RCPs have been developed, corresponding to four progressively higher values of radiative forcing that are considered to be plausible for year 2100. Radiative forcing (or climate forcing) refers to the difference between insolation received and given back to space by the Earth and is measured in watts per square metre. The four RCPs are: RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5.

For our analysis we have used the second and the fourth trajectories. RCP 4.5 corresponds to greenhouse gas concentration trajectories consistent with a year 2100 radiative forcing of 4.5 W/m^2. This represents an increase of average surface temperatures of 1.4 °C (in 2046-2065) or 1.8 °C (in 2081-2100), compared to preindustrial levels. The corresponding figures for RCP 8.5 are 8.5 W/m^2, 2.0 °C (in 2046-2065) and 3.7 °C (in 2081-2100).

'Downscaling' is a technique by which properties of the free atmosphere are used to predict local meteorological conditions. In the context of climate change, 'downscaling' makes it possible to generate local-level projections of climatic variables (such as precipitation or temperature) on the basis of regional- or global-level projections.

Two main ‘downscaling’ techniques exist: so-called dynamic downscaling and statistical downscaling. ‘Dynamic downscaling’ relies on a high-resolution regional climate model (or a global model that offer higher resolution for the region of interest). ‘Statistical downscaling’ uses a statistical function to relate observed, reanalysed, or (global climate) model-derived large-scale climate descriptors to observed local-scale descriptors.

Comparisons of ‘statistical’ and ‘dynamic’ downscaling have found similar skill in reproducing historical climate statistics. While this does not necessarily imply that the same will hold true for downscaled estimates of future climate, ‘statistical’ and ‘dynamic’ downscaling techniques are in practice treated as performing on par. ‘Statistical downscaling’ is used more widely, because it does not require the availability of a local-level model.

Both techniques require that biases are removed from the resulting projections. With regard to ‘statistical downscaling’, historical meteorological data is used to eliminate those biases. To this end high-quality observations are required, spanning at least thirty years into the recent past. When these data are not available from national governments, data from international repositories can be used, as was done to obtain the projections presented in this report.

We have obtained projections from ten different models.[24] The models are all part of a so-called model inter-comparison project, which sought to homogenise approaches and improve methods in the area of ‘downscaling’.[25] By selecting the models among those participating in this project, we ensure a higher degree of comparability across model results than would have otherwise been the case.

About twenty modelling groups participated in the above project. We used a subset of those models, which we selected according to a number of performance criteria.[26] The models we used (ten in total) are:

- Beijing Climate Center Climate System Model (BCC-CSM1-1-M),
- Community Climate System Model (CCSM4),
- Community Earth System Model – Biogeochemistry (CESM1-BGC),
- Geophysical Fluid Dynamics Laboratory’s Coupled Physical Model (GFDL-CM3),
- Goddard Institute for Space Studies’ E2 Model (GISS-E2-R),
- Institut Pierre Simon Laplace’s CM5A Model (IPSL-CM5A-MR),
- Max Planck Institute for Meteorology Earth System Model LR (MPI-ESM-LR),
- Max Planck Institute for Meteorology Earth System Model MR (MPI-ESM-MR),
- Meteorological Research Institute at Tsukuba CGCM Model (MRI-CGCM3),
- Norwegian Earth System Model (NorESM1-M).

[24] Using several models allows us to characterise the uncertainty associated with our results. We present those results through a range of the set of ten estimates that we obtain for each parameter.

[25] The project, which run between 2010 and 2014, was dubbed ‘coupled model inter-comparison project’ (or CMIP5 for short, as it was the fifth in a series of related projects). Additional information on the project is available online at http://pcmdi-cmip.llnl.gov/cmip5/

[26] Additional information on those criteria can be obtained from the authors.

A.2. Approach used to summarise the data

The following paragraphs describe the procedure chosen to summarise the projections. Of all possible procedures, we have chosen the approach which we feel may be easier to understand by the non-technical reader.[27]

We have split the country's surface in grids of 0.5 degrees of latitude by 0.5 degrees of longitude (that is, 374 grids). For each of those grids, we have obtained estimates of maximum temperature, minimum temperature, precipitation and wind speed. Specifically, for each of these four variables we have obtained daily estimates for the period January 1st, 2006 to December 31st, 2100 (that is, some 34,675 estimates per variable and grid).[28] Further, since we have used ten different models (see above), the number of estimates is in fact ten times this figure (that is, 346,750 estimates per variable and grid). In addition, since we have considered two plausible degrees of climate change (corresponding to RCP 4.5 and RCP 8.5, see above), the actual number of estimates is twice as large (that is, 693,500 estimates per variable and grid).[29]

Precipitation

We have added up all the precipitation in a given year (all the rain registered through the 365 days in the year, combined in one single figure) for every year in the period 1950-2100 and have calculated the slope of the straight line that fits the trend observed over that 150-year period. A negative slope indicates a decrease in precipitation over time, whereas a positive slope indicates increase. For each climate change scenario (RCP 4.5 and RCP 8.5) we have compared the ten slopes (one for each model) and have suggested a range. We have also conducted this analysis on a monthly basis (as opposed to annually), to identify seasonal changes. This analysis allows us to gauge, with a synthetic range, whether precipitation increases or decreases, and by how much.

In addition, we have defined a threshold for historical heavy rain levels.[30] Using this level of rain, we have counted the number of days that, each year within the period 2006-2100, the threshold is reached or surpassed. We have then calculated the slope of the straight line that fits the trend

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[27] Other procedures could have been chosen. For example, we could have calculated probability distributions (to summarise all the information in one single expression) or conducted an analysis of extremes (to highlight the most significant deviations from a given trend). The approach we have chosen is simpler and therefore clearer. We believe that increased clarity compensates for the information that is lost in the simplification. Notwithstanding, since the full dataset of projections will be available to the Colombian government, more complex analyses could be conducted in the future, if these are deemed necessary.

[28] Note that, for the purpose of modelling, 2006 is considered a 'future' year. This is because historical data of good enough quality is available for the period 1950-2005, but not beyond. For this reason, projections are given starting in 2006, even though, today, 2006 obviously corresponds to the past. Additional information on this issue is available from the authors.

[29] It is worth nothing that these estimates are only meaningful from the point of view of the long-term trends they (collectively) describe. Put differently, a single estimate (for a given variable, grid and future date) cannot be read in the same way that one would read a weather forecast for the following 24 hours. For this reason, having more, rather than less, estimates is useful, as they allow for a more robust identification of those long-term trends.

[30] We have done this by (i) sorting all days in the period 1976-2005 according to the amount of rain each day, (ii) eliminating the days in which it rained less than 1 mm, (ii) identifying the top 1 percent of days with rain, and (iv) defining our threshold as the level of rain in the day with less rain within that top 1 percent group of days.

observed over that 75-year period. We have also conducted this analysis on a monthly basis (as opposed to annually), to identify seasonal changes. This analysis allows us to gauge, with a synthetic range, whether heavy rain episodes are likely to increase or decrease, and how much.

Maximum temperature
We have conducted the exact same analysis, with two variations:

- instead of annual or monthly totals, we have worked with maximum annual or monthly values;
- instead of 1 percent, we have used 10 percent to define our threshold for historical high temperatures.

A.3. Projections

This section summarises the trends arising from the projections introduced in the previous paragraphs. We have limited our analysis on two variables: precipitation and maximum temperature. The summary focuses on two sites (Barrancabermeja and Mamonal) where the two largest refineries in the country are located.

Trends in minimum temperature are of little relevance to risk management in the oil and gas industry in Colombia.[31] Therefore, we have not analysed these projections in detail. Nonetheless, we will submit them to OLADE, because they may be relevant in other contexts (Chapter 9).

Projections for wind speed are rather uncertain, no matter which parts of the world they are obtained for. For this reason, using several models (as we have) becomes all the more necessary. Projections of winds speed are of use when the estimates produced by different models convergence toward a discernible trend. This was not the case for Colombia and therefore we have decided not to use these projections. We will submit the projections to OLADE, in case that interested parties in Colombia may want to use them.

Precipitation trends in Barrancabermeja
Concerning annual precipitation levels under the RCP 4.5 trajectories, one model shows a clear decrease (slope of -1.06), three models show a very moderate decrease (slopes between -0.01 and -0.6), one model shows a modest increase (slope of 0.12) and the remaining five models show a marked increase (slopes between 1.47 and 2.58). Under the RCP 8.5 trajectories four models show sharp decreases in precipitation (slopes between -4.86 and -3.63), one model shows a modest increase (slope 0.39), whereas the remaining five models show sharp increases (slopes between 2.5 and 3.42). Therefore, given this wide spread of results, it is not possible to draw clear conclusions regarding annual precipitation levels.

The top 1 percent of wet days corresponds to daily precipitation levels between 53 and 60 mm of rain. Using that range as a threshold, we find that equal or higher levels of rain were registered, on average, in 1.8 days per year in the period 1976-2005 (that is, our historical

[31] They would be relevant in colder climates, where extreme low temperatures may affect industry operations.

reference). Under the RCP 4.5 trajectories this figure would increase slightly (to 2.3 days per year) in the period 2006-2100. It would increase further (to 2.5 days per year) over the same period under the RCP 8.5 trajectories.

Maximum temperature trends in Barrancabermeja
Concerning maximum temperatures, there is likely to be little change at the aggregate level: under both the RCP 4.5 and RCP 8.5 trajectories all models show slopes close to zero through the period considered (1976.2100). However, on individual days, daily maximum temperatures appear to be on the rise, with values moving from 34.1 (historical) to 36.4 (in 2025) and 37.1 (in 2050) under the RCP 4.5 trajectories, and 36.5 (in 2025) and 37.9 (in 2050) under the RCP 8.5 trajectories.

Precipitation trends in Mamonal
Concerning annual precipitation levels under the RCP 4.5 trajectories, seven models show clear decreases (slopes between -0.66 and -2.32), two models show slight increases (slopes between 0.13 and 0.14) and one model showing a clear increase (slope of 1.37). Under the RCP 8.5 trajectories seven models show sharp decreases (slopes between -4.66 and -3.31), one model shows a very small decrease (slope of -0.05) and two models show increases (slopes between 0.77 and 1.05). Since most models point to decreases in precipitation and the few models that point to increases show less marked departures from today's precipitation levels, it may be concluded that precipitation will decrease in the site of Mamonal.

The top 1 percent of wet days corresponds to daily precipitation levels between 64 and 82 mm of rain. Using that range as a threshold, we find that equal or higher levels of rain were registered, on average, in 0.8 days per year in the period 1976-2005 (that is, our historical reference). Under the RCP 4.5 trajectories this figure would increase slightly (to 0.9 days per year) in the period 2006-2100. It would decrease again (to 0.8 days per year) over the same period under the RCP 8.5 trajectories.

Maximum temperature trends in Mamonal
Concerning maximum temperatures, there is likely to be little change at the aggregate level: under both the RCP 4.5 and RCP 8.5 trajectories all models show slopes close to zero through the period considered (1976.2100). However, on individual days, daily maximum temperatures appear to be on the rise, with values moving from 37.3 (historical) to 39.5 (in 2025) and 39.9 (in 2050) under the RCP 4.5 trajectories, and 39.5 (in 2025) and 40.3 (in 2050) under the RCP 8.5 trajectories.

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Appendix C Individuals interviewed

Table C.1 lists the names, affiliations and e-mail addresses of the individuals we interviewed during our visit to Bogota on 23-25 February 2015.

Table C.1 Individuals interviewed

Contact	Institution	email
Juan Bernardo Carrasco	Ecopetrol	juan.carrasco@ecopetrol.com.co
Sandra Álvarez	Ecopetrol	sandraya.alvarez@ecopetrol.com.co
Julián Chávez	Ecopetrol	julian.chaves@ecopetrol.com.co
Emilio Rodríguez	National Hydrocarbons Agency	edgare.rodriguez@anh.gov.co
Sandra Tovar	National Hydrocarbons Agency	sandra.tovar@anh.gov.co
Marcela Bonilla	Planning Unit of Mining and Energy	marcela.bonilla@upme.gov.co
Hector Herrera	Planning Unit of Mining and Energy	hector.herrera@upme.gov.co
Cristian Rojas	Ministry of Mines and Energy	cdrojas@minminas.gov.co
Giovanni Pabón	Ministry of Environment and Sustainable Development	gpabon@minambiente.gov.co
Josefina Sánchez	Ministry of Environment and Sustainable Development	josanchez@minambiente.gov.co
Luis Fabián Ocampo	Ministry of Mines and Energy	lfocampo@minminas.gov.co
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Hector Moreno	Ministry of Mines and Energy	hemoreno@minminas.gov.co

Appendix D Current and planned industry assets

Table D.1 lists the geographical distribution of industry assets, by industry segment, noting whether the site is actual or planned, as well as the relative importance of the site (in comparison with similar sites in other locations).

Table D.1 Current and planned industry assets

Department	Industry segment			
	Extraction	Transportation	Refining	Distribution
Antioquia				
Caldas				
Bogotá D.C.				
Atlántico				
Bolívar				
Córdoba				
San Andrés y Providencia				
Sucre				
Arauca				
Boyacá				
Casanare				
Amazonas				
Caquetá				
Cauca				
Chocó				
Guainía				
Guaviare				
Nariño				
Putumayo				
Quindío				

Department	Industry segment			
	Extraction	Transportation	Refining	Distribution
Risaralda				
Valle del Cauca				
Vaupés				
Cundinamarca				
Meta				
Vichada				
Cesar				
La Guajira				
Magdalena				
Norte de Santander				
Santander				
Huila				
Tolima				

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