# CLIMATE CHANGE RISKS AND PREPAREDNESS FOR OIL & GAS SECTOR IN INDIA

## EXECUTIVE SUMMARY

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# Executive Summary

## I. Background

The energy sector faces multiple challenges due to climate change. While the need to reduce greenhouse gas (GHG) emissions requires reducing reliance on fossil fuels for meeting energy demands, the energy infrastructure itself is vulnerable to the physical impacts of climate change. There is a large volume of literature and discussion, in policy as well as research, on the challenges and opportunities for the energy sector in the context of mitigation of GHG emissions. However, the same is not true in case of impacts of climate change on the energy sector. Addressing mitigation as well as adaptation in the energy sector is important not only from the perspective of addressing climate change but also from the perspective of ensuring energy security and sustained development.

The Paris Agreement on climate change requires countries to better document their mitigation and adaptation challenges and efforts as well as progressively revise their nationally determined contributions (NDCs) towards achieving the global goal of limiting mean temperature rise to well below 2˚C. India's NDCs set a target of reducing GHG emissions intensity of the gross domestic product (GDP) by 33% to 35% from 2005 levels by 2030, including, among other measures, with an installed non-fossil fuel based power generation capacity accounting upto 40% of the total. Increasingly reduced reliance on fossil fuels, including oil & gas, is the essence of India's NDC.

In the Indian context, the oil & gas sector epitomizes the development vs. climate change debate. The sector is critical for India's energy security as well as its growth trajectory. In 2017, oil & gas constituted over one-third of India's primary energy mix. While India has significant dependency on imported crude and gas, India is a net exporter of refined oil products. Gas is the mainstay of India's pursuit to increase agricultural productivity through use of fertilizers and environmental improvement through provision of cleaner and efficient cooking fuels, and cleaner fuels for transportation and power. Heavy reliance on oil & gas sector for transportation of people and goods makes it the lifeline for smooth functioning of the economy, and in the absence of alternative viable technologies, also the foundation to achieving high economic growth. With rapid urbanization, wherein it is estimated that about 60% of the Indian population will live in urban areas by 2050, greater increase in provisioning of transport and cleaner cooking services would mean deeper reliance on oil & gas. Moving away from oil & gas in the immediate future, therefore, would be the equivalent of deviating from higher levels of development itself.

Various modelling studies show that achieving the target set in the Paris Agreement to limit the temperature rise to well below 2°C would require decarbonization of the energy sector and electrification of the transport sector globally. According to the International Energy Agency (IEA) (2015), achievement of the 2°C goals will require stagnation in the global consumption of oil and a marginal rise in global consumption of natural gas post 2020. Recent policy initiatives in India on renewable energy, energy efficiency, and electric vehicles align with the direction of moving away from fossil fuels. While both IEA and British Petroleum project India and China accounting for half of the increase in demand for oil & gas through 2030s, how long it will actually take for the oil & gas sector in India to feel the impact of transition towards low-carbon development is subject to the pace of technological change in the electric vehicles and renewable energy sector.

Unmitigated climate change poses a threat of increased frequency and intensity of extreme climatic events, such as extreme rainfall, heat waves, cyclones, storm surges, droughts, etc., as well as other risks, such as reduction in water availability, agricultural productivity, loss of land mass, increase in heat stress and vector borne diseases, etc. Past experience shows that of the range of risks posed by climate change, the oil & gas sector is primarily vulnerable to extreme climatic events, such as cyclones, storm surges, and floods. It is also sensitive to slow onset events, such as rise in mean ambient temperature, increased water scarcity, and declining soil moisture. The physical infrastructure and efficiency of processes in various oil & gas sector plants are sensitive to climatic conditions. The impacts could range from financial losses to serious infrastructure damage. Disruption in the supply chain of the oil & gas sector can also significantly hamper other economic sectors.

Given that India's oil & gas sector sustains more than a third of India's primary energy supply, which is likely to grow in absolute terms for at least two decades, the potential impacts of climate change on the sector are a reason for worry from the reliability of energy supply point of view. Moreover, since these impacts may vary depending on the location, a better understanding of potential impacts is necessary for improving the resilience of India's oil & gas sector to the threat of climate change. The vast infrastructure spread across the land-locked locations, coastal areas, and deep sea make it vulnerable to a range of climatic events, such as cyclones, storm surges, floods, heat waves, etc., to varying degrees. There have been instances in the past where occurrence of extreme weather events have led to damage to infrastructure or disruption in operations causing significant losses to companies as well as economic losses to the country.

Climate change, thus, poses three types of challenges to the oil & gas sector. First, and the obvious challenge, is the threat to the future of industry itself due to regulations for mitigating GHG emissions. Second, is the risk to infrastructure and operations, particularly due to extreme weather events. Third, relates to the nature of the Paris Agreement requiring improved transparency in the accounting of GHG emissions.

This study is a first step towards understanding the nature and spread of the three types of risks that the oil & gas sector in India is likely to face in the near future due to climate change. It identifies hotspots where the oil & gas infrastructure is likely to be affected the most by climate change along with the likely impact on demand for oil & gas based products nationally as well as internationally, if current climate policies are fully implemented. It also analyses the preparedness of India's oil & gas sector to meet the reporting requirements under the Paris Agreement. On the basis of this analysis, the study proposes a set of short-term and long-term action points for better preparing India's oil & gas sector to meet the challenges of climate change. A brief summary of relevant good practices from global industry as well as some technological options for industry to address climate change are also provided.

## II. Climate change in Indian context

Climate change pertains to changes in future patterns of various meteorological parameters, such as temperature, precipitation, humidity, wind, etc., that result in changes in future variability (both in frequency and intensity) of climatic events (including extremes), such as heat waves, droughts, floods, cyclones, and sea level rise. A general practice in scientific research on climate change is to compare patterns, observed or projected, over 30-year time period. Most of the climate models take the period of 1971-2000 as the base period for their results (IPCC, Fifth Assessment Report, Volume I).

### (A) Approach for projecting change

For this study, data from 9 climate models was analysed for their accuracy in representing climatic patterns over India. The models were assessed on their ability to simulate the temperature patterns and rainfall variability of the past. The analysis resulted in finalizing of a climate model which represented the patterns better than the rest. In addition, since the objective of the present study required the climate information on a much higher horizontal resolution, a regional climate model, PRECIS, was selected on account of its accuracy of representation, availability of a larger meteorological dataset, fewer data gaps, and high resolution information at spatial scale. The model was run in-house and extensively validated over spatial and temporal scales using the Indian meteorological observations available all over India on a high resolution gridded format. The results from the model were analysed for temperature and rainfall variations of past and future, including future changes in extremes of rainfall and temperature. The PRECIS model has also been used extensively in the Indian domain in many government reports such as India's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC), in respect of the North-Eastern states, and a number of vulnerability, impact, and risk assessment projects for different states of India, such as Maharashtra, West Bengal, Rajasthan, Himachal Pradesh, Punjab, Assam, Uttarakhand, and Goa.

Occurrence of a climatic event depends on a number of meteorological parameters which vary over time and location. Every location has been exposed to different climatic events in the past. The primary impact of climate change will manifest as the change in the patterns of exposure in terms of frequency and intensity. Hence, this study focusses on the change in pattern of exposure to various climatic events in future period of 2020-2050 compared to the baseline period of 1970-2000. The change in exposure has been assessed by considering past occurrences of climatic events together with results of PRECIS model on projected change during 2020-2050 in the meteorological parameters, namely precipitation and temperature, contributing to the respective climatic events. The data for historical occurrences as well as future projections was extracted from various sources, including running the PRECIS model, for each asset-specific location (Table ES.1)

**Table ES.1:** Parameters to assess change in pattern of climatic events

| Climatic Event | Historical pattern | Projection of Change |
|---|---|---|
| Floods | Past occurrences (1985-2011)[a]<br>Exposure to cyclone[b] | Change in no. of extreme rainfall days (99th percentile events) during 2020-2051 over 1970-2000[c]<br>Change in mean annual rainfall during 2020-2051 over 1970-2000[c] |
| Water scarcity | Drought intensity of past occurrences (1985-2011)[a]<br>Water stress (1985-2011)[a] | Change in cumulative dry days in a year during 2020-2051[c] |
| Lightning | Average annual rainfall during 1970-2000[c] | Change in no. of extreme rainfall days (99p) during 2020-2051 over 1970-2000[c] |
| Temperature | Mean annual temperature[c] | Change in mean annual temperature (2020-2051 over 1970-2000)[c]<br>Change in number of hot days (>45°C)[c] (2020-2051 over 1970-2000) |
| Change in soil moisture | Drought intensity of past occurrences (1985-2011)[a]<br>Water stress (1985-2011)[a] | Change in number of hot days (>45°C) (2020-2051 over 1970-2000)[c]<br>Change in cumulative dry days in a year during 2020-2051[c] |
| Cyclones and storm surges | Past occurrences (1985-2015)[d] | Extrapolated trend of sea surface temperature and sea level rise.[e] |

*Source of Data:*
- *a: Aqueduct Global Maps 2.0*
- *b: Geographic location*
- *c: PRECIS model results (TERI)*
- *d: Cyclone eAtlas-IMD*
- *e: INCCA-MoEF (2010)*

Past patterns of exposure to climatic events has been included to moderate the bias that may result if only the projected future changes in meteorological parameters are considered. In other words, if the projected change in meteorological parameters for a location is high but the past occurrences of concerned event are insignificant, then it may be erroneous to conclude that the change in the exposure to that particular climate event in future would be high. Hence, the assessment of change in exposure in this study takes a conservative approach (Figure ES.1). The parameters considered for assessing the change in pattern of climatic events are summarized in Table ES.1.

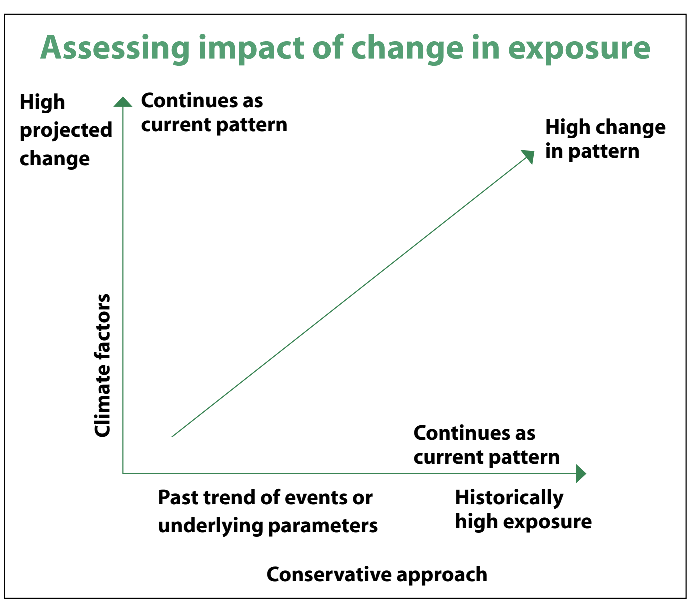


**Figure ES.1:** Approach to determine change in exposure to climatic events

## (B) Projected change

**A warmer India:** The PRECIS model simulations show an increase in the warming pattern all over India in the future period 2021-2050 compared to the period 1971-2000. This warming will be more prominent in increase in the minimum temperatures, compared to mean and maximum temperatures. This warming will be reflected in the number of hot days (>45°C) increasing by upto 800 days in 2021-2050 period compared to 1971-2000, that is, on average every year would experience upto 27 more hot days than in the historical average of 30 years. The instances of consecutive 5 days with temperature higher than 45°C (that primarily contribute to heat wave events) will also increase by 40 days during the same period, that is, an average increase of 1.3 heat waves. These changes in hot days are seen primarily for North-West, North Central, Inland Peninsula, and East Coast covering the entire Indo-Gangetic belt, the arid regions of Rajasthan, Inland Peninsula, and East Coast comprising of the states of Odisha, Andhra Pradesh, and Eastern Maharashtra.

**Higher annual rainfall:** As per historical observation, the pattern of rainfall is projected to vary. Most places in India will experience an increase in total annual rainfall up to 35% compared to 1971-2000. The Inland Peninsula and the North-western region show a relatively higher percentage (18% to 32%) contribution from high rainfall days towards the total rainfall in future as compared to other regions. This corresponds to around 4 to 18 more days of very high rainfall (more rains than the 99th percentile of historical observation during 1971-2000) on average in a year for future years. Most of this is contributed by the amount of rainfall received during the monsoon season: June-July-August-September (JJAS).

**More dry days:** An associated pattern to more concentrated rainfall is the increase in the number of dry days in a year. This occurs since the total seasonal rainfall remains more or less the same as the long term normal, however, most of it is received in fewer number of days, thereby leaving the remaining days drier and more prone to meteorological drought conditions.

**Increased lightning:** Historically, the North-east and the eastern coast have received a high flash rate. Statistically, a strong correlation has been found between the instances of heavy rainfall and flash rates of lightning strikes (Michaelides *et al.* 2010; Murugavel *et al.* 2014). Hence, in addition to lightning continuing as a risk in regions with historically high rainfall, particularly the North-east and Eastern coast, its frequency and intensity is also likely to increase in North-west India where both annual rainfall as well as extreme rainfall days are projected to increase.

**Sea level rise:** The global mean sea level has risen by 0.19 m (0.17 to 0.21) over the 1901-2010 time period (IPCC, 2013) with a higher observed rate during 1993-2010. The regional sea level changes at close to 2.0 mm/yr over the North Indian Ocean and 4 mm/yr over the Bay of Bengal region. Kolkata shows the highest trend on net sea level rise of 5.74 mm/yr, with Kochi showing 1.75 mm/yr, Mumbai with 1.20 mm/yr and Vishakhapatnam with 1.09 mm/yr (Unnikrishnan and Shankar, 2007). It is seen that despite some missing data, the general trend shows an increasing sea surface height over most of the Indian coastal cities. Chennai shows the least increasing trend whereas Garden Reach station (proxy for Kolkata) shows the largest increase in sea surface height.

**Cyclones and Storm surges:** Impacts of cyclones and sea level rise are felt in the form of storm surges in coastal areas. Historically, over a period of 1891 to 2008, it has been observed that 78% of the cyclones (485 in total) were formed over the Bay of Bengal. For the Indian subcontinent, the cyclone prone months are May, June, September, and October. The estimated future cyclone frequency for 2020-2050 with respect to model baseline (1970-2000) for the months of May, June, July, September, October, and November for Bay of Bengal indicate that although the total number of cyclones in future does not increase over Bay of Bengal, there is an increase in the occurrence of intense cyclones— Cyclonic Storms of sustained wind speed of 62–88 km/h for 3 mins, and Severe Cyclonic Storms of sustained wind speed of 89–117 km/h for 3 mins—for the months of September, October, and November is likely. Also, it is seen that there may be fewer cyclonic and super cyclonic storms in future for the months of May, June, and July. The assessment of future cyclone tracks shows no significant change in either number or variation from the historical tracks of the past. However, other studies conclude that the future surges on the East Coast would be 15%-20% higher than the historical pattern, particularly at Visakhapatnam, Kalingapatnam, Gopalpur, Paradip, False Point, and Short Island stations. Accordingly, with increased frequency of intense cyclones, more frequent and higher storm surges are likely on the East Coast.

**Rapid warming of Arabian Sea:** The West Coast is relatively less studied, yet a trend of rise in intensity of cyclones has been observed in the recent past (Murakami *et al.,* 2017). It has been reported that the sea surface temperature of the Arabian Sea has been consistently rising at a faster rate in recent decades leading to relatively higher cyclonic activity (Prasanna Kumar *et al.*, 2009). However, over the Arabian Sea (West Coast), no increase in the number of intense category cyclones has been projected for the study time period of 2020-2050. It may be noted here that the model takes the baseline of 1970-2000 to project in the future and has not taken the immediate past into consideration. Also, the model currently underestimates the simulated intensities due to the inherent dynamical limitations and computational uncertainties and hence the results shown should be essentially taken as an indication for the trend for the future and not as absolute intensities. It is also seen that most of the recent high intensity cyclonic storms have resulted in landfalls. With increasing global warming, a continued rise in sea surface temperature at the West Coast is likely to result in increased intensity of cyclones and storm surges.

## III. Impact of climate change

The impacts of climate change must be understood in terms of change in the observed patterns. The findings of this study, therefore, should be interpreted as relative to past experience for a given asset at a given location. A particular climatic event, such as extreme rainfall, may become more (or less) frequent or more (or less) intense compared to past patterns. Hence, when considering climate change induced risks to infrastructure, we consider how risk profile at a given location is likely to change with respect to the existing risk profile. Simultaneously, it is important to keep in mind that risk to infrastructure is a function of its vulnerability and exposure to specific climatic events. Vulnerability implies that the infrastructure is likely to be negatively affected if it is exposed to a climatic event. Exposure implies occurrence of a climatic event at the location of the infrastructure. While the vulnerabilities of assets can be treated as given, on account of technological factors and capacity, variation in climate-induced risks is on account of variation in exposure. Increase in exposure to a climatic event implies increased risk vis-à-vis past experience.

The oil & gas industry will experience the impacts of climate change in two ways. The extreme climate events, heavy rainfall, heat waves, cyclones and storm surges may cause delays in infrastructure development, damage to assets, shutdown of production, disruption of supply chains, or health issues for the employees. These impacts will however, vary according to the location. The slow onslaught of climate change, such as rise in average temperature, increase in the number of dry days, and depletion of water resources may impact the efficiency of units such as cooling towers and compressor stations, which will imply increase in the cost of operations. These changes, along with increase in salinization of ground water and soil may lead to corrosion of pipelines.

**Supply chain disruptions due to floods:** Oil & gas operations are sensitive to flooding. Impacts include full or partial shutdown of refineries, disruption in road-based supply chains, including road accidents, ruptures in pipelines, disrupted access to infrastructure for maintenance and repair, etc. Taking into account the projected change in annual rainfall and number of extreme rainfall days, together with past pattern of flood occurrences during 1985-2011, and possibility of exposure to cyclones as contributing factors for extreme rainfall or flooding, this study projects an overall increase in exposure to flood risk across India. The largest increase in impacts due to floods will be experienced in the North-western region and Inland Peninsula of India. Considering that these regions have multiple oil & gas assets and supply infrastructure, for instance pipelines for crude, petroleum products, natural gas and liquefied petroleum gas; refineries, petrochemical plants, liquified petroleum gas (LPG) bottling plants, and tap off points to supply fuel to other industries, disruptions and losses to oil & gas industry due to floods in this area are likely to be more challenging than earlier experiences. Particularly, the assets which rely significantly on road-based backward and forward linkages such as the Pata Petrochemical Plant (GAIL) and Panipat Refinery Complex (IOCL) (section 3.2.2) and many LPG bottling plants and bulk depots in North and North-West India (section 3.2.5), will face more disruptions due to floods. Generally, most of the refineries and petrochemical plants will experience a medium level of increase in flood risk with the exceptions of Koyali (high level increase) and Digboi, Numaligarh, Bina, Manali, Nagapatinam, and Tatipaka (low level increase).

Other than the variation in rainfall, the degree of variation in risk is also influenced by the capacities of the plants and their location. A plant of high capacity at the same location is likely to be affected much more if exposed to similar variation in rainfall than a lower capacity plant. Similarly, a plant at the East coast is likely to face higher impact compared to a similar capacity plant at a land locked location with similar variation in rainfall. The refineries and petrochemical plants that have fallen in the tracks of cyclones include Paradip, Haldia, Vizag, Tatipaka, Manali, Nagapatinam, and Mumbai.

Further, the regions with projected rise in flood instances also overlap with the Luni, Ganga, Krishna, and Kaveri river basins where many pipeline networks either cross or run along the rivers, and hence are more exposed to flood-induced damages. It must be kept in mind that the actual impact of floods depends on a number of other factors as well, such as land use pattern, topography of the region, etc. Hence, a detailed localized flood modelling studies for specific infrastructure in these regions needs to be carried out.

**Fresh water scarcity for refineries and petrochemical plants:** Fresh water is critical for refineries and petrochemical plants. Changes in the availability of fresh water can affect the throughput and cost of water. A preliminary analysis by TERI using a Systems Dynamics model suggests that a 5% reduction in the availability of fresh water may result in a decline of more than 5% in total throughput of a refinery. Of course, this impact would vary depending upon the water intensity of a refinery or petrochemical plant. Large and water-intensive plants will be more vulnerable to change in fresh water availability due to climate change. Taking into account the projected increase in number of dry days during 2020-2051 compared to 1970-2000, together with drought intensity of past occurrences (1985-2011) and observed water stress (extraction to replenishment ratio) levels during 1985-2011, this study suggests that water scarcity will increase more acutely in North-western India compared to other regions. This is on account of historically high water stress in this region, coupled with increase in the number of cumulative dry days. A greater number of high temperature days will also contribute to increase in dryness. However, considering the capacity as well as water intensity of refineries as a positive stressor on vulnerability to fresh water scarcity, a number of refineries are likely to face a medium-level increase in exposure to fresh water depletion due to climate change. These include refineries and petrochemical plants located at Barauni, Guwahati, Panipat, Koyali, Haldia, Paradip, Mumbai, Mangalore, Kochi, and Pata. While the coastal plants will have the option of using sea water with desalinisation facilities, land locked plants will need to source water from far off places. This will Implyan increase in the cost of operation. Some of the refineries, such as Kochi and Mangalore, have already made such investments while others are in the process of planning such as the Mumbai refinery of Hindustan Petroleum Corporation Ltd (HPCL). The magnitude of 'medium increase' will be higher for plants, such as the Mangalore refinery, which are already facing water scarcity. The Mathura refinery is likely to face the highest variation compared to the past in terms of fresh water availability. Currently, water stressed plants located in other regions will experience little change in the risk profile related to water stress due to climate change, implying that their current status may continue (or change on account of non-climatic factors).

**Cyclone and storm surge risk to LNG/LPG terminals:** The infrastructure on the East coast will be exposed to increased frequency and intensity of cyclones as well as storm surges due to the rise in sea surface temperature and rising sea levels. Terminals and ports are the most sensitive infrastructure. Considering that India receives multiple shipments of liquified natural gas (LNG) and LPG weekly, increased frequency and intensity of cyclones will cause greater disruptions in supply. Rise in storm surge heights will pose even a greater risk of damages to jetties, which may lead to additional costs of repair or rebuilding as well as prolonged delays or reduced capacity to receive imports. These risks may be further deepened by other non-climatic factors, such as silting. While the West coast is projected to experience no significant variation, it must be interpreted in the context that the west coast is relatively less studied.

**Efficiency of cooling towers at refineries and petrochemical plants:** Variation in ambient air temperature affects efficiency of cooling towers at refineries and petrochemical plants. Depending upon the design and capacity utilization of the cooling towers, rise in ambient air temperature may lead to increased water requirement and energy consumption or constraints on throughput. In particular, the increased frequency of five or more consecutive days with temperatures higher than 45°C and increase in total number of extreme hot days will have significant impacts. Considering the projected change in mean annual temperature and number of hot days along with historical mean annual temperature at given locations, the plants at Mathura, Panipat, Bhatinda, Bina, and Pata are projected to experience a medium level of increase in risk of reduced efficiency of cooling towers. Since these are also the locations where medium level of increase in water scarcity is projected, the combined impact of climate change on the cooling system is likely to be high.

**Efficiency of gas processing units:** The gas processing units recovering C2, C3, and C4 may experience reduced average productivity due to upward change in temperature conditions. Yield variation during winter and summer seasons has been reported to be in the range of 3% to 5%. However, in the absence of sufficient time series data on change in ambient air temperature, production from the fractionators, and energy consumption, any initial estimates could not be arrived at. The PRECIS model result show that average temperatures may rise upto 2°C over next 30 years with the maximum change being in North, Central, and North-West India. This will have implications for the assets at Vijaipur, Pata, Vaghodia, Usar, Gandhar (GAIL), and Hazira (ONGC).

**Energy consumption at compressor stations and regasification plants:** The compressor stations along the gas pipeline network are particularly sensitive to climatic conditions. Energy consumption at the compressor stations vary according to the levels of ambient air temperature and humidity. While the precise impact on the efficiency of plant would require detailed plant level modelling and analysis, increase in energy consumption with increase in ambient air temperature and humidity has been experienced. At the Dibiyapur compressor station of GAIL, for example, variation in energy consumption has been observed in the range of 2% between day time and night time. Hence, projected rise in average air temperature is likely to increase the average energy cost of operating compressor stations. Particularly, the assets situated in North West, North Central, and Inland Peninsula will face increased energy consumption. In particular, the pipeline segments of Panipat-Mohunpura (IOCL, natural gas), Panipat-Nabha-Jalandhar (IOCL, LPG), Hazira-Vijaypur-Auraia-Shahjahanpur (GAIL), and Ajmer-Jaipur-Gurugram-Loni (GAIL) will be more exposed to increased energy consumption.

The experience of the heat exchangers at the LNG regasification plants, such as Dahej and Kochi (PLL), will be different. These plants are likely to benefit from rise in temperature in terms of both production rate as well as energy consumption. However, they may face extreme variations in temperature resulting in very low temperatures. The PRECIS model results show minor variations in average temperature, minimum temperature, and maximum temperature at the locations of regasification plants. Hence, no significant impact, positive or negative, in terms of production rate or energy consumption is expected.

**Flood risks to pipeline infrastructure:** Pipelines are the most convenient as well as most climate resilient mode of transportation for the oil & gas sector. While most of the pipelines in India will be immune to climate change on account of being underground, the other supporting infrastructure necessary to operate pipelines efficiently along the route of pipelines will be more exposed to climate change as mentioned in para 26. Pipelines, however, may be more vulnerable where they cross a river in a high flood risk zone. Since the pipelines are laid about 4 m below the river bed, they are immune to the risk of scouring due to high water flows during flood. However, since the points of horizontal drilling on both sides of the river are only about 500-600 m from the river banks, they are more vulnerable to exposure and scouring during floods, especially in cases where the rivers change course. This risk will be heightened in the North West and Inland Peninsula, particularly in the flood plain of rivers Luni, Ganga, Krishna, and Kaveri. Above ground pipelines, particularly the LPG pipelines in high flood risk areas of North West and East Coast regions, will be generally more prone to damage.

**Decline in soil moisture and risks to pipelines**: Other potential impacts of climate change on pipelines include reduction in soil moisture. For the underground pipelines, reduction in soil moisture may affect the stability of pipelines. For laying new pipelines, assessment of how soil moisture along the route is likely to change would be of significant value. Considering the historical pattern of drought severity and water stress along with future projections of increase in number of hot days as well as dry days, the North-West region is projected to be more prone to decline in soil moisture. This is enhanced by the general high vulnerability of India to desertification. It is important to note that the pipeline infrastructure in India is highly concentrated in the North-West region. Hence, more detailed regional assessment of change in soil moisture in particular and desertification in general for this region are advisable.

**Impact of lightning:** The historical pattern of high flash rates of lightning indicates that the North-East region is more exposed to lightning in monsoon season and Southern West Coast is more exposed during post-monsoon season. However, the projected change in rainfall pattern implies that North West, North Central, and Inland Peninsula may also face increased exposure to lightning instances. Lightning can elevate minor industrial problems, such as leakages of inflammable material, into bigger industrial accidents such as fires.

# IV. Impact of climate policy

The Paris Agreement on climate change aspires to limit temperature rise to 2°C or below. In the run up to the Paris Agreement, countries had submitted their NDCs towards this goal. According to the analysis by the Climate Action Tracker, even if the targets included in NDCs are fully implemented, the temperature rise could still be more than 3°C. Hence, the Paris Agreement has set up a process of regular monitoring of progress and revision of the NDC targets to align with the overall goal of the Paris Agreement. It is expected that countries will revise their targets with more stringent targets beyond the current timeframe of 2030.

Climate policies will impact the oil & gas sector in three ways. First, the push for low-carbon development trajectories will affect the consumption of fossil fuels in the form of combustion, such as in power, transport, etc. This will place limits on the size of the global as well as national markets for the oil & gas sector. Particularly, if the climate policies adopted by the countries, which account for bulk of India's oil exports, focus on reducing consumption of the oil products they import from India, export prospects for Indian companies could be seriously affected. Second, the imperatives of low-carbon development, embedded in India's NDCs, will also put tremendous pressure on the sector to invest in lower emission-intensive technologies. Third, the requirements of transparency of actions and reporting under the Paris Agreement would necessitate that companies better document their efforts at GHG emission reduction and measurement of results achieved. While such documentation may involve modest costs, it is bound to contribute to the decision-making process immensely in the context of climate change, not only for the companies but also nationally.

## (A) Impact on the global market

Various modelling studies conducted by international agencies, such as the IEA or international research consortia, such as the Deep Decarbonisation Pathways Project (DDPP), Modelling and Informing Low Emission-Strategies (MILES) Project, Linking Climate and Development Policies (CD-LINKS), etc., point out that in order to achieve the 2°C goal significant reduction in global fossil fuel consumption before 2050 is necessary. Achievement of this target is contingent upon, first, aggressive decarbonization of the power sector (reducing coal consumption), and second, electrification of transport sector (reducing consumption of petrol, diesel and gas) over a timeframe upto 2050.

In most assessments, the global demand for oil either stagnates or declines post-2020. However, the stagnation or decline will be a net result of decline of demand in Organisation for Economic Co-operation and Development (OECD) countries and rise in non-OECD Asia and Africa. For example, according to IEA, the global demand for oil will increase by only 78 Mtoe between 2013 and 2030 whereas the corresponding figures for non-OECD Asia, India and China are 359, 134, and 164 Mtoe, respectively. Africa would account for a rise in demand by about 58 Mtoe during the same period. In comparison, demand for oil would decline by 179, 153, and 149 Mtoe in USA, Middle East, and EU, respectively. The global demand for natural gas, however, is expected to increase by 30% by 2030 from the 2013 level under the 2°C scenario accounting for 3547 Mtoe. India would see a rise of 60% in natural gas consumption in 2030 compared to 2013.

In the first instance, such evolution of global hydrocarbon markets, constrained by climate concerns, implies that Indian oil companies will not face any loss of demand in the domestic market. However, the international market is likely to face increased competition from the oil-exporting OECD and Middle East countries where domestic consumption would need to decline if their mitigation efforts are consistent with the 2°C goal. The natural gas sector, on the other hand, may face higher import prices due to global rise in natural gas consumption.

## (B) Impact on exports

Exports of petroleum products by India, including sales to Nepal and Bhutan, consists of Liquefied Petroleum (LPG) Products, Motor Spirits (MS), Naphtha, aviation turbine fuel (ATF), Kerosene, High Speed Diesel (HSD), Light Diesel Oil (LDO), Lube Oil, Fuel Oil (FO), Bitumen, and others. Total exports by India have increased at the rate of almost 14% per year from ~8 million tonnes (MT) in 2000-01 to ~65 MT in 2016-17. Of these, the share of MS, Naphtha, ATF, HSD, and FO has increased from 76% in 2000-01 to ~93% of the total product exports in 2016-17 with HSD constituting ~45% of the total product exports. In terms of net exports, ATF has seen the highest growth of 27% since 2000-01 while growth rates of Naphtha, MS, and HSD have been 19%, 17%, and 19%, respectively. This export basket is likely to change in the light of climate commitments made by the different countries that India exports to, in their respective NDCs.

The top 14 countries accounting for the bulk of India's petroleum product exports in 2016-17, in quantity, include Singapore, the Netherlands, USA, Turkey, South Africa, Saudi Arabia, Tanzania, People's Republic of China, Korea, and Oman. Singapore has consistently been the top country to which India has exported petroleum products since 2011-12, followed by Netherlands and USA. India's exports to Brazil which were significant until 2014-15, have seen a fall from ~3MT in 2011-12 to ~74,000 metric tonnes in 2016-17.

NDCs and climate policies in each of these 14 countries aim at reducing their emissions intensity by 21% and 40% by 2030 from different base years. While the NDCs and other climate policies state that they would cover all sectors of the economy – IPPU (Industrial Processes and Product Use), Agriculture, Energy, Transport, Land-Use Change, Forestry, and Waste – their focus hinges primarily on reducing energy consumption in energy- intensive industries and other sectors, such as buildings and transport. The main policy thrust is on energy efficiency, increasing the share of renewables in the electricity mix and sustainable transport. The focus on energy efficiency in energy-intensive industries cuts across different climate policies where countries are looking to invest heavily in energy efficient technologies. Most importantly, they are also considering fuel switching where fuel oil is directly burned to meet heating needs. Countries, such as Turkey, Oman, UAE, and Korea are seen to focus more on the transport and power sectors. In the transport sector, while there is no explicit commitment on electric vehicles, climate policies are seeking options to reduce petrol and diesel consumption by increasing usage and share of public transport, cleaner fuels, and technologies for private and public transport, building infrastructure to encourage cleaner multi-modal transportation, complemented by tax reductions on hybrids and electric vehicles, carbon tax on polluting cars, etc.

The countries of Singapore, UAE, and Saudi Arabia together account for ~50% of petroleum product exports from India in the last six years. Summarizing their efforts to meet the NDC goals, there is increasing shift away from refined petroleum products in these countries either because of increased energy efficiency, domestic refining capacity, or fuel shifting in the demand sectors (Table ES.2). Given these factors, it is imperative that Indian downstream players revisit their export strategies for these three destinations.

**Table ES.2:** NDCs of India's top 3 petroleum product export destinations

| Countries | NDCs | Sector related policies |
|---|---|---|
| **Singapore** | Reduce emission intensity by 36% from 2005 levels by 2030 and aim to peak emissions by 2030 | • Adopt cleaner fuels such as natural gas<br>• Fuel switch to cleaner fuels (fuel oil to natural gas in boilers) which could decrease carbon emissions by 25%<br>• Make public transport the preferred mode of transportation (the aim is to achieve 75% use of public transport by 2030) from the 63% in 2012<br>• Tracks for cycling and walking,<br>• Regulations to improve vehicle fuel efficiency<br>• Curb consumption of petroleum products in vehicles with schemes such as the Vehicle Emissions Scheme (VES)<br>• Pilot Electric Vehicle (EV) programme with 1000 EVs and island-wide charging infrastructure<br>• A carbon tax between S$10 to S$20 from 2019 for upstream users<br>• Growth rate in petroleum product consumptions slows down from 5% (2010-15) to 3% (2015-30) |
| **UAE** | Pursue a portfolio of actions including increasing the clean energy to 24% of the total energy mix by 2021 from 0.2% in 2014.<br><br>Reduce energy consumption by 30% by 2030 across all sectors | • Decarbonize the power sector and reduce the reliance on natural gas to 76% (which accounts for 98% of total generation)<br>• Tariff reform to avoid wastage and reduce energy consumption<br>• Fuel switching to CNG in the transport sector<br>• Increase the share of travel by public transport to ~30% by 2030 from 16% in 2016 (Dubai)<br>• Consumption of petroleum products reduces from 28 per cent of the total final consumption in 2015 to 20 per cent in 2030.<br>• Increase refining capacity |
| **Saudi Arabia** | Avoid up to 130 million tonnes of $CO_2$eq emissions by 2030 | • Double production of natural gas and construct a national natural gas distribution network<br>• Investing ~USD 32bn in efficiency initiatives with the aim of reducing domestic energy consumption by 600,000 barrels per day<br>• Fuel economy standards<br>• Increasing domestic refining capacity to 3.3 mb/d from a baseline of 2.9 mb/d and increase penetration of natural gas in different sectors by increasing dry gas production capacity from a baseline of 12 bcf/day to 17.8 bcf/day<br>• 10% of electricity from renewable energy sources by 2020 |

ATF has seen the highest growth in net energy exports since 2000-01 followed by HSD, MS, and Naphtha. Given the increasing shift towards cleaner fuels in the top 14 countries India exports to, the exports of MS and HSD could decline. Alternatively, given the projected increase in domestic consumption, India may not remain a net exporter of MS and HSD, unless new refining capacity is created, and India finds newer markets for exports of these products. Most of the top 14 export destinations have policies aimed at decreasing consumption of fossil fuels and decarbonizing the remaining sectors.

This means that Indian downstream players would need to revise their export strategy beyond 2025 and seek other markets where petroleum product consumption could see an upswing. The market for ATF though continues to remain strong, given that so far no alternative fuel or technology has become commercially viable for air travel. Naphtha consumption is seen increasing within India, however, using naphtha as feedstock can increase emissions. Given the existing ban on using naphtha in some countries across the world, increasing natural gas reserves and the possibility of substituting Naphtha with natural gas in the petrochemical sector would mean that Indian refiners use Naphtha for domestic uses, while seeking to export sustainable feedstock.

## (C) Impact on national market

India's national climate policy has been determined by material concerns, particularly those related to energy and poverty alleviation. India faces a unique dilemma where it will have to provide access to basic energy services, increase incomes, provide employment while committing to the global challenge of climate change mitigation. This is challenging because most other large nations faced the pressure of mitigation very late in their development path. Therefore, there is no proven pathway for development in climate change that India can follow, but will have to set a new sustainable pathway. Considering these factors, India through its NDCs has committed reduction in emission intensity of GDP by 33%-35% (relative to 2005) by 2030 and increasing the share of non-fossils to 40% of the total installed power generation capacity.

In India's NDCs, no particular mitigation strategies have been listed in the oil & gas sector. However, going forward, mitigation strategies on the demand-side sectors could have implications for oil & gas consumption. Some of these measures include the Perform-Achieve-Trade (PAT) scheme, Smart Cities Mission, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), dedicated freight corridors (DFCs), Jal Marg Vikas to promote inland waterways transport, Sagarmala project, increase in Mass Rapid Transport System, FAME mission which focuses on hybrid & electric vehicles, Vehicle Fuel Efficiency programme, national policy on biofuels and energy efficiency measures for Small & Medium-sized enterprises (SMEs), among others. Given these factors, there is a need for informed decision-making in the oil & gas sector on the impact of these policies on demand of different petroleum and natural gas products.

In the context of the NDCs, India's long-term energy demands are expected to be influenced not only by its economic growth targets, but also with the way government policies and consequently alternative technologies evolve in terms of their costs and efficiencies. While the current NDCs set 2030 as terminal year, the five year cycle of NDC revision under the Paris Agreement may imply higher targets for subsequent periods for all countries, including India. In order to assess the implications of alternative energy development paths for India, a scenario-based analysis using TERI's MARKAL model is undertaken.

In TERI's MARKAL model, the Indian energy sector is disaggregated into five major energy consuming sectors, namely, agriculture, commercial, industry, residential, and transport sectors. Each of these sectors is further disaggregated to reflect the sectoral end-use demands. The model is driven by end-use demands in these sectors. End-use energy demands at the country level are estimated exogenously using econometric models across various energy-consuming sectors of the Indian economy. On the supply side, the model considers the various energy resources that are available both domestically and from abroad for meeting various end-use demands. These include both the conventional energy sources, such as coal, oil, natural gas, and nuclear, as well as renewable energy sources such as hydro, wind, solar, biomass, etc. The availability of each of these fuels is represented by constraints on the supply side. The relative energy prices of various forms and source of fuels play an integral role in capturing inter-fuel and inter-factor substitution within the model. Furthermore, various conversion and process technologies characterized by their respective investment costs, operating and maintenance costs, technical efficiency, economic life, etc., that meet the sectoral end-use demands are also incorporated in the model. For this study in particular, the model database extending from 2001-2051 has been updated to a limited extent, mainly to better validate and align the energy consumption across sectors especially in the recent past. The cost and technology data has been updated based on expert opinions sought during the capacity building workshop held in May 2017 with participating companies.

**Three Scenarios:** In keeping with the intent of achieving and maintaining a high rate of economic growth for achieving India's development objectives, as mentioned in India's current NDCs, we assume the same economic growth rates across all Scenarios for this study. India's NDCs is an economy wide aggregate target. Eventually, it will be achieved through a combination of various sectoral measures without altering the economy wide target of NDC. Each of these combinations is defined as a scenario. Here we present the findings of three different scenario-based analyses beyond 2030 keeping in mind the global objective of limiting carbon emissions to stay within the range of 2 °C, and the mechanism of 5 year progressive revision of NDCs as per the Paris Agreement. The three scenarios – Reference Scenario, Balanced Scenario, and Ambition Scenario – have been developed based on stakeholder discussions as well as our understanding of the impact of different policies which have been announced by the government. The three Scenarios developed for this study vary in terms of the stringency of mitigation requirements and expectations regarding policies towards end-use efficiency and uptake of alternative fuels and technologies.

- **Reference Scenario (REF):** The Reference Scenario charts the baseline development pathway for India under the current climate policy regime. This scenario thus lays out the probable path for India if India does not implement any more climate or energy policies but development continues in line with the existing trends and policies.
- **Balanced Scenario (BAL):** This scenario is a stylised version of the development pathway of India towards achievement of her NDCs with special focus on uptake of cleaner fossil fuels. Essentially, this scenario looks into net positive carbon technologies that can co-exist with prospective carbon neutral technologies. Such technologies include co-existence of CNG-based vehicles and electric vehicles, electric cooking, and LPG/PNG based cooking, etc., and the carbon neutral technologies considered here mostly include electrification of end use, e.g. EVs whose carbon neutrality is contingent on decarbonization of the electricity sector.
- **Ambition Scenario (AMB):** The Ambition Scenario is a deeper mitigation pathway for India which pushes the boundaries of energy efficiency improvement across all sectors, penetration of cleaner fuels, enhanced uptake of renewables, phase out of obsolete and inefficient technologies, etc. This scenario is aimed at a deeper decarbonization of the Indian energy sector over and above India's NDCs.

### *Assumptions and sectoral demand projections*

**Agriculture Sector:** Energy consumption in agriculture is mainly on account of land preparation and irrigation. Diesel remains the main fuel for land preparation and the technologies remain the same across the three Scenarios. In irrigation, there will be a trend of a shift towards electric pumps as availability and reliability of electricity increases. The efficiency of electric pumps also increases but is maintained the same across Scenarios. The penetration of electric pumps in 2051 is assumed as below:

**Table ES.3:** Penetration of electric pumps (2051)

| Scenario | Penetration |
|---|---|
| REF | 80% |
| BAL | 90% |
| AMB | 100% |

**Commercial Sector:** The reduction of energy consumption in this sector comes from the development of energy efficient buildings instead of conventional buildings. The key is to influence the change right at the time of construction. The other end-use in this sector includes commercial cooking where penetration of PNG varies. We do not assume any variations across the three Scenarios for energy consumption for end-uses such as public lighting and water works and sanitation due to the small share in the overall energy consumption of the sector. The penetration of efficient buildings, and PNG in 2051 is assumed as below:

**Table ES.4:** Penetration of efficient buildings (2051)

| Scenario | Penetration |
|---|---|
| REF | 20% |
| BAL | 45% |
| AMB | 95% |

**Table ES.5:** Penetration of PNG (2051)

| Scenario | Penetration |
|---|---|
| REF | 15% |
| BAL | 25% |
| AMB* | 15% |

* Penetration of PNG in AMB Scenario is lower compared to BAL Scenario on account of greater emphasis on non-fossil fuel based cooking services.

**Residential Sector:** With increasing electrification of households, the demand for electricity is expected to increase and so is the electrification of end-uses. However, with increasing penetration of efficient appliances, the energy consumed per unit of energy required is also expected to decrease.

**Table ES.6:** Penetration of efficient buildings (2051)

| Scenario | Penetration of Efficient Appliances (2051) | Penetration of LED (2051) | Penetration of PNG (2051) | Penetration of LPG (rural) (2051) | Penetration of improved biomass cookstoves (2051) |
|---|---|---|---|---|---|
| REF | 40% | 85% | 30% | 45% | 20% |
| BAL | 60% | 85% | 35% | 60% | 75% |
| AMB | 100% (by 2041) | 100% (by 2046) | 40% | 50% | 90% |

**Industry Sector:** The demand of different industry sub-sectors is projected based on the sectoral GDP growth forecasts, using econometric tools. In case of exponential growth trends, the demands are expected to follow an S-curve with saturation levels assumed in line with sectoral development aspirations and based on appropriate levels as existing in other countries. Further, where planned production targets are available at the industry sub-sector levels, as in case of iron and steel production, we ensure alignment of the sectoral growth trends.

**Table ES.7:** Demand of major sub-sectors in industrial sector

| Industry | Units | 2016 | 2021 | 2031 | 2041 | 2051 |
|---|---|---|---|---|---|---|
| Glass | Million Tonnes | 5 | 6 | 11 | 16 | 19 |
| Aluminium | Million Tonnes | 2 | 3 | 5 | 7 | 9 |
| Iron & Steel | Million Tonnes | 116 | 178 | 374 | 585 | 723 |
| Cement | Million Tonnes | 311 | 433 | 762 | 1085 | 1300 |
| Fertilisers (Nitrogenous) | Million Tonnes | 20 | 24 | 32 | 41 | 46 |
| Bricks | Million Tonnes | 669 | 748 | 905 | 1063 | 1221 |

Over the modelling period, with the increasing shift towards renewables in some sectors, and the resultant freeing up of demand of oil & gas, we assume that in the BAL, a higher growth of the petrochemical sector would create a better opportunity of transforming the use of crude oil derivatives and natural gas in the form of fuels to its use in producing petrochemical feedstock / building blocks. Petrochemical building blocks are of two categories, namely, olefins-based and aromatics-based. These petrochemical building blocks are then used to produce a variety of value-added products ranging from plastic products, synthetic rubber, fibres, textiles, etc. Ethylene is the key olefin-based petrochemical feedstock which is used to produce High Density Polyethylene (HDPE) and Linear Low Density Polyethylene (LLDPE) while Para-Xylene paraTetraphthalic acid (PX-PTA) is the key base aromatic petrochemical feedstock which is used to produce a variety of value-added products, such as polyesters, resins, etc. Apart from these two products, linear alkyl benzene (LAB) is also used for the production of surfactants and detergents. The feedstock used in the petrochemical industry depends to a large extent on the nature of value-added products being produced. In general, PX-PTA based derivatives use Light Aromatic Naphtha (LAN) or Heavy Aromatic Naphtha (HAN) as the key feedstock, whereas the ethylene-based products use either naphtha or natural gas. Some ethylene plants also employ dual feedstock crackers where both natural gas and naphtha can be thermally cracked to enable the production of LLDPE and HDPE. LAB is produced using special cut kerosene and benzene as feedstock.

Given that the market share of petrochemicals has increased by 13% in 2016-17 with Reference to 2013-14, it is reasonable to assume that demand for petrochemicals will increase significantly in the years to come. We have accounted for this likely change in the Balanced Scenario where the demand for petrochemicals is estimated under the assumption that it will saturate at current per capita consumption levels in the US. The REF and AMB Scenarios on the other hand account for the demand of petrochemicals based only on past trends. Accordingly, the REF and AMB Scenario assume an average annual growth rate of 3.2% between 2011 and 2051 for the petrochemical industry. On the other hand, allowing less stringent mitigation pressure on the oil & gas sector, the BAL Scenario assumes an average annual growth rate of 5.5% for the industry between 2011 and 2051.

**Transport Sector:** The transport sector considers surface transportation, air transportation, as well as water transportation. Surface transportation includes both roadways and railways. Further, both surface transportation and air transportation cover movement of goods and passengers. Water transportation accounts only for freight movement. Based on TERI's econometric sectoral demand models, the transport sector demands are estimated (Table ES.8). The detailed assumptions in accordance with the broader objective of the Scenarios are listed in Table ES.9.

**Table ES.8:** Transport sector demands

| | Units | 2016 | 2021 | 2031 | 2041 | 2051 |
|---|---|---|---|---|---|---|
| Airways- Freight | btkm | 1 | 1 | 2 | 3 | 5 |
| Airways- Passenger | bpkm | 97 | 144 | 323 | 645 | 1038 |
| Surface Transportation- Freight | btkm | 1925 | 2660 | 5345 | 9686 | 13955 |
| Surface Transportation- Passenger | bpkm | 9518 | 12918 | 21133 | 29353 | 36402 |
| Waterways- Freight | Million Tonnes | 1224 | 2050 | 5965 | 15525 | 31639 |

*bpkm = billion passenger kilometre; btkm = billion tonne kilometre

**Table ES.9:** Assumptions for transport sector

| | | % Share in 2051 | | |
|---|---|---|---|---|
| **Mode** | **Fuel** | **Reference** | **Balanced** | **Ambition** |
| Cars & Taxis | CNG | 5% | 50% | 1% |
| Cars & Taxis | EVs | 0% | 50% | 90% |
| Two-Wheelers | EVs | 2% | 45% | 90% |
| Three-Wheelers | EVs | 10% | 45% | 90% |
| Three-Wheelers | CNG | 20% | 45% | 1% |
| Buses | CNG | 5% | 25% | 45% |
| Railways- Freight | Electricity | 70% | 95% | 80% |
| Railways- Passenger | Electricity | 70% | 95% | 75% |
| Share of Railways in Freight Transportation | | 25% | 35% | 30% |
| Share of Railways in Passenger Transportation | | 12% | 15% | 12% |

## *MODEL RESULTS*

Fuel mix and emission intensity of GDP associated with the three Scenarios are exhibited in Tables ES.10 and ES.11, respectively. Under each of the three Scenarios, India is able to meet the NDC targets. The demand for oil & gas is also set to increase under all the Scenarios. While total commercial energy consumption increases by a factor of 4, 3.6, and 3 between 2021 and 2051 in the REF, BAL, AMB Scenarios, respectively, the final consumption of oil increases by a factor of 4.5, 3.7, and 3.4 respectively. The consumption of gas, however, plays a more significant role in the BAL Scenario, where it increases by a factor of 5.1 compared to a factor of 4.1 and 3.2 in REF and AMB Scenarios, respectively. Hence, for subsequent decades, the oil & gas sector does not face any serious challenge in terms of absolute aggregate demand. However, the rate of growth with which alternatives to petroleum products penetrate across various end-uses could vary depending upon the emissions mitigation target India adopts in subsequent NDCs as well as the global technological progress for such alternatives.

**Table ES.10:** Primary energy mix in different Scenarios (Mtoe)

| Year | Scenario | Coal | Oil | Natural Gas | Nuclear | Hydro | Solar | Wind | Others |
|---|---|---|---|---|---|---|---|---|---|
| 2021 | **Reference** | 591.9 | 258.5 | 65.0 | 19.7 | 18.4 | 4.5 | 7.2 | 8.4 |
| | **Balanced** | 576.4 | 252.1 | 72.5 | 19.7 | 18.4 | 14.7 | 11.1 | 8.7 |
| | **Ambition** | 576.8 | 257.3 | 64.8 | 19.7 | 18.4 | 14.7 | 11.1 | 5.0 |
| 2026 | **Reference** | 837.6 | 345.1 | 88.5 | 21.1 | 21.6 | 7.0 | 9.3 | 10.9 |
| | **Balanced** | 788.9 | 322.0 | 113.7 | 21.1 | 21.6 | 18.4 | 14.7 | 11.5 |
| | **Ambition** | 754.7 | 324.4 | 86.8 | 21.1 | 20.9 | 43.0 | 28.3 | 6.8 |
| 2031 | **Reference** | 1147.2 | 453.9 | 113.1 | 26.8 | 24.3 | 9.6 | 11.8 | 16.2 |
| | **Balanced** | 1048.6 | 403.0 | 165.2 | 26.8 | 24.3 | 22.1 | 19.2 | 17.1 |
| | **Ambition** | 920.4 | 415.4 | 124.1 | 26.8 | 24.0 | 71.4 | 48.9 | 14.0 |
| 2036 | **Reference** | 1439.4 | 592.4 | 148.6 | 32.2 | 28.5 | 12.1 | 13.3 | 22.8 |
| | **Balanced** | 1308.9 | 499.2 | 213.6 | 32.2 | 28.5 | 30.6 | 27.2 | 24.8 |
| | **Ambition** | 1063.2 | 486.2 | 139.3 | 32.2 | 27.0 | 174.7 | 66.5 | 21.2 |
| 2041 | **Reference** | 1760.6 | 750.2 | 165.9 | 37.5 | 29.6 | 14.6 | 14.8 | 32.2 |
| | **Balanced** | 1551.9 | 612.3 | 245.1 | 37.5 | 32.7 | 39.0 | 38.5 | 34.4 |
| | **Ambition** | 1162.8 | 589.9 | 161.4 | 37.5 | 26.9 | 221.2 | 84.2 | 31.5 |
| 2046 | **Reference** | 2031.1 | 983.1 | 201.1 | 42.8 | 30.8 | 17.3 | 16.3 | 43.2 |
| | **Balanced** | 1731.6 | 806.2 | 314.9 | 42.8 | 36.9 | 48.9 | 49.8 | 45.7 |
| | **Ambition** | 1223.2 | 769.8 | 182.5 | 42.8 | 27.4 | 268.0 | 101.6 | 42.4 |
| 2051 | **Reference** | 2262.1 | 1155.5 | 268.2 | 48.1 | 31.9 | 19.8 | 17.7 | 55.9 |
| | **Balanced** | 1899.3 | 934.1 | 369.8 | 48.1 | 41.1 | 68.3 | 67.9 | 58.8 |
| | **Ambition** | 1266.7 | 871.1 | 206.5 | 48.1 | 27.8 | 314.7 | 119.2 | 54.9 |

**Table ES.11:** Emission intensity under different Scenarios (kg$CO_2$/Re)

| | 2006 | 2016 | 2021 | 2026 | 2031 | 2036 | 2041 | 2046 | 2051 |
|---|---|---|---|---|---|---|---|---|---|
| Ambition | 0.035 | 0.028 | 0.028 | 0.024 | 0.019 | 0.014 | 0.011 | 0.008 | 0.007 |
| Balance | 0.035 | 0.028 | 0.028 | 0.025 | 0.021 | 0.017 | 0.014 | 0.011 | 0.009 |
| Reference | 0.035 | 0.028 | 0.028 | 0.026 | 0.023 | 0.019 | 0.015 | 0.013 | 0.011 |

The variation in demand, however, would be felt for some products due to fuel switching. For example, increased penetration of electric-based cooking may moderate demand for LPG or PNG. The use of LPG increases significantly in the AMB Scenario to 54.6 Mtoe in 2041 and then declines to 26 Mtoe in 2051, whereas in the other two Scenarios, LPG consumption continues to grow at a slower rate. The consumption of PNG continues to grow across all Scenarios, maximum being 13Mtoe in 2051 in the Ambition Scenario.

Diesel may be replaced by CNG based as well as electric vehicles. Increased penetration of electric pumps will have a definite impact on diesel consumption in the agriculture sector accounting for a difference of upto 8Mtoe between REF and AMB Scenarios in 2051. Solar pumps substitute only upto 4 Mtoe by 2051 in the AMB Scenario as per our assumptions. Nevertheless, diesel remains a major fuel in the long term even in the AMB Scenario. For road-based freight transport, diesel will remain the primary fuel till commercial viability of LNG-based vehicles is achieved. Decrease in diesel consumption for road-based freight transportation occurs only because of increase in the share of railways. Demand for gas in power sector may also increase in an aggressive renewable energy deployment case. The analysis also shows that the demand of certain distillates (naphtha, ATF) will increase while that of others (gasoline) is likely to fall.

On the whole, there seems to be limited substitutability of petroleum products in the transport sector at present. The pace of introduction of electric vehicles may have the largest implications for the substitution, but there are mixed views about the potential at this point in time. The primary apprehension is concerned with the future of storage technology, development of supporting infrastructure, and the cost of electric vehicles. Accordingly, the Scenarios also do not indicate a very large change in the use of petroleum products in the transport sector. Hence, climate policy would require the industry, in addition to continued efforts to improve energy efficiency, to take into account those distillates which are expected to face reduced demand.

## (D) Challenges of transparency

The implementation of the Paris Agreement hinges upon credible transparency practices adopted by the countries, in particular, precise accounting and monitoring of GHG emissions from various sources. The reporting of GHG emissions from India's oil & gas sector under the NATCOM (National Communications to the United Nations Framework Convention on Climate Change) is as per IPCC guidelines[2] and covers the following aspects summarized in Table ES.12.

**Table ES.12:** Coverage of oil & gas sector GHG emissions in NATCOM

| Sector | Sub-sector | Code | Description |
|---|---|---|---|
| Energy | Refining | 1A1b | Stationary combustion of fuel in refineries |
| Energy | Fugitive Emissions (Refining) | 1B2b(i) | Includes emissions from venting; flaring; well drilling, servicing and testing; gas processing; gas transmission and storage; distribution |
| Energy | Fugitive Emissions (Exploration) | 1B2b(ii) | Includes emissions from flaring and other sources |

The methodology adopted for the estimation of GHG emissions is the basic 'Tier 1' approach which employs activity data that is relatively coarse, such as nationally or globally available estimates, national industrial production statistics, global land cover maps, etc., and default emissions factors provided by the IPCC for developing countries. More comprehensive approaches use more granular activity data and country-specific emission factors (Tier 2 Approach) or rely on models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by disaggregated levels (Tier 3 Approach). In general, it has been observed that the default emissions factors for developing countries are significantly higher compared to the default emissions factors for developed countries (Table ES.13).

**Table ES.13:** Default emissions factors for developing countries (DC) and developed countries (IC) (Gg $CO_2$/unit Activity Data*)

| Industry Segment | Sub-category | Default emission factor for $CO_2$ | | Default emission factor for $CH_4$ | |
|---|---|---|---|---|---|
| | | DC | IC | DC | IC |
| Oil Production | Conventional Oil | 0.0485 | 0.041 | 2.95E-05 | 2.1E-05 |
| | Default Weighted Total | 0.0405 | 0.034 | 2.5E-05 | 2.1E-05 |
| | Heavy Oil/Cold Bitumen | 0.026 | 0.022 | 0.000165 | 0.00014 |
| | Thermal Oil Production | 0.032 | 0.027 | 1.9E-05 | 1.6E-05 |
| Well Drilling | All | 0.0009 | 0.0001 | 0.0002965 | 3.3E-05 |
| Gas Processing | Default Weighted Total | 0.0675 | 0.04 | | |
| | Sour Gas Plants | 0.1065 | 0.063 | | |
| Gas Transmission | Transmission | 5.2E-06 | 3.1E-06 | 0.000392 | 0.000182 |

* Unit = $10^6 Sm^3$

*Source: IPCC Emissions Factor Database*

The oil & gas sector constitute a part of India's regular reporting to UNFCCC on its GHG emissions. Currently, the calculation of GHG emissions from the sector uses default emissions factors for developing countries and Tier 1 data (national aggregates) (Table ES.14). Considering that there have been continuous efficiency improvements in the sector over the years, it is likely that this approach to calculating emissions from the sector result in over estimation. It is important therefore that country-specific emissions factors and more disaggregated plant level data (Tier 2) is used for more realistic assessments. The pressure on industry to reduce GHG emissions, is likely to increase with subsequent revisions of NDCs.

**Table ES.14:** Summary of tier methodology and choice of emission factor for oil & gas sector in India's NATCOM

| Sector | $CO_2$ | | $CH_4$ | | $N_2O$ | |
|---|---|---|---|---|---|---|
| | Tier | EF | Tier | EF | Tier | EF |
| Refineries (1A1b) | T1 | CS | T1 | D | T1 | D |
| Fugitive (1B2) | - | - | T1 | D | - | - |

## V. Preparedness of oil & gas sector

**Well placed in context of national climate policy:** Of the three types of challenges posed by climate change, the Indian oil & gas companies are broadly aware of the impacts of the national climate policies. They have provided inputs to the preparation of India's NDCs in terms of planned mitigation measures. The annual sustainability reports of the companies provide enough information to assess their ongoing efforts at improving energy efficiency and promoting renewable energy. In fact, the level of efforts as well as investments in promoting energy efficiency, renewable energy deployment, fuel switching, and R&D has been increasing over the years. Companies also keenly observe the developments in the market as well as demand projections by international agencies, such as the BP and IEA. While the Indian plants are at par with global levels in term of efficiency, practices such as regular energy audits keep them updated on the further scope of improvement. Pilot projects, such as the LNG-based freight corridor are well in line with the national climate policy objectives.

**In line with resource efficiency imperatives:** One of the key resources for processing plants within the industry is fresh water, availability of which is projected to be severely affected by climate change and other stressors, such as increased demand for drinking, irrigation, and other industrial purposes. Improving water efficiency and reducing reliance on fresh water therefore are critical for industry's resilience to climate change. The companies have already identified water efficiency as a key area of improvement and considerable efforts are being made in the direction of reducing reliance on fresh water as well as eliminating waste water discharge. While these efforts are not driven by climate concerns, they certainly are in right direction. Whether these would turn out to be adequate, needs further examination.

**Scope of improvement in data management:** Companies are increasingly maintaining elaborate data on energy consumption and GHG emissions. This is in line with the requirement of transparency at the national as well as international levels. However, this data is not fully incorporated into the national inventory of GHGs. There is a need to streamline the transparency aspects related to GHG emissions from the sector.

**Less informed about international climate policy:** While companies keep tab on the development in international markets, they are less informed about the international climate policy pressures and their impacts on the changing structure of global demand, particularly in countries that import petroleum products from India. Partly, this could be accounted for by the lack of such information available in the public domain. However, the sector is well placed in terms of infrastructure planning to withstand the likely changes in the global as well as domestic markets in the next two decades.

**Less aware of climate change risks:** The sector has been exposed to extreme climatic events, and has in place the health and safety measures in place as per the regulatory guidelines. However, these risks are not understood in the context of science of climate change, instead as standard risks based on historical experience. In the sustainability reports, indeed, physical risks due to climate change do not find any noticeable mention. The fact that the pattern of climatic events will be different from the historical pattern is not properly understood by the companies. A more glaring oversight in terms of understanding is the impact of slow onset events, particularly the rise in temperature and water scarcity. It is worth highlighting that the personnel at different levels are well aware of the sensitivity of the sector to ambient temperature and water scarcity. Yet, nuanced understanding of this sensitivity, the impact of climate change on it, and its cost implications, are not analysed at the plant level.

**Scope of improvement in risk management:** As per the stipulated regulatory requirements related to environment, health and safety, companies have established standard procedures, including regular review and provisions for improvement. However, these practices are based on the procedures developed through the past experiences. Lack of understanding of potential changes in the pattern of climatic events, may mean that the established risk management procedures are inadequate, and require improvement. Precise understanding of the resilience of the sector therefore cannot be determined with available expertise in the sector. However, it must be noted that the sector has been exposed to a range of climatic events and their potential impacts, such as storm surges, floods, water scarcity, heat , etc., and hence, is aware of the broad range of resilience measures that can be undertaken. Yet, there is little preparatory planning for assessing how these impacts may vary in the future due to climate change. The current practice of taking into account the historical trend at the designing stage may prove insufficient in the context of extreme climate change.

**Scope of improvement in regulatory framework and guidelines:** There are elaborate regulatory requirements and guidelines for risk assessment and resilience measures at the design and construction phase. These requirements recognize that climatic events, such as floods, wind speed, cyclones, etc., need to be taken into consideration. While these institutional processes provide necessary components of governance for risk management and resilience, they do not acknowledge the variability of such events due to climate change. Hence, regulatory framework and guidelines too need to be aligned with current scientific findings on climate change and its impact on the Indian sub-continent. At the very least, a clear requirement to consult current scientific knowledge on future climate change should be included.

**Lack of systematic monitoring of vulnerabilities**: From prior experience the sector is aware of the vulnerabilities to extreme climate events, such as cyclones and floods, it is less informed about the slow onset events, such as rise in ambient temperature and variations in the pattern of precipitation. While this does not necessarily mean that the industry is not thinking about potential adaptation measures, it implies that there is a lack of a systematic empirical assessment of these risks going beyond the prior experience, and considering potential changes in the pattern of extreme events as well as climatic conditions. For example, the energy audits of plants focus only on mitigation opportunities. How change in climatic conditions may affect the energy-related costs, independent of the cost of mitigation actions, is not properly evaluated. While the plant level data for operational parameters, such as water consumption, energy consumption, etc., are monitored extensively, and broad experiential observations are made with respect to variation in these parameters with change in climatic conditions, systemic monitoring and data gathering is lacking. Even the available data has not been analysed to generate quantitative insights related to climate change-induced challenges or opportunities.

Overall, the sector is at a critical juncture where it needs to integrate climate change projections in its operations and planning in a holistic manner. It may be argued that, at this stage, incremental improvements and adjustments in practices and regulations, particularly integrating current scientific findings on climate change, can significantly contribute towards improving resilience of the sector to the risks emanating from both, climate policy at national and international levels as well as projected change in the pattern of climatic events. The sector already has the necessary institutional as well as organizational infrastructure to make these adjustments at a relatively low cost.

## VI. Way forward

The oil & gas sector will remain significant in India's final energy mix, even if the targets in the NDCs become more stringent. The current NDC targets of 33%-35% reduction by 2030 in emissions intensity of GDP from 2005 levels is likely to be achieved in the Reference Scenario itself. The BAL and AMB Scenarios show a reduction in emissions intensity of GDP by 39% and 45% respectively, hence provide a possible way forward for India's climate policy. Nevertheless, the Indian oil & gas sector is bound to feel the impact of climate change. With respect to market size, in the coming two decades the impact is only in relative terms, that is, slower growth in demand. In absolute terms, the market size will grow. While there may be significant substitutions in some end-uses, on the whole, use of petroleum products may see an increasing role as products rather than fuel, and do not seem to face a significant threat at least in the next decade or two. Hence, the climate policy induced risks are moderate. The sector has already begun to take measures on energy efficiency and renewable energy. Nevertheless, the scope for improvement and better integration of impacts of slow onset events on energy efficiency cannot be ruled out.

In the context of climate change, the Indian oil & gas sector should be concerned more from the resilience point of view than mitigation of GHG emissions. The regions which can be considered as hotspots are North-West India and the East Coast. These areas need to be further studied more comprehensively to better assess the vulnerability and resilience of oil & gas industry assets. Nevertheless, climate change poses different challenges to the sector over different time horizons. In order to better align its growth with mitigation and adaptation imperatives of climate change, the sector should adopt an explicitly articulated strategy. Broad contours of such a strategy may be divided into two categories of actions: immediate actions and long term actions.

## (A) Immediate company level actions

These preparatory actions primarily pertain to the existing infrastructure and should be taken by concerned companies within the next five years. The five most important actions are listed as follows:

i. **Location-specific flood modelling exercises taking into account long-term precipitation projections:** Considering that the occurrence of floods may disrupt the supply chain as well as operations, it is important to properly assess the resilience of different assets as well as backward-forward linkages to different intensities of floods. To start with, local flood modelling studies should be undertaken at locations which are flood prone and where this study projects increase in flood occurrence due to change in pattern of extreme rainfall. It should also take into consideration the fact that vulnerability to natural events is also sensitive to the factors, such as topography of the location and existing pattern of land use. Change in land use in the past as well as future plans at a given location should be given special attention. In particular, it is recommended that companies develop location-specific flood models taking into account long-term precipitation projections. The benefits of such an exercise would go beyond the companies and contribute to building climate resilience of the concerned region. For example, TransCanada has implemented a number of measures to minimize the damage caused by extreme precipitation and cyclone events. The company has asset specific teams that interpret, model, and manage physical risks with the commercial and engineering teams of each business.

ii. **Explore plant-specific water efficiency improvement options:** Unlike the threat of floods, water stress will become severe over time. However, it is a known risk, with or without climate change. Hence, a more concerted effort at water efficiency and water conservation is warranted. It would be advisable that such efforts are implemented in cooperation with other actors in the region, either responsible for water resource management, or dependent on water resources. For example, StatOil develops water management plans based on projections of water availability six years into the future. In addition, a substantial portion of the R&D budget worth NOK 3.0 billion is allocated for water management projects.

iii. **Build plant-specific database to properly establish impact of temperature rise on energy consumption and efficiency of operations:** The impact of temperature rise may offset the achievements of companies on energy efficiency. It is important that companies begin to compile and analyse data on temperature variations, energy consumption, and efficiency of operations. It will not only help them better assess impacts of climate change, but also provide more opportunities to improve energy efficiency.

iv. **Develop plant-specific GHG emissions database using Tier 2 or Tier 3 methodologies:** Companies do maintain detailed data on materials balance. It should not be difficult therefore to develop plant-specific GHG emissions inventory and develop country-specific emission factors for the sector. This will not only lead to precise, and probably lower, calculation of emissions from the sector, but also help in designing better mitigation strategies in the sector.

v. **Learn from global good practices:** In recent years global majors in oil & gas sector have started taking precautionary measures towards better integrating climate change issues into planning. A living database of best practices may be developed by companies as a joint effort. A number of global partnerships have been initiated to share knowledge and experience, such as the oil & gas Methane Partnership of the Climate and Clean Air Coalition (CCAC). A strategic engagement with such initiatives for learning purposes is advisable for the Indian oil & gas companies.

vi. **Partnership with local governments and neighbouring industries:** Considering that water availability and floods affect the operations and distribution network of the oil & gas industry, along with civilian population and other industries, there is greater scope of cooperation between industrial units and local government units in the field of water conservation, water harvesting, and improving flood resilience through CSR activities.

## (B) Long-term sectoral actions

These actions pertain to existing as well as planned infrastructure and relate to building institutional capacities at the national level in terms of building strategic knowledge as well as aligning regulatory framework to capture the specific challenges posed by climate change. The precise nature of these actions should be based on further studies incorporating engineering aspects of the industry as well. The broad direction of these actions can be summarized as follows:

i. **Predictive risk management:** The general practice in the oil & gas industry to protect against natural events is to set design and operation parameters based on rapid risk assessment and historical trends along with a safety margin, for example, keeping the height about 0.5 m above the historically highest level of flood. Since the most significant impact of climate change is departure from the historical patterns, the design and operation parameters of infrastructure and different equipment need to be revisited in light of projected climate change for predictive risk management. An expert committee involving experts from agencies such as the Engineers India Ltd may be constituted to prepare guidelines for consideration by appropriate authority.

ii. **System of systems-based planning for climate risk hotspots:** While direct impacts on plants are more visible and easily understood, it is the inter-linkages between multiple sectors and backward-forward linkages in the supply chain that are most important. A plant specific measure may not be sufficient to address the geographically widespread nature of climate risks. For example, climate proofing of road and rail infrastructure is critical for the oil & gas supply chain, yet the companies themselves do not have any control over that infrastructure. Similarly, the industries dependent on supply of petroleum products as key inputs to their production have no control over climate proofing of oil & gas supply infrastructure. In other words, the oil & gas sector, from the perspective of climate change impacts, is a system of multiple sub-systems. Hence, a more comprehensive analysis, based on 'system of systems approach', of how different infrastructure and industry subsystem linkages may be affected, and what their associated economic impacts would be, needs to be carried out at least for the regions identified as climate hotspots for the oil & gas sector, that is, the North West and East Coast regions of India. A technical task force involving appropriate agencies and institutes, such as the FIPI, the National Disaster Management Authority, National Highways Authority of India, Confederation of Indian Industries (CII), FICCI, etc., may be constituted to undertake this exercise due to their requisite experience in this field.

iii. **Revision of regulation and guidelines** to determine design parameters to accommodate projected change in climatic events and impacts, particularly intensity and frequency of wind speed and storm surges at coastal areas. The current practice is to consider only past patterns, which are likely to be altered due to climate change. For example, British Petroleum (BP) has adopted a proactive approach that addresses the issue starting from the design phase of the project based on due consideration of asset design parameters. It is strongly recommended that existing regulations and guidelines relating to risk management in the oil & gas sector explicitly integrate potential climate risks. These could, at the very least, include:

- A framework to periodically assess the fitness of infrastructure in the light of current scientific assessments on climate change,
- Regulations to improve water use efficiency in industry along the lines of the Perform, Achieve and Trade scheme for improving energy efficiency,
- Requirement to consider latest scientific knowledge on projected climate change in project design and risk management plans

The companies have large data sets on performance parameters over the years. However, that data has not been analysed from the perspective of sensitivity to variation in climatic conditions. It is strongly recommended that a national exercise in **data generation, management, and analysis to better quantify the impacts of climate variations on the efficiency and cost of operations** for different units within their assets may be carried out. Such an analysis would also help in designing other industrial activities in the area.

iv. **A comprehensive scientific programme involving industry, academic institutions, and government agencies** to build necessary knowledge base and integrated impact models to better assess coastal vulnerability. For example, Chevron has collaborated with experts at the National Centre for Atmospheric Research as well as federal and state governments to better understand the possible changes in the frequency and magnitude of hurricanes in the Gulf of Mexico over the next 50 years so as to better use the information from the work to support development of new design parameters (meteorology and oceanography) specifically for offshore Gulf of Mexico assets.

v. **Transition strategy for oil & gas companies:** Exploration of pathways to better integrate the large infrastructure and supply network of the oil & gas sector into India's transition to low carbon development trajectory. An integral part of these pathways could be a long term plan for transition of oil & gas companies into energy companies consistent with low-carbon energy system. This task may be spearheaded by the NITI Aayog. Considering the projected increase in global demand for natural gas, an integral part of this strategy should focus on scope of increasing supply of natural gas domestically.

vi. **A comprehensive R&D strategy** to enable the industry not only to build resilience to physical as well as policy threats due to climate change but also to contribute meaningfully to the national imperatives of addressing challenges of energy security, economic development, and NDCs.

vii. **South-South Cooperation:** In a climate constrained world, there is greater scope for South-South Cooperation in the field of petroleum products. India's policy goal of increasing exports of refined oil products should examine the prospects of oil exports to Africa and Asia. Strategic alliances with other oil exporters in this region may be explored.

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IndianOil | ONGC | GAIL | HP | Bharat Petroleum | Oil India Limited | PETRONET LNG LIMITED | ENGINEERS INDIA LIMITED