

TOPICAL REVIEW

## Oil and gas company strategies regarding the energy transition

To cite this article: Ensieh Shojaeddini *et al* 2019 *Prog. Energy* **1** 012001

View the [article online](#) for updates and enhancements.

### Recent citations

- [How will energy transition impact the major EU natural gas suppliers?](#)  
Maria Olczak
- [Kathleen Krah \*et al\*](#)
- [Introducing \*Progress in Energy\* issue 2](#)  
N P Brandon

# Progress in Energy



## TOPICAL REVIEW

# Oil and gas company strategies regarding the energy transition

RECEIVED  
11 January 2019

REVISED  
26 May 2019

ACCEPTED FOR PUBLICATION  
28 May 2019

PUBLISHED  
16 July 2019

Ensieh Shojaeddini<sup>1,4</sup>, Stephen Naimoli<sup>2</sup>, Sarah Ladislav<sup>2</sup> and Morgan Bazilian<sup>3</sup>

<sup>1</sup> Colorado School of Mines, Golden, CO, United States of America

<sup>2</sup> Center for Strategic and International Studies, Washington, DC, United States of America

<sup>3</sup> Payne Institute, Colorado School of Mines, Golden, CO, United States of America

<sup>4</sup> Author to whom any correspondence should be addressed.

E-mail: [eshojaed@mines.edu](mailto:eshojaed@mines.edu)

**Keywords:** oil and gas, energy transition, climate change

## Abstract

This paper considers the role of oil companies in the energy transition. That is, what strategies and investments these companies have made and what roles they have taken in response to the potential challenges of a likely transition to a low-carbon world. Previous work considered the role of several of the international oil companies in investing in renewable energy, and this paper expands the scope of inquiry to national oil companies and to other technologies such as carbon capture and storage and hydrogen fuel cells.

## 1. Introduction

An energy transition is described as a long-run structural change in energy systems (Hauff *et al* 2014). The process is broad and encompasses numerous facets of the energy sector. In this paper, however, we focus on the actions of oil majors. Recent technological developments in electric cars could result in a substantial decline in oil consumption (Cherif *et al* 2017), which could speed the transition even beyond current estimates. The expected decreased demand for fossil fuels and concerns over damage from climate change will create business risks for oil majors and could result in a significant number of stranded reservoirs (McGlade and Ekins 2015). Therefore, from the perspective of oil majors, it is vitally important to find solutions that keep them in the market while contributing to global climate change mitigation. International oil companies (IOCs) and national oil companies (NOCs) have begun exploring investments in sectors other than oil and gas while also seeking to reduce emissions in their own operations.

Heretofore, we examined the renewable energy investments of several IOCs in renewable energy (Zhong and Bazilian 2018). Now, we contribute to the existing literature by expanding the analysis to include both IOCs and NOCs and showcasing a range of additional strategies, including investments in technologies such as carbon capture and storage, or carbon capture and sequestration (CCS), and hydrogen. Developments in company strategies and investments are moving at a rapid pace and we focus on highlighting illustrative examples of oil and gas company actions. Some of the companies are engaged in strategies such as increasing the share of gas and low-carbon oil in their portfolios, purchasing carbon offsets, encouraging end-user energy conservation through efforts such as ridesharing. This study does not consider those strategies, choosing to focus on more fundamental strategies being utilized across the oil and gas industry. This analysis is not a comprehensive, nor a systematic review, but rather a snapshot of the state of the industry in relation to the energy transition.

This study focuses on transformation and transition in the industry, in particular transformation related to decreasing greenhouse gas (GHG) emissions, energy efficiency, investments in new technologies, and new business models. We analyze IOCs and NOCs separately because their governance structures can differ in fundamental ways. NOCs are primarily managed directly by governments, so their decision-making is notably policy driven, while IOCs are private companies, and thus their goals and actions are driven primarily by business concerns.

The remainder of this study is organized as follows. Section 2 gives an account of the energy transition and the methodology used in this paper. Section 3 explores the role of IOCs in the energy transition and section 4 explores the role of NOCs. Finally, section 5 presents our conclusions.

**Table 1.** Energy transition assessment.

GHG emissions intensity	Degree of investment in low-carbon technologies	
	Tight	Loose
High	Integrating low-carbon technologies in oil and gas production	Not engaged in energy transition
Low	Expanding beyond oil and gas production	Aiming to lower operational emissions

## 2. Energy transition and methodology

There are a variety of methods that oil companies can use to adapt to the energy transition. In this paper, we review various strategies that oil majors have employed or plan to employ to reduce GHG emissions. We use a method similar to the one used by Zhong and Bazilian (2018) to categorize these companies into four main groups: (1) integrating low-carbon technologies into oil and gas production, (2) expanding beyond oil and gas production, (3) not engaging in low-carbon investments or emissions reduction, and (4) aiming to lower operational emissions. This framework is summarized in table 1. It enables us to assess the level of oil companies' actions to build low-carbon businesses as well as the level of their success. We should note that this is not a comprehensive study; we include highlights and important data points that show how oil companies are seeking to navigate the energy transition. The highlights are from public data made available over the past two years until September 2018.

Oil companies try to reduce carbon emissions by improving energy efficiency in operations and products, investing in renewable energy (solar, wind, biomass, geothermal, hydro-power, and marine energy), increasing the share of gas in production, and investing in new low-carbon technologies such as electric vehicles, hydrogen technologies, and carbon capture and storage (CCS).

Figure 1 shows the level of operational GHG emissions from various oil companies compared to the level of their oil production. The figure also presents the level of emissions intensity which is calculated by dividing the amount of emissions by total production. In addition, figure 2 demonstrates the degree of investment in low-carbon technologies by some of these companies. This information can help us assess these companies' efforts towards a low-carbon business. For instance, companies such as Equinor and BP have relatively high low-carbon investment and relatively low emissions intensity. This implies that these companies are among group 2, where they are extending their expertise in the energy transition. The remainder of this study delves into the details of their investments and reviews various energy transition strategies employed by these companies. In section 3 we focus on the strategies of IOCs, and in section 4 we summarize the strategies of NOCs.

## 3. The role of IOCs in the energy transition

IOCs are facing increasing pressure from shareholders and the public to decrease their carbon footprints. There is also risk that, in the coming decades, investments in oil and gas could become unsustainable due to carbon prices and current investments could become stranded assets. To address these concerns, IOCs are increasingly employing strategies to adapt to the energy transition and maintain business viability in what is expected to become a changing energy sector.

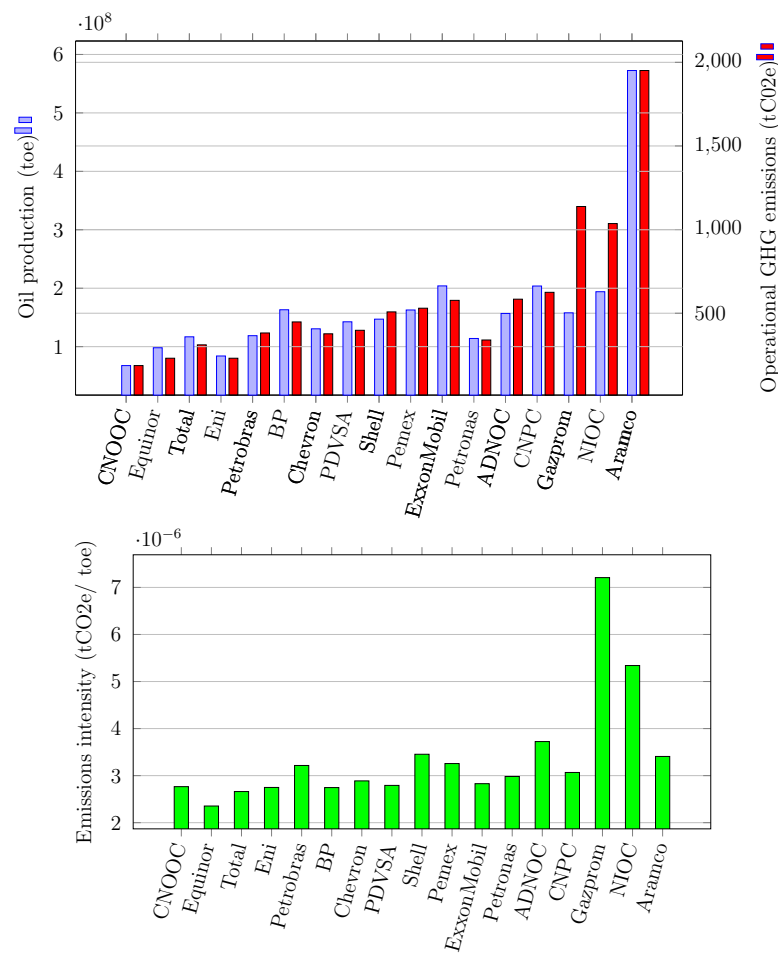
In this article, we outline the strategies of BP, Chevron, Eni S.p.A., Equinor (formerly Statoil), ExxonMobil, Royal Dutch Shell, and Total S.A. Equinor, as a company that is majority owned by the government of Norway, could be classified as an NOC. However, the company's governance structure and level of autonomy mirrors those of IOCs. Thus, for the purposes of this study, Equinor will be treated as an IOC. This section's layout is as follows. In section 3.1, we focus on the strategies employed by IOCs with respect to different technologies, and in section 3.2, we examine the scale of investments.

### 3.1. IOC strategies and plans

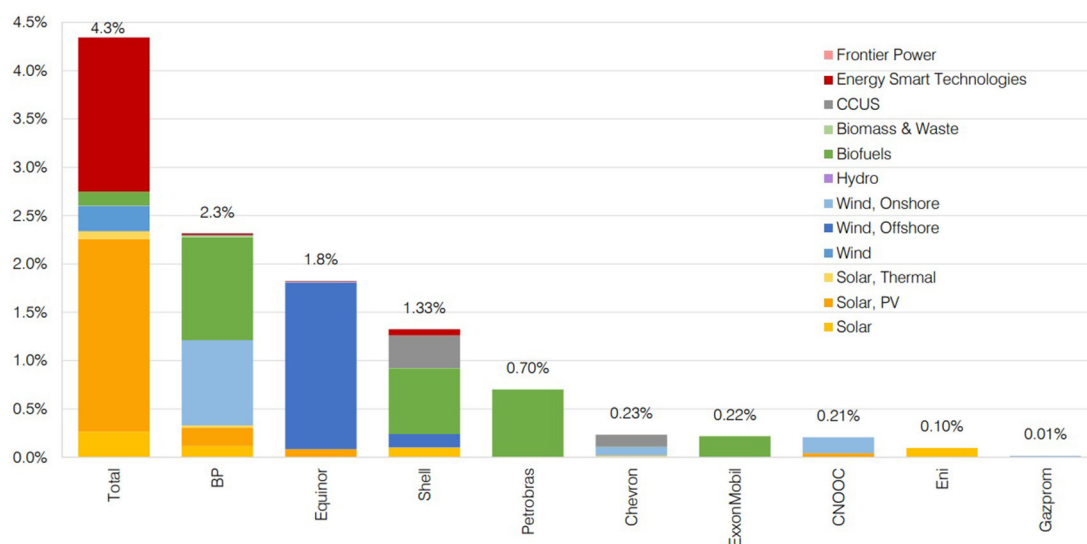
IOC strategies to navigate the energy transition comprise a variety of areas: achieving operational emission reductions, utilizing renewable energy, developing low-carbon transportation fuels, commercializing carbon capture and storage (CCS), and developing technologies for using hydrogen in power generation and in transportation.

#### 3.1.1. Energy conservation and emissions reduction

From both an environmental and an economic perspective, IOCs have an incentive to reduce emissions. Companies face pressure from shareholders and society to reduce GHG emissions to lessen their contribution to climate change. Methane, the primary component of natural gas, is a potent GHG that lasts only ten years in the



**Figure 1.** 2015 oil production and GHG emissions (Data sources: CDP report (2017) and company reports).



**Figure 2.** Disclosed low-carbon investment as a proportion of total CAPEX (2010–Q3 2018). Includes Asset Finance, M&A and Venture Capital spend. Note: No disclosed investment for Anadarko, Apache, Hess, Noble Energy, Occidental, OMV, Rosneft and Woodside. Source: CDP Investor Research (Fletcher *et al* 2018).

atmosphere but absorbs much more energy than carbon dioxide (CO<sub>2</sub>), giving it a global warming potential 28 to 36 times higher than CO<sub>2</sub> over a 100-year time frame and 84 to 87 times higher over 20 years (U.S. Environmental Protection Agency 2017). Because of this, even though it only accounts for 16 percent of global GHG emissions, it has an outsized impact on global warming (IPCC 2014). Fossil fuel production accounts for approximately 105 million tons of methane emissions per year, making it approximately 30 percent of anthropogenic methane

emissions (Global Carbon Project 2016). Oil and gas companies could therefore contribute significant cuts to global methane emissions by addressing their operational emissions. In addition, reducing fugitive or flared methane emissions released during the oil and gas extraction process can also increase the amount of usable product if sufficient markets exist (Chakrabarti 2012). IOC strategies to cut GHG emissions from their operations frequently include emissions reduction goals, including absolute CO<sub>2</sub> emissions reductions, reductions in emissions intensity or increases in energy efficiency, and methane emissions reductions.

In September 2018, the Oil and Gas Climate Initiative (OGCI), an industry group in which all seven IOCs are members, announced an upstream methane emissions intensity target of 0.25 percent of production by 2025 (Oil and Gas Climate Initiative 2018b). All seven IOCs are also members of IPIECA, an industry group seeking to help improve companies' environmental and social performance, and the Global Gas Flaring Reduction Partnership, a World Bank-led project seeking to help reduce the flaring of natural gas. BP, Eni, Equinor, Shell, and Total are members of the Oil and Gas Methane Partnership, a UN-led project that seeks to reduce methane leakage from oil and gas operations. BP, Chevron, Equinor, Shell, and Total are members of the Environmental Partnership, an American Petroleum Institute-led series of voluntary programs to reduce methane emissions through technological and operational changes at oil and gas sites.

BP announced in 2018 that it would seek to make 3.5 million CO<sub>2</sub>-equivalent tons of sustainable emissions reductions by 2025 through improvements in energy efficiency, fewer methane emissions, and reduced flaring (BP 2018a). The company is also planning to hold net operational GHG emissions at 2015 levels to 2025 by offsetting any of the company's emissions growth with carbon offsets. Holding net GHG emissions at 2015 levels would mean maintaining 51.2 million CO<sub>2</sub>-equivalent tons. BP is controlling methane leaks through replacing old equipment, limiting the number of production facilities, and automating extraction processes (BP 2018h). Prior to the OGCI methane target announcement, BP set its own goal requiring methane emissions to be limited to 0.2 percent of its natural gas production, a target that the company reports it has already achieved in 2017 (BP 2018a).

Aside from the OGCI methane intensity target, Chevron has not set any GHG emission reduction targets. The company has, however, achieved some reductions in GHG emissions through energy efficiency and methane emission reductions. In Chevron's Upstream division, energy conservation methods such as predictive analytics and monitoring and optimization software have reduced 180 000 metric tons of GHGs from 2014 to 2017 in its San Joaquin Valley business unit and reduced energy intensity by 27 percent from 2014 to 2016 in its IndoAsia business unit (Chevron 2018c). The company also has 1075 megawatts (MW) of cogeneration capacity at some of its refineries and upstream production facilities. Chevron has reduced natural gas flaring by 22 percent from 2012 to 2017.

In 2018, Eni CEO Claudio Descalzi announced the company was putting together a plan for the company to become carbon neutral and would provide the details by the end of the year (Mandala 2018). In the meantime, the company has set a target of reducing the intensity of its upstream GHG emissions by 43 percent from 2014 levels by 2025 (Eni 2018b). This would mean a reduction from 0.19 tons of CO<sub>2</sub>-equivalent per ton of oil-equivalent (tCO<sub>2</sub>e/toe) in 2014 to approximately 0.11 tCO<sub>2</sub>/toe in 2025. Eni implements leak detection and repair programs to address fugitive methane emissions, reducing approximately 2 million tCO<sub>2</sub>e from 2014 to 2017. The company has set a goal of reducing methane emissions by 80 percent from 2014 levels by 2025. This would mean a reduction from 2.89 million tCO<sub>2</sub>e in 2014 to 0.58 million tCO<sub>2</sub>e in 2025.

Equinor is seeking to cut its CO<sub>2</sub> emissions by 3 million tons per year from a business as usual baseline through 2030 (Equinor 2017c). In 2017, the company reported a reduction of 356 000 tons, chiefly from optimizing operation times at a liquefied natural gas (LNG) plant, energy efficiency measures at a gas processing plant, and carbon capture and storage from its demonstration projects. Equinor set an emissions intensity target for its upstream portfolio of 8 kilograms (kg) CO<sub>2</sub> per barrel of oil-equivalent (boe) by 2030. The company reported an intensity of 9 kg CO<sub>2</sub>/boe in 2017, so this would represent a 12.5 percent reduction. In 2017, Equinor announced that it would charter two offshore platform supply vessels powered by hybrid energy systems that included batteries supplied by Corvus Energy, in which Equinor Energy Ventures is an investor (The Motorship 2015, Offshore Energy Today 2017).

Exxon has approximately 5500 MW of cogeneration technology installed at its facilities around the world, avoiding approximately 6 million metric tons of GHGs per year (ExxonMobil 2018b). Exxon is implementing leak detection and repair programs using optical gas imaging cameras and replacing high-bleed components in the extraction process (ExxonMobil 2017). Exxon has also set an ambition of reducing its methane emissions by 15 percent by 2020 from a 2016 baseline (ExxonMobil 2018c). In 2016, Exxons methane emissions were 7 million CO<sub>2</sub>-equivalent metric tons (ExxonMobil 2017), so the company intends to reduce emissions to approximately 5.95 million metric tons in 2020.

In 2017, Shell announced it would reduce the intensity of its emissions from its operations, its purchased power, and the consumption of its products by 20 percent by 2035 and 50 percent by 2050 (Royal Dutch Shell 2017a). Shells emissions intensity was 83 grams (g) CO<sub>2</sub>e/megajoule (MJ) in 2017, so the company plans to

reduce it to 66.4 g CO<sub>2</sub>e/MJ in 2035 and approximately 43 g CO<sub>2</sub>e/MJ in 2050 (Royal Dutch Shell 2018d). In 2014, Shell invested in Glasspoint, which manufactures solar steam generators for enhanced oil recovery (EOR) (Wesoff 2014). Shell has also agreed to purchase 50 percent of the output from the Borssele III and IV wind farm in the Netherlands, in which it owns a 20 percent stake (Weston 2018), and pledged to incorporate solar into its operations, starting with a chemicals site in the Netherlands (Royal Dutch Shell 2018f). Shell uses leak detection and repair strategies utilizing optical gas imaging cameras to monitor methane emissions from its shale operations (Royal Dutch Shell 2017b). Prior to the OGCI methane target announcement, Shell set its own goal of a 0.2 percent methane emissions intensity by 2025 (Royal Dutch Shell 2018c). The baseline leak rate is between 0.01 and 0.8 percent.

In 2016, Total set a target of increasing energy efficiency by 1 percent per year from 2010 to 2020 (Total 2017a). Beyond 2020, the company's ambition is to reduce the carbon intensity of its products by 15 percent from 2015 to 2030 and between 25 and 35 percent by 2040 (Total 2018c). This would represent a decrease from 75 grams CO<sub>2</sub>-equivalent per 1000 BTUs in 2015 to about 64 grams in 2030 and between 49 and 56 grams per 1000 BTUs in 2040. The company is also aiming to eliminate routine flaring by 2030, with an interim target of an 80 percent reduction from 2010–2020. The company says it met the 80 percent reduction target in 2017 (Total 2018c). Total is also emphasizing the role of natural gas in its portfolio, identifying it as the heart of our ambition to be the responsible energy major.

With the OGCI methane reduction target, it is clear that all seven IOCs are committed to keeping their methane emissions low. However, when it comes to overall GHG emissions reduction goals and emissions intensity goals, the European IOCs outpace their American peers. Even among the European majors, strategies clearly differ. For example, Shell's inclusion of the emissions from the consumption of its products in its emissions reduction goal is unique, given the fundamental difficulty of reducing this category of emissions without decreasing sales or shifting the products the company sells. BP's goal to offset its emissions growth through 2025 is also unique among its peers. Assuming Eni delivers on its promise to outline a plan for carbon neutrality, it would be the first oil major to entirely cancel out its GHG footprint.

### 3.1.2. Renewable energy

IOCs are moving into the electric power sector through four categories of strategies: acquisitions and minority investments; venture capital investments; direct ownership of renewable generation assets; and research and development (R&D).

A prominent category of strategies employed by the IOCs in the renewable energy space is acquisitions and minority investments. IOCs have invested in or acquired developers, manufacturers, and utility companies. In 2017, BP took a 43 percent stake in solar developer Lightsource, renaming the company Lightsource BP (BP 2018g). Lightsource owns 1.3 gigawatts (GW) and operates 2 GW of solar. In November 2018, Equinor took a 9.7 percent stake in Scatec Solar, which owns 357 MW in operation and approximately 5.3 GW under construction or in development (Equinor 2018a). Shell has acquired power distribution companies First Utility in the UK and MP2 Energy in the United States (Royal Dutch Shell 2018f), the latter of which owns 1.7 GW of wind, solar, and gas (Lacey 2017). Shell has a minority stake in Silicon Ranch Corporation, which owns approximately 900 MW of solar (Royal Dutch Shell 2018f), and a minority stake in Cleantech Solar, a commercial and industrial solar developer in Asia (Stoker 2018). Shell also maintains a joint venture with Cosan called Raízen, which owns 940 MW of biomass-fired electricity generation capacity (Raízen 2018). Total owns a majority stake in SunPower, the U.S.'s largest solar panel manufacturer (Gheorghiu 2018), and an indirect interest in wind, solar, and hydro developer Total Eren (Total 2017a, 2017c). Total has also acquired power distribution companies Lampiris (now called Total Spring) and Direct Energie, the latter of which owns 800 MW of gas-fired generation capacity and 550 MW of renewables (Total 2017a, 2018f), battery manufacturer Saft (Total 2017a), and energy efficiency company GreenFlex (Total 2017b). Total also develops a range of off-grid solar products called Awango by Total (Total 2018c).

IOCs are also investing venture capital in technology companies through their venture firms. BP has invested in concentrating solar power (CSP) developer BrightSource, battery manufacturer StoreDot, Fulcrum Bioenergy, EV charging company FreeWire, and biofuel developer Synthetic Genomics (BP Ventures 2019). Chevron has invested in biofuel company Ensyn and EV charging company ChargePoint (Chevron 2018a). Equinor has invested in energy storage developer Convergent Energy and Power (Equinor 2016a) and perovskite solar manufacturer Oxford Photovoltaics (Willuhn 2018). Shell has invested in many companies in the past few years, including off-grid solar company SolarNow in Uganda, off-grid smart meter company SteamaCo., Singaporean solar developer Sunseap, and German battery developer Sonnen (Eckert 2018, Royal Dutch Shell 2018f). In September 2018, Shell announced a partnership with the National Renewable Energy Laboratory to create the Shell GameChanger Accelerator Powered by NREL to fund new clean energy technologies (GCxN 2018). Total has invested in solid-state battery manufacturer Ionic Materials (Felix 2018), fuel cell company Sunfire, biofuel company NexSteppe, storage developer Sunverge, and off-grid solar developer Off-Grid Electric (Total 2018e).



The most direct, and arguably the most prevalent, strategy among IOCs is direct ownership of renewable generation assets. BP owns interest in 2259 megawatts of wind energy projects in the United States. Chevron owns a 16.5 MW wind farm in the United States and has invested in 73 MW of solar and 49 MW of geothermal projects in the United States (Chevron 2018d). Eni is seeking to own 1 GW of wind and solar by 2021 and 5 GW by 2025 (Eni 2018b). The company is investing primarily in solar, but also in wind, in Europe, Asia, the Middle East, and Africa (Eni 2018a). Equinor owns interests in seven offshore wind projects that are operational or in development in Europe and the United States totaling approximately 6.4 GW (Equinor 2017c). The company also has an approximately 44 percent share of a 162 MW solar project in Brazil with Scatec Solar and a local company and is pursuing a joint venture with Scatec on a 117 MW solar project in Argentina (Kenning 2018, Scatec Solar 2018). Equinor is also exploring developing offshore wind with Brazil's Petrobras (Valle 2018). In 2017, the company provided around 830 GWh of electricity from renewable sources, including serving 630 000 households in the UK (Equinor 2017c). Exxon does not presently own any renewable generation assets but signed a power purchase agreement with Orsted to use 500 MW of wind and solar in its operations in the Permian Basin (Parnell 2018). Shell owns stakes in about 740 MW of onshore wind power in the U.S. and owns a 50 percent stake in the 100 MW Noordzeewind offshore wind farm in the Netherlands (Royal Dutch Shell 2018e). Shell also owns a 20 percent stake in the consortium that is developing another 731.5 MW offshore wind project in the Netherlands (Weston 2018). As recently as September 2018, Shell was considering buying wind projects from Brazil's Eletrobras (Valle 2018). Total owns interest in 1.9 GW of renewable energy through its subsidiaries, and has set a goal of owning 5 GW by 2022 (Total 2017a, 2018c). Total develops solar projects through its subsidiary Total Solar, which owns 300 MW of solar generation capacity (Total 2018a), and its affiliate Total Eren, which has 1 GW of renewable energy installed or under construction and aims to own over 3 GW within five years (Total 2018d, 2018c). SunPower has also developed, owned, and operated solar projects, but the company exited utility-scale development and sold most of its assets to Clearway Energy Group in September 2018 (Roselund 2018). Total is partnering with Brazil's Petrobras to develop wind and solar projects and has separately pledged to develop 165 MW of solar in the country (Valle 2018). In 2017, Total also partnered with the GoodPlanet Foundation to build 8400 new biodigesters in India to produce biogas for 45 000 residents and offset the emissions from Total employees' plane travel (Total 2018c).

BP funds research into low-carbon technologies at Princeton, Harvard, and Tufts (BP 2018a). Exxon funds what it identifies as breakthrough energy research at Massachusetts Institute of Technology, Princeton, the University of Texas, and Stanford (ExxonMobil 2018d). Many of the IOCs conduct R&D internally, and Eni runs a Renewable Energy and Environmental R&D Center in Italy, which is investing in solar photovoltaic and CSP technologies (Eni 2018d).

While IOCs have long made investments in 'new energies' such as biofuels and wind energy, the emergence of new business areas within these companies is a new trend. This reflects a greater degree of institutionalization of these companies' interest in navigating the energy transition than before. Shell, for example, has been investing in wind power for 15 years, but did not set up a formal New Energies business unit until 2016 (Royal Dutch Shell 2018a). Similarly, Total says it has been investing in renewable energy for 30 years, but its Gas, Power, and Renewables division was just established in 2016 (Total 2016). Companies have traditionally been cautious about moving beyond their core oil and gas business, but they appear to be beginning to more heavily invest in renewables; whether the growth continues remains to be seen. In terms of generation assets, Equinor stands out with its 6.4 GW of offshore wind projects. In terms of acquisitions, Total stands out for how many acquisitions it has made in renewable energy, but especially for its ownership of SunPower.

### 3.1.3. Low-carbon transportation

Given the importance of oil in transportation, low-carbon transportation is a sensible area into which IOCs looking to green their portfolios can direct their investments. The IOCs low-carbon transportation investments go to alternative fuels and electric vehicle infrastructure.

BP has long-standing investments in biofuel development, partnering with Copersucar in Brazil and DuPont in the United States (BP 2018a). The company also acquired Clean Energy Fuels Corporation's upstream business, which produces biomethane for natural gas vehicle fueling (Clean Energy Fuels Corporation 2017). Eni is converting some of its oil refineries to biofuel refineries and is directing R&D at its Renewable Energy and Environmental R&D Center to biofuels (Eni 2018d). The company also plans to install new natural gas fueling infrastructure in Italy over the next four years (Eni 2018b). Exxon is conducting biofuels research with multiple partners, including companies such as Synthetic Genomics and Renewable Energy Group and universities like Colorado School of Mines, Michigan State University, and University of Wisconsin (ExxonMobil 2017). Shell began a joint venture with Cosan in 2010 to develop Raízen, which produces ethanol from sugarcane and manages the distribution and sale of its fuel across Brazil (Raízen 2018). Shell has also partnered with SBI Bioenergy to commercialize its biofuels made from waste oils, greases, and vegetable oils (Royal Dutch Shell 2017c) and is working to commercialize a waste-to-fuel technology in India (Royal Dutch Shell 2018f). Total has formed a joint

venture with Amyris and is participating in the BioTFuel project to develop biofuels for blending in diesel and aviation fuels (Total 2019). Total also operates 450 natural gas fueling stations in Asia, Africa, and Europe, and has acquired PitPoint, which has added 100 more (Total 2017a). The company is also converting its La Mède oil refinery in France to produce biofuels derived from used oil or vegetable oil. Total's aviation biofuels have been used by Air France, Cathay Pacific, and Air China (Total 2018c).

The IOCs are also investing heavily in electric vehicle (EV) charging infrastructure. BP has partnered with FreeWire, which develops mobile EV charging stations (BP 2018d), and StoreDot, which develops EV batteries (BP 2018e). The company has also acquired UK EV charging infrastructure company Chargemaster (BP 2018f) and is partnering with Chinese private equity fund NIO Capital to explore opportunities in advanced mobility in China and internationally (BP 2018b). Equinor has invested in ChargePoint, which owns over 28 000 EV charging stations in the U.S (ChargePoint 2016). Shell has acquired NewMotion, which operates 30 000 private charging stations and provides access to 50 000 public charging stations across Europe (Royal Dutch Shell 2018f), and invested in Ample, which promises ultra-fast EV charging using autonomous robotics and smart-battery technology (Ample 2018). The company has also contracted with Allego and with IONITY to install chargers at Shell stations in Europe (Lambert 2017, Royal Dutch Shell 2018f). Total is using its power distribution business to install 1000 EV charging stations across western Europe (Total 2017a); has acquired G2mobility, which adds almost 10 000 charge points to its network (Total 2018b); and is a founding member of the Michelin Movin'On Lab, a think tank seeking to develop short-term sustainable transportation solutions (Total 2018c). Total's acquisition of PitPoint also adds EV charging stations to its portfolio.

In the past, companies tended to invest in either biofuels or EVs, mostly choosing the former because the latter still had not achieved cost reductions necessary to scale. Now, companies are increasingly investing in both, primarily choosing to focus on early-stage research and development of biofuels and largely avoiding the production of EVs (with the exception of BP), instead directing investments to the enabling infrastructure that can help speed their deployment. Shell, which already has a significant network of gas stations around the world, is beginning to add chargers to its existing stations in addition to acquiring a separate network of standalone chargers, while the others focus on the latter strategy.

#### 3.1.4. Carbon capture and storage

In a carbon-intensive industry, carbon capture and storage (CCS) poses an investment opportunity for IOCs that can help meet the world's GHG emission reduction goals while allowing hydrocarbon production and use to continue.

IOCs are invested in both efforts to promote CCS and demonstration projects to prove its utility and effectiveness. As of September 2018, all seven IOCs are members of OGCI, whose investments include CCS technology (Oil and Gas Climate Initiative 2015, 2018c). BP and Chevron are members of the Energy Advance Center, an industry association to promote CCS (Geman 2018). Chevron's Gorgon Project in Australia is expected to store 4 million tons of CO<sub>2</sub> per year (Chevron 2017) and the Quest CCS project in Canada, a Shell project in which Chevron is a partner, has reportedly captured 3 million tons of CO<sub>2</sub> from 2015 to 2018 (Royal Dutch Shell 2018b). Equinor, Shell, and Total are all partners in Norway's Technology Centre Mongstad, which can store 100 000 tons of CO<sub>2</sub> per year (Total 2017a), and the Northern Lights project, which is expected to store 1.5 million tons of CO<sub>2</sub> per year (Total 2018c). Equinor also maintains the Sleipner and Snøhvit CO<sub>2</sub> storage projects in Norway (Exxon and Total are partners at Sleipner and Total is a partner at Snøhvit) (Equinor 2017c), and stored 3 million tons at the In Salah gas field in Algeria from 2004 to 2011 (Equinor 2018b). Equinor reported capturing and storing 1.36 million tons of CO<sub>2</sub> in 2017 and 22.3 million tons cumulatively. Exxon has partnered with Fuel-Cell Energy to test carbon capture using fuel cells at an Alabama power plant (ExxonMobil 2016). Exxon is also working with the Energy Research Centre of the Netherlands and University of California-Berkeley to develop CCS technologies (ExxonMobil 2018a). Shell, in addition to partnering with Chevron, Equinor, and Total, has developed CCS technology that is in use at a SaskPower coal-fired power station in Canada (Royal Dutch Shell 2018d). Total is also partnering with Stanford University on simulated carbon storage and with Chinese and European partners on using captured CO<sub>2</sub> as a power and heat source (Total 2018c).

All seven IOCs are invested in developing CCS technology, which is a sensible business decision considering its utilization would allow them to continue producing and selling hydrocarbons, and thus would be the least disruptive to their core businesses. IOC efforts on CCS frequently involve partnerships, often among oil and gas companies, which is not common in the other strategies covered in this study. This may simply be because pooled resources can scale up and speed up research efforts. It may also be because CCS is a technology that can materially benefit all carbon-intensive companies, rather than benefiting individual companies over others, so there is incentive to collaborate rather than compete.



### 3.1.5. Hydrogen

Hydrogen can serve as a cleaner substitute for natural gas in heating or in a fuel cell to power electric vehicles or to store electricity like a battery. When hydrogen is burned, it produces only electricity, heat, and water (U.S. Department of Energy 2017). The use of hydrogen is an important part of the energy transition, and the Hydrogen Council estimates that it could provide around one fifth of total final energy consumption by 2050 (Hydrogen Council 2017), leading to a reduction of approximately 200 million tons of CO<sub>2</sub> emissions (Adolf *et al* 2017). To date, hydrogen has not captured a significant portion of IOC attention as a low-carbon fuel, likely because there are currently few markets for it. However, IOCs have begun making investments in developing these potential markets, particularly in power generation and fuel cell vehicle infrastructure.

Equinor has partnered with Vattenfall and Gasunie to study the feasibility of converting a natural gas-fired power plant into a hydrogen-powered plant and integrating CCS technology (Equinor 2017b). This project could reduce CO<sub>2</sub> emissions by four million tons per year. Equinor, Shell, and Total are members of the Hydrogen Council, which seeks to create markets for hydrogen solutions across sectors (Hydrogen Council 2018). Shell is part of a joint venture with partners such as Daimler and Total called H2 Mobility to install hydrogen vehicle fueling infrastructure in Germany, with ITM Power to do the same in the UK, and with Honda and Toyota to do so in California (Royal Dutch Shell 2018f, Total 2018c). Shell and ITM Power are also partnering to build a 10 MW hydrogen electrolysis plant in Germany (ITM Power 2018). Total's acquisition of PitPoint gives the company access to a developing network of hydrogen fueling stations (PitPoint 2017, Total 2017a).

Many of the IOCs are exploring investments in hydrogen, mostly for use as an alternative transport fuel. Hydrogen is perhaps the technology in which IOCs have initiated the least number of projects, although that does not necessarily mean it sees the smallest amount of investment or interest. IOC partnerships with power and transportation sector companies suggest an acknowledgment that developing hydrogen as a climate solution would create new opportunities in all of their respective business areas.

## 3.2. IOC investments

BP plans to invest approximately \$500 million per year in low-carbon activities, including operating its current renewables businesses, acquiring new companies, and investing in ventures and start-ups (BP 2018a). BP's total capital expenditures in 2017 were \$17.8 billion (BP 2018c). BP's investments include \$200 million in Lightsources as well as \$5 million in FreeWire and \$20 million in StoreDot through BP Ventures (BP 2018a).

Chevron has invested \$75 million in CCS since 2008 (Chevron 2018c). At the Tengizchevroil project in Kazakhstan, in which Chevron has a 50 percent interest, a \$258 million gas utilization project helped contribute to an 85 percent reduction in flaring from 2000 to 2017. In 2018, Chevron Technology Ventures launched a \$100 million Future Energy Fund to invest in technologies to lower GHG emissions (Chevron 2018b).

Eni invested over 72 million (\$84.64 million in 2018 dollars) on lowering GHG emissions in 2017, a plurality of which (35 percent) was spent on renewables (Eni 2018b). The company expects to spend 1 billion (\$1.14 billion in 2018 dollars) on green energy from 2018–2021, including 280 million (\$329 million) on R&D (Eni 2018c).

Equinor has set a target of devoting 25 percent of its R&D funding to go to new energies (wind, solar, hydrogen, and CCS) by 2025 (Equinor 2017c). In 2017, R&D funding to new energies reached 18 percent. Equinor also expects its spending on new energies to reach 15–20 percent of total capital expenditures in 2030. Total capital expenditures in 2017 were \$10.8 billion (Equinor 2017a). Equinor Energy Ventures, established in 2016, is a \$200 million fund that invests in renewable energy companies (Equinor 2016b).

Exxon has invested \$250 million in biofuels R&D in the past decade (ExxonMobil 2018d). The company's research partnerships with Massachusetts Institute of Technology, Princeton, the University of Texas, and Stanford total \$145 million. Since 2000, Exxon has invested \$4 billion on upstream efficiency projects and flaring reductions, \$2 billion to reduce emissions at refining and chemical facilities, and \$2 billion on cogeneration at upstream and downstream facilities (ExxonMobil 2018a).

Shell has pledged \$1–2 billion per year on biofuels, EVs, and wind from 2018 to 2020, out of a total expected capital investment of \$25–30 billion per year (Royal Dutch Shell 2017a).

Total expects 10 percent of its R&D to be devoted to CCS in the future (Total 2017a). Spending on R&D in 2017 was \$912 million (Total 2018a). Total aims to invest about 20 percent of its \$130 billion in assets in its low-carbon businesses (renewable energy and fuels, energy efficiency, storage, and midstream and downstream natural gas) by 2035 (Stothard 2016, Total 2017a). The company's operational emission reduction investments have included \$300 million to install solar at industrial sites and over 30 percent of service stations (Total 2017a).

OGCI, in which all seven IOCs are members, is designed to invest in low-emissions technologies through its Climate Investments Fund in low-carbon technology over 10 years (Oil and Gas Climate Initiative 2018a). Each

member company is expected to contribute \$100 million to the OGC Climate Investments Fund over 10 years, so the current membership of 13 can be expected to contribute \$1.3 billion to the fund.

IOCs are looking to manage the energy transition, but they are proceeding cautiously, and their investments still make up a small part of their portfolios. Shell stands out among its peers for its pledge of \$1–2 billion per year on renewables, although that only accounts for 3–8 percent of its total capital expenditures. Equinor stands out for its target of 15–20 percent of capex spending on new energies in 2030.

#### 4. The role of NOCs in the energy transition

NOCs and their home countries expect to face business risk in the future due to GHG emissions from fossil fuels and the potential damages from climate change. To mitigate these risks, they are trying to harness all possible efforts to keep up with the global energy transition, not only to maintain the sustainability of their businesses, but also for the future of their home economies. The role of NOCs in lowering carbon emissions, however, is mainly policy-driven and is enforced by their governments. It could stem from their Nationally Determined Contributions towards climate change mitigation, their stakeholders' concerns regarding climate change, and/or national energy security. Regardless of the reason for their action, NOCs can play a critical role in the global energy transition.

In this article, we outline the role of NOCs such as Abu Dhabi National Oil Company (ADNOC), China National Offshore Oil Corporation (CNOOC), China National Petroleum Corporation (CNPC), Equinor (Norway), Gazprom (Russia), Kuwait Petroleum Corporation (KPC), National Iranian Oil Company (NIOC), Petroleum Development Oman (PDO), Mexican Petroleum (Pemex), Petronas (Malaysia), Qatar Petroleum (QP), Rosneft (Russia), and Saudi Arabian Oil Company (Saudi Aramco). We did not include NOCs such as Sonatrach, SINOPEC, Pertamina, PDV, NNPC, Libya NOC, Ecopetrol, EGPC, Kazmunaigas, and Turkmengas due to data paucity.

This section's layout is as follows. In section 4.1, we discuss some structural features associated with the governance of NOCs. In section 4.2, we focus on the technologies the NOCs are backing, and in section 4.3, we look at the scale of investments.

##### 4.1. NOCs' relationships to their owner governments

The flexibility and attitude of NOCs towards the energy transition depends substantially on various factors such as the non-oil burdens on NOCs and their governance structures. NOCs that are funding fuel subsidies, social programs, and/or paying high taxes usually experience a high burden (Victor *et al* 2012) and we expect that they have less ability to be involved in lowering GHG emissions. Governance structures can range from a unified authority to a fragmented authority. The former refers to the NOCs that have a specific line of authority such as national leaders or energy ministers, while the latter refers to the NOCs that have multiple lines of authority, and these lines might compete with each other over oil policy due to having different interests (Victor *et al* 2012). NOCs such as Equinor, Petrobras, ADNOC, Petronas, Saudi Aramco, Gazprom, and PDVSA are examples of a unified authority where they operate in a monitoring-heavy system and they have vast decision-making power (Victor *et al* 2012). On the contrary, NOCs such as Pemex, KPC, and NIOC have fragmented authority within a procedure-heavy system (Victor *et al* 2012).

In addition, institutional features of home countries such as political stability, regulatory quality, and the rule of law influence the ability and effectiveness of NOCs to adapt to the energy transition in their countries. Employing Worldwide Governance Indicators issued by the World Bank, figure 3 shows the average percentile ranking of each NOC's home country for regulatory quality and the rule of law from 1996 to 2014. Based on these criteria, these countries can be classified in different categories of government quality and the ordering is roughly similar along most of the governance indicators.

Although country ratings on these indicators do not fully elucidate the level of NOCs' strategies in navigating the energy transition, there appears to be a relationship between countries' scores on these indicators and how engaged their NOCs are in navigating the energy transition. NOCs whose home countries have a very low percentile rank of governance are less engaged in the energy transition process, while those in higher percentile ranks tend to do more. These factors can explain why Equinor, which is majority state-owned, behaves similarly to IOCs and is actively committed to the energy transition. In this study, we discuss Equinor's strategy with the IOCs, but it is an example of a hybrid governance structure where the company has some non-government ownership while employing various strategies to move towards a low-carbon economy.

##### 4.2. NOC strategies and plans

Similar to the strategies of IOCs, the strategies of NOCs addressed in this section include reducing energy consumption or emissions in oil production processes and facilities, using renewable energies, investing in alternative fuel vehicles, and investing in new technologies such as CCS and hydrogen.

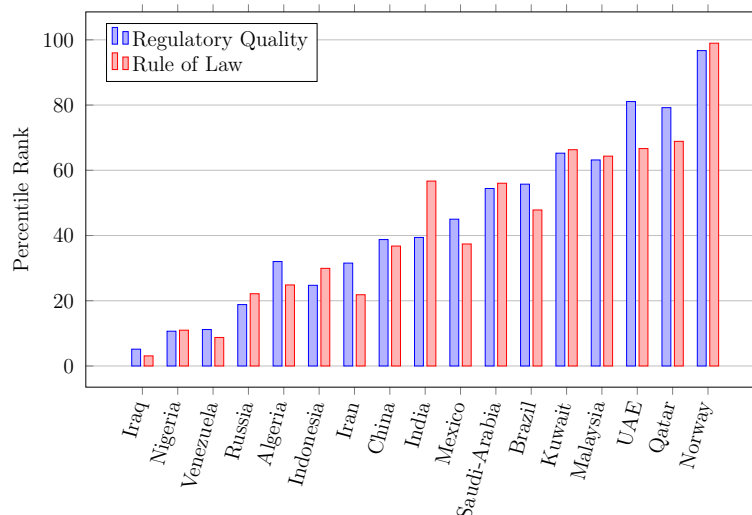


Figure 3. Governance indicators (data source: World Bank).

#### 4.2.1. Energy conservation and emission reductions

Almost all oil companies include energy efficiency improvements and emission reductions, including gas flaring reductions, in their strategies to lower their emissions. We summarize some of the energy conservation activities in this section.

CNOOC has been lowering its emissions by employing various low-carbon management regulations and projects such as upgrading to energy-efficient lighting in its office buildings in 2016, upgrading the quality of its oil products, implementing pollutant emission standards and establishing a carbon inventory in 35 key controlled discharging subsidiaries, and undertaking research projects such as the ‘Carbon Emissions Effects Analysis of Newly Developed Domestic Offshore Oil and Gas Fields’ in the 13th Five-Year Plan period (CNOOC 2016, 2017c, CNOOC 2018). In addition, CNOOC’s natural gas recovery project in the south Bohai Sea is capable of recovering 60 million cubic meters of natural gas and reducing GHG emissions by 140 000 tons of CO<sub>2</sub>-equivalent (CNOOC 2017b). The other Chinese national oil company, CNPC, has undertaken efforts such as implementing 58 projects to reduce emissions in 2016, developing a low-carbon roadmap, and specifying low-carbon development goals such as reducing at least 1 million tons of CO<sub>2</sub> emissions per year as of 2017 (CNPC 2018b, 2018c, 2017).

With the goal of reducing emissions to 75% of its 1990 emissions level, Gazprom has implemented programs such as an independent audit review carried out by KPMG; Gazprom PJSCs energy savings and energy efficiency program; methane leak monitoring, assessment, and documentation; Gazproms Energy Saving and Energy Efficiency Program (saving at least 28.2 million tons of fuel-equivalent from 2011 to 2020); and a plan to reduce its own gas consumption by at least 11.4 percent and GHG emissions by at least 48.6 million tons of CO<sub>2</sub>-equivalent (Gazprom 2016, 2017b, 2018a, 2018c).

Saudi Aramco has a plan of 2% annual reductions in energy intensity in industrial facilities by employing plans such as designing new energy efficient facilities, increasing overall energy efficiency, and employing carbon management technologies (Ramady 2018, Saudi Aramco 2018). The company’s Peak Summer Production Program reduced the use of liquids in power generation, which resulted in savings of around 11.5 million barrels of crude oil in 2017 and reduced emissions (Saudi Aramco 2017). Rosneft also plans to reduce GHG emissions by one quartile in 2022 compared to 2017, and is implementing programs such as its Gas Investment Program, Energy Efficiency Program, and refinery modernization (Rosneft 2017a, 2017b).

NIOC is implementing the Carbon Management Plan to reduce gas emissions (NIOC 2018), and KPC plans to limit hydrogen sulfide emissions to a maximum of 2 parts-per-million in ship fuel production (KPC 2017). PDO has a plan to reduce domestic power demand by 3% per year and has implemented projects such as an LED lighting replacement project (PDO 2016). Petrobras is part of the Carbon Disclosure Project (since 2006), and it also is the founder of Brazilian GHG Protocol program and administers emission inventory of the greenhouse gases such as carbon dioxide, methane, and nitrous oxide. One of the company strategies towards lower carbon emissions is employing technologies such as CO<sub>2</sub> capture and separation; the company has re-injected 7 million metric tons of CO<sub>2</sub> that were separated from the gas produced in the Santos Basin pre-salt fields from 2008–2017 (Petrobras 2017b).

Pemex has the goal of 25% (15 million tons) CO<sub>2</sub>-equivalent emissions reductions by 2021 through improving energy efficiency, operational efficiency, flaring reduction, and increased gas use. It includes actions such as

external cogeneration in the Salamanca refinery and the ‘Heat Recovery at the Terminal Maritima Dos Bocas’ project (Pemex 2016). In addition to commencing a halons phase-out program in 1997, ADNOC obtained ISO 50001 certification in energy management in 2015 to ensure energy efficiency improvement in their business and operations (ADNOC 2015).

Various national oil companies have begun reducing gas flaring through employing technical and regulatory instruments, including ADNOC (13% reduction in 2015), CNOOC (recovering and reusing 15 000 cubic meters of natural gas of Hai Yang Shi You 113 FPSO per day) (CNOOC 2017b), CNPC (light hydrocarbon recovery projects at Tarim, Xinjiang, and Tuha oilfields), Gazprom (APG utilization level of no less than 95%) (Gazprom 2017b), NIOC (gas recovery contract with a French company in 2017) (NIOC 2017), PDO (Zauliyah AP Educator Gas Recovery and a 38% reduction in 2016) (PDO 2017), Pemex (7 million Canadian dollars of investment) (Pemex 2016), Petronas (Exploring economic solutions), Saudi Aramco (master gas system and Flaring Minimization Program, flaring intensity of less than 1% of gas production in 2017 (Saudi Aramco 2017)), and Sonatrach (carrying out regulatory functions).

Of the NOCs, CNPC, Saudi Aramco, Pemex, and Petrobras are members of OGCI (OGCI 2018).

#### 4.2.2. Renewable energy

Although NOCs are employing various strategies to navigate the energy transition, renewable energy and energy efficiency are the main paths. More than 90% of the required reduction in energy-related CO<sub>2</sub> emissions can be achieved through increased energy efficiency and renewable energy utilization (IRENA 2018). NOCs have begun utilizing renewable energy in their facilities or, in some cases, providing renewable energy to other sectors. The latter, however, is not the main focus of most of the NOCs. Their actions are mostly policy-driven, and renewable energy production is mainly the purview of other companies in their countries. For example, ADNOC has not developed renewable energy assets, letting the Abu Dhabi Future Energy Company, Masdar, play this role while cooperating with ADNOC (Graves 2016). NOCs’ actions related to renewables are highlighted as follows.

Since 2010, CNOOC has started production of biodiesel with an annual capacity of 60 000 tonnes for use in vehicles (CNOOC 2012). CNPC has also evaluated and begun using biomass (aviation biofuel), wind, solar, and geothermal; this includes pilot tests for the use of geothermal energy in the Huabei Oilfield and projects for photovoltaic power generation, wind power generation, and the development and utilization of geothermal energy in the Xinjiang and Liaohe oilfields (CNPC 2018a).

Gazprom operates 1959 power generation units, generating from both fossil fuels and renewable energy, for auxiliary needs and to sell to third-party consumers in remote or off-grid areas where it is economically and technically feasible (Gazprom 2018b). In 2017, the Gazprom Group generated 471 470 kWh of electricity from its power plants (excluding hydro) (Gazprom 2017b). Gazprom’s renewable energy production includes but is not limited to generating around 13 million MWh of electricity from hydroelectric power in 2016 through Gazprom Energoholding LLC and generating more than 360 000 kWh of electricity in 2016 by using other renewable energy sources such as solar panels, wind turbines, turboexpanders, and thermoelectric generators (Gazprom 2016). Additionally, Gazprom is building a 102 MW wind power plant in cooperation with the Serbian company Energowind NIS, and it also has plans to build a geothermal power plant in northern Serbia in partnership with Singapore company Betec (Gazprom 2016).

KPC has also stepped into renewable energy and commenced several initiatives such as the Renewable Energy Dashboard with the goal of producing at least 15% of Kuwait’s energy from renewable energy by 2030 (KPC World and Bouresly 2016). It includes but is not limited to the following actions (KPC World and Bouresly 2016, KPC 2017, K-Pulse 2018a):

- Launching the largest solar project in Kuwait, named Sidra 500, with electricity capacity of 10 MW.
- Building and maintaining solar panels in the parking lots of the oil complex (in cooperation with the Kuwait Institute for Scientific Research (KISR)).
- Using solar to light the 6.5 km road in the north of Kuwait.
- Producing electricity from solar and wind to light the head office building and for irrigation purposes (Waha Al-Subaihiya project).
- Producing steam from CSP to use in injection operations at the South Ritqa field in the north of Kuwait.
- Building the Abdaliya Integrated Solar Combined Cycle project and establishing the first solar thermal power plant in Kuwait by 2020.
- Operating two fuel stations in the Al-Zahra and Al-Riqqa areas powered by solar energy.
- Planning to build an integrated CSP plant to produce power and steam for enhanced energy recovery.

PDO’s utilization of renewables is mainly focused on solar energy; it involves projects such as a CSP plant with electricity capacity of 1021 MW to use in EOR in 2017 (a joint venture between Shell, Total, Partex, and the



Government of Oman) and the Mina Al Fahal solar parking project commissioned in early 2018 (PDO 2017, Power Technology 2018).

NIOC has begun employing solar energy in some of its facilities, including installing four solar energy lighting systems in the southwest of Iran due to the availability of sunshine more than 300 d a year (Makvandi 2018). Petronas has produced around 13 628 MWh of solar energy from existing solar PV investment projects in 2017 (Petronas 2017). Petrobras has been investing in renewable energies such as solar and wind. For instance, the Alto Rodrigues Photovoltaic Unit is a pilot plant with installed capacity of 1.1 MW. In solar and wind energy segments, the company also has partnership with other oil companies such as CNPC (Comperj and Marlim cluster), Equinor (offshore wind energy), and the Total group (solar and onshore wind) (Petrobras 2018).

Saudi Aramco is currently a member of the Carbon Sequestration Leadership Forum (CSLF) and OGCI. It has launched investments in renewables projects and has plans to use renewable energy for remote facilities and well sites; they include installing 9.5 GW of solar and wind capacity by 2023, 3.3 GW of solar PV power, and 800 MW of wind in 2018 (Bloomberg 2017, Dhahran 2018, Habboush 2018). The company currently owns a wind power project, called the Turaif oil storage depot, with one turbine and a generation capacity of 2750 kW (Wind Power 2018).

#### 4.2.3. Low-carbon transportation

Oil companies expect a higher demand for clean vehicle fuels in the future, so they are investing in cleaner vehicle fuels mainly in natural gas as well as electric vehicles, bio-fuels, and hydrogen.

Compressed natural gas (CNG) and liquefied petroleum gas (LPG) are alternative natural gas vehicle fuels in which some NOCs are investing. ADNOC's strategy in this area is providing CNG conversion centers and equipping all ADNOC stations with at least one CNG terminal by the end of 2018 (Ahmad 2017). CNOOC owns a network of gas stations in 21 provinces serving natural gas-powered vehicles as well as 116 gas stations under construction (CNOOC 2012). Gazprom is involved in expanding the natural gas vehicle market by producing EcoGas fuel and developing gas filling infrastructure in Russia (Gazprom 2016). While Iran is among the top CNG producers and consumers with four million natural gas vehicles and around 2300 CNG refueling stations in 2017 (NGV Global 2017), natural gas projects are mainly carried out by the National Iranian Gas Company, and NIOC is not directly involved.

Regarding EVs and biofuels, some NOCs have provided the required infrastructure, such as charging stations. For example, Petronas has a plan to build 25 000 EV charging stations in the country by 2030 (Petronas 2017). According to ADNOC Distribution deputy CEO John Carey, ADNOC plans to provide EV fast chargers at 10 sites in two years (Al Rashdi 2018). It is also cooperating with a renewable energy company named Masdar as well as Toyota, and it has set up two hydrogen stations at Dubai Festival City and Abu Dhabi to test Toyotas Mirai (a hydrogen fuel cell EV) as a pilot project (Abdul Kader 2018).

CNOOC has been involved in the production of biodiesel for use in vehicles since 2010 with a production capacity of 60 000 tons per year (CNOOC 2012). Pemex has a contract with Ciprof Energies, a Mexican biofuel producer, to buy 18–20 million liters of ethanol per year to replace an additive and produce less-polluting fuels (MexicoNow 2018). Gazprom is also expanding its natural gas vehicle market by producing EcoGas fuel and developing gas refueling infrastructure across Russia as well as running 60 CNG refueling stations in Europe in 2016 (Gazprom 2016).

Petrobras is actively engaged in biofuel energy generation and fully owns the Petrobras Biocombustvel subsidiary; the company's biodiesel plants had a production capacity of 1054 thousand m<sup>3</sup> in 2018 (Petrobras 2018).

#### 4.2.4. Carbon capture and storage

CCS is a climate change solution that could help NOCs stay in the market and produce oil with fewer emissions. NOCs are mainly looking at capturing CO<sub>2</sub> to inject into oil reservoirs for EOR. ADNOC's joint venture with Masdar, known as Reyadah, is the first commercial-scale carbon capture use and sequestration (CCUS) facility in the Middle East. The company has stored approximately 240 000 metric tons of CO<sub>2</sub> from Emirates Steel Industries to use in EOR; it is aiming to expand its CO<sub>2</sub> utilization to around 250 million standard cubic feet per day by 2027 by capturing additional CO<sub>2</sub> from its gas processing plants (Saadi 2018). KPC signed a contract in 2017 to study CCS and GHG emission reductions in the company (KPC 2017).

CNOOC Shenzhen and the Global CCS Institute undertook a three-year desk study in 2014 to develop a pilot capture, transport, and storage full-chain project (Global CCS Institute 2015b). CNPC also ran a pilot test in its Jilin Oilfield employing CCS; they used the discharged CO<sub>2</sub> from oilfield production to flood oil, which resulted in more oilfield recovery and sequestration of 940 000 tons of CO<sub>2</sub> (CNPC 2018a, 2018b). Saudi Aramco has begun investing in CCS to reduce its carbon footprint. These investments include launching the first large-scale CCS facility in the Middle East, known as Uthmaniyah CO<sub>2</sub>-EOR Demonstration Project, which captures around 0.8 million tonnes of CO<sub>2</sub> per year from the Hayiwah natural gas liquids recovery plant to use in EOR (Saini 2017).



#### 4.2.5. Hydrogen

There are applications for hydrogen in various sectors, but in this review, we did not find evidence that NOCs are making considerable investments in it. We highlight a few examples that we found.

The major application of hydrogen is that it can be used as a low-carbon energy carrier. Hydrogen is currently employed mainly as a feedstock for ammonia production, with a 35% share for oil refining (Hanley *et al* 2018). The Fertil-2 Project, a joint venture between ADNOC and Total, is an example of using hydrogen in ammonia and urea production (Chemicals Technology 2008). Saudi Aramco and Japan are also jointly examining the feasibility of extracting hydrogen from crude oil and transporting it to Japan in the form of ammonia (Crolius 2018). Gazprom's Omsk Refinery has an annual capacity of 12 300 tons for hydrogen production (Gazprom 2016). The Al-Shuaiba Refinery, owned by KPC, is the world's first hydrogen refinery using hydrogen extracted from gas. The Environment Department has implemented a system at the refinery to ensure compliance with international environmental standards (Al-Azmi 2013).

Hydrogen production by oil companies mainly comes from fossil fuels, and therefore is associated with CO<sub>2</sub> emissions. CCS is found to be one of the crucial strategies to reduce net carbon emissions from hydrogen (Council *et al* 2004). The link between ADNOC's Taweelah CCS project (the joint venture with Masdar) and its hydrogen plant is an example of a hydrogen project with the low emissions.

In addition to hydrogen's use in oil refining, it has the potential to be employed in hydrogen-based systems in energy demand sectors (e.g. fuel cell electric vehicles in transport and fuel cell micro cogeneration in the residential sector) as well as energy supply sectors (e.g. variable renewable energy integration and energy storage including power-to-fuel, power-to-power, and power-to-gas) (Körner *et al* 2015, Hanley *et al* 2018). ADNOC is cooperating with Toyota to provide hydrogen stations for fuel cell vehicles in the United Arab Emirates. CNOOC is also conducting research into hydrogen-powered systems and sea-based nuclear power plants to expand its clean energy business.

#### 4.3. NOC investments

In the previous subsection, we summarized various strategies and projects carried out by NOCs from a technological standpoint. Depending on the availability of data, in this section, we focus on the size of investment in and/or savings from some of these strategies.

ADNOC spent AED 698 million (around \$190 million) in environmental expenditures by 2015 (ADNOC 2015). Compared to 19.8 billion AED (around \$5.4 billion) in total revenue in 2017, its Fertil-2 Project (hydrogen in ammonia and urea production) costs \$1.2 billion, and the Al Reyadah CCS project costs AED 450 (\$122.5) million (Chemicals Technology 2008, ADNOC 2015, 2017).

Out of total expenses of approximately 149.34 billion RMB (\$21.81 billion) in 2017, CNOOC's investment in energy conservation and emissions reduction was 350 million RMB (around \$51 million) in 2017 (CNOOC 2017a, 2017c). The company spent \$300 million in a joint venture with Spain's solar company, Isofoton SA, in 2012 to invest in solar projects with a 51% stake (Reuters 2012). The efficient lighting project in CNOOC's office buildings resulted in more than 10 million RMB (around \$1.5 million) of cost savings (CNOOC 2016).

Through its subsidiary Kunlun Financial Leasing, CNPC has given 200 million RMB (around \$29 million) to State Power Investment Corporation to buy eco-friendly generator sets for a waste-fired power plant project (CNPC 2017). The company's total operating cost was around 2294.97 billion RMB in 2017 (CNPC 2017).

In 2017, the Gazprom's operating expenses (excluding the asset impairment provision and other reserves) were around 5714.1 billion RUB (Gazprom 2017a). The company's capital investments for environmental protection in 2017 increased by 58% compared to 2016 and reached 70.82 billion RUB (Gazprom 2017b). Implementing the energy efficiency program in the upstream sector in 2017 created energy savings worth 1500 mm RUB. Gazprom investments include a \$100 million investment in biodiesel by one of its subsidiaries in 2013 for export to the European Union (Sapp 2013).

KPC's consolidated expenses were around 18.91 billion KD (around \$62.43 billion) in 2017 (KPC 2017), and the contract between KPC's subsidiary and Hyundai Heavy Industries of South Korea in 2018 for building three giant LPG tankers is valued at \$213.36 million (K-Pulse 2018b).

NIOC made a 42 million gas recovery contract with the French company Sofregaz in 2017 to reduce gas flaring (NIOC 2017). In addition, NIOC is among the Iranian organizations that have supported replacing gasoline with CNG as a vehicle fuel; it resulted in saving more than \$37 billion over 12 years (Hashemian 2017). Pemex has invested \$3600 million to meet the goal of 98% gas use from Pemex (2016).

As a member of OGCI, Petrobras is committed to investing one billion USD in low carbon technologies over a period of 10 years (Petrobras 2017a). In 2017, the company invested BRL 52.4 million in research and development in the areas of Carbon Capture Utilization and Storage, renewables (wind, solar, biomass) and climate change from which BRL 16.5 million is dedicated to 1st generation biofuels as well as advanced biofuels (Petrobras 2017b).

Saudi Aramco has invested \$5 billion to produce 10 GW of power from renewable energy by 2023 (Bloomberg 2017) while its net income only in the first half of 2017 was \$33.8 billion (Blas 2018). Saudi Aramco and Novatek's energy memorandum in 2018 to cooperate in the Arctic LNG-2 plant has a value of \$20 billion (Mahdi and Mazneva 2018). In addition, Saudi Aramco has invested in startup businesses, including a \$30 million investment in Silurias oxidative coupling of methane technology (Lane 2014).

To sum up, there is enormous potential for NOCs to contribute to the energy transition, and some of the NOCs have shown a commitment to do so. However, there might be some barriers that limit the size of efforts in this area, particularly in the short-term, such as technology access, financial issues, governance structures, and political conflicts.

## 5. Conclusion

This study focuses on transformation and transition in the industry, in particular transformation related to decreasing greenhouse gas (GHG) emissions, energy efficiency, investments in new technologies, and new business models. We analyze IOCs and NOCs separately because their governance structures can differ in fundamental ways. IOCs are private companies governed by executives and boards of directors who are ultimately accountable to shareholders, and they must respond to market forces and shareholder intent. Decisions are also constrained by the countries in which they are operating both in terms of obeying country policies and in terms of regulations governing operational practices such as gas flaring or wastewater disposal. IOCs also seek to maintain their social license to operate granted through the trust of countries and stakeholders that their activities are socially acceptable. Notwithstanding, we have not provided a full treatment of driving forces in this paper.

Beside technological feasibility, cost and economic viability are the key factors in adopting a clean technology, and regulatory design plays a fundamental role in making the technology viable. Regulation can reduce the cost of a clean technology by providing subsidies or increasing the opportunity cost of alternative fossil fuel utilization by implementing carbon taxes to make the technology viable. In general, regulation is more important to NOCs, whose management (i.e. government) has the authority to make policy.

Furthermore, among IOCs and NOCs, cooperation is becoming more attractive than competition as sustainability gains priority. They can cooperate on the risk management, technology access, or financial investment; this collaboration could even accelerate the energy transition and improve their contribution to mitigating climate change.

One significant distinction that arises when comparing IOCs and NOCs is in the direct ownership of renewable energy assets. IOCs have begun investing in renewable energy generation, especially wind and solar, to diversify their portfolios. NOCs, meanwhile, tend to leave the renewable energy ownership to their electricity sector counterparts in their countries. ADNOC coordinating with Masdar serves as a useful example of this trend.

In addition to company-level strategies, global and national actions influence the pace of oil majors' actions. For instance, one of the main motivations for oil majors to think about the energy transition is the possibility of carbon pricing. Higher carbon prices increase the opportunity costs of fossil fuel production and, therefore, make investment in low-carbon technologies more attractive and economically viable. When one looks at Equinor's investments in CCS, where it is one of the more aggressive actors among the oil majors, it is important to think about how its strategy would look if it did not have any government ownership and how much of its investment is because the Norwegian government is providing funding or other credible routes to investment recovery.

This study does not represent a look at oil and gas companies' climate-related investments. Further work might benefit from organizing the activities systematically. One of the organizing principles might be the level of difficulty. Another organizing principle might be whether the efforts are within the core competency of the organization or outside their core competency. Many traditional oil and gas companies are now, once again, thinking about becoming electricity companies. For the most part, they do not have significant institutional knowledge in the electric power industry. A notable exception is Equinor, which emphasizes how it has translated experience in building offshore oil exploration infrastructure into building offshore wind farms. Some companies, notably Total, have made up for their lack of experience in electricity by acquiring companies already in the electricity market. CCS investments, which many, if not all, of the oil companies in this study are making, are very much within their core sets of competencies. From an organizational theory point of view, these distinctions are likely to be important.

Further research may consider more discussion about the internal incentives for firms to take risks and deploy capital around those risks. This is one of the standard reasons why we think private firms behave differently from state-owned firms, but there is a debate in the literature as to whether this leads to more or fewer risk-taking activities. Private firms, on the one hand, tend to be more efficient and thus can place better bets. State-owned firms, however, often operate with soft budget constraints and a reliable mechanism for capital recovery that might make it feasible for some of them to take higher risks in some settings. China provides an illustrative example of this high-risk activity with guaranteed returns.

## ORCID iDs

Ensieh Shojaeddini  <https://orcid.org/0000-0001-9584-6399>

Stephen Naimoli  <https://orcid.org/0000-0001-7916-630X>

## References

- Abdul Kader B 2018 Second hydrogen station in uae to open in abu dhabi Gulf News (Retrieved from <https://gulfnews.com/news/uae/environment/second-hydrogen-station-in-uae-to-open-in-abu-dhabi-1.2155940>)
- ADNOC 2015 Sustainability report 2015, taking innovation to new heights. Abu Dhabi National Oil Company (Retrieved from [https://www.adnoc.ae/-/media/adnoc/files/publications/adnoc\\_sr\\_main-eng.ashx](https://www.adnoc.ae/-/media/adnoc/files/publications/adnoc_sr_main-eng.ashx))
- ADNOC 2017 Annual report (retrieved from [https://www.adnocdistribution.ae/reports/ar2017/pdf/ADNOC\\_Annual\\_Report\\_2017.pdf](https://www.adnocdistribution.ae/reports/ar2017/pdf/ADNOC_Annual_Report_2017.pdf))
- Adolf J, Balzer C H, Louis J, Schabla U, Fischedick M, Arnold K, Pastowski A and Schüwer D 2017 Shell hydrogen study energy of the future? Sustainable mobility through fuel cells and h2 *Technical Report* (<https://doi.org/10.13140/RG.2.2.31848.57604>)
- Ahmad A 2017 Abu dhabi speeds cng conversions for vehicles Gulf News (Retrieved from <https://gulfnews.com/news/uae/transport/abu-dhabi-speeds-cng-conversions-for-vehicles-1.2142410>)
- Al-Azmi M 2013 Al-shuaiba refinery is the world's first hydrogen refinery using hydrogen extracted from gas *KPC World* **65** 10–3
- Al Rashdi S 2018 Revealed: Adnoc distribution's plans for next-generation petrol stations Arabian Business (Retrieved from [www.arabianbusiness.com/retail/397002-revealed-adnoc-distributions-plans-for-next-generation-petrol-stations](http://www.arabianbusiness.com/retail/397002-revealed-adnoc-distributions-plans-for-next-generation-petrol-stations))
- Ample 2018 Ample secures \$31 million series a financing round Business Wire (Retrieved from [www.businesswire.com/news/home/20180806005207/en/Ample-Secures-31-Million-Series-Financing/](http://www.businesswire.com/news/home/20180806005207/en/Ample-Secures-31-Million-Series-Financing/))
- Blas J 2018 The aramco accounts: inside the worlds most profitable company Bloomberg News (Retrieved from [www.bloomberg.com/news/articles/2018-04-13/the-aramco-accounts-inside-the-world-s-most-profitable-company](http://www.bloomberg.com/news/articles/2018-04-13/the-aramco-accounts-inside-the-world-s-most-profitable-company))
- Bloomberg 2017 Saudi aramco said to weigh up to \$5 billion of renewable deals Gulf News (Retrieved from <https://gulfnews.com/business/sectors/energy/saudi-aramco-said-to-weigh-up-to-5-billion-of-renewable-deals-1.1969857>)
- BP 2018a Advancing the energy transition (Retrieved from [www.bp.com/energytransition/](http://www.bp.com/energytransition/))
- BP 2018b Bp and china's nio capital to explore opportunities in advanced mobility BP (Retrieved from [www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-and-chinas-nio-capital-to-explore-opportunities-in-advanced-mobility.html](http://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-and-chinas-nio-capital-to-explore-opportunities-in-advanced-mobility.html))
- BP 2018c Bp annual report and form 20-f 2017 BP (Retrieved from [www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-annual-report-and-form-20f-2017.pdf](http://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-annual-report-and-form-20f-2017.pdf))
- BP 2018d Bp invests in mobile electric vehicle charging company freewire to deliver rapid charging at retail sites BP (Retrieved from [www.greencarcongress.com/2018/01/20180130-bp.html](http://www.greencarcongress.com/2018/01/20180130-bp.html))
- BP 2018e Bp invests in ultra-fast charging battery company storedot BP (Retrieved from [www.bp.com/en/global/corporate/news-and-insights/bp-magazine/bp-invests-in-ultra-fast-charging-battery-company-storedot.html](http://www.bp.com/en/global/corporate/news-and-insights/bp-magazine/bp-invests-in-ultra-fast-charging-battery-company-storedot.html))
- BP 2018f Bp to acquire the uk's largest electric vehicle charging company BP (Retrieved from [www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-to-acquire-uks-largest-electric-vehicle-charging-company.html](http://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-to-acquire-uks-largest-electric-vehicle-charging-company.html))
- BP 2018g Lightsources and bp join forces to drive growth in solar power development worldwide BP (Retrieved from [www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-alternative-energy-announcement-december-2017.html](http://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-alternative-energy-announcement-december-2017.html))
- BP 2018h BP 2018h Tesla wind project starts in U.S. BP (Retrieved from [www.bp.com/enus/united-states/home/news/features-and-highlights/tesla-wind-project-starts-in-us.html](http://www.bp.com/enus/united-states/home/news/features-and-highlights/tesla-wind-project-starts-in-us.html))
- BP Ventures 2019 Our portfolio BP (Retrieved from [www.bp.com/en/global/ventures/our-portfolio.html](http://www.bp.com/en/global/ventures/our-portfolio.html))
- Chakrabarti S 2012 Reducing gas flaring provides significant opportunities European Bank for Reconstruction and Development (Retrieved from [www.ebrd.com/news/speeches/reducing-gas-flaring-provides-significant-opportunities.html](http://www.ebrd.com/news/speeches/reducing-gas-flaring-provides-significant-opportunities.html))
- ChargePoint 2016 Chargepoint raises \$50 million to extend market leadership and drive electric vehicles into the mainstream ChargePoint (Retrieved from [www.chargepoint.com/about/news/chargepoint-raises-50-million-extend-market-leadership-and-drive-electric-vehicles/](http://www.chargepoint.com/about/news/chargepoint-raises-50-million-extend-market-leadership-and-drive-electric-vehicles/))
- Chemicals Technology 2008 Fertil-2 project (Retrieved from [www.chemicals-technology.com/projects/fertil-2-project/](http://www.chemicals-technology.com/projects/fertil-2-project/))
- Cherif R, Hasanov F and Pande A 2017 Riding the energy transition: oil beyond 2040 *IMF Working Paper* 17/120
- Chevron 2017 2016 corporate responsibility report highlights (Retrieved from [www.chevron.com/-/media/shared-media/documents/2016-corporate-responsibility-report.pdf](http://www.chevron.com/-/media/shared-media/documents/2016-corporate-responsibility-report.pdf))
- Chevron 2018a Chevron technology ventures Chevron (Retrieved from [www.chevron.com/technology/technology-ventures](http://www.chevron.com/technology/technology-ventures))
- Chevron 2018b Chevron technology ventures launches future energy fund Chevron (Retrieved from [www.chevron.com/stories/chevron-technology-ventures-launches-future-energy-fund](http://www.chevron.com/stories/chevron-technology-ventures-launches-future-energy-fund))
- Chevron 2018c Climate change resilience: a framework for decision making Chevron (Retrieved from [www.chevron.com/-/media/shared-media/documents/climate-change-resilience.pdf](http://www.chevron.com/-/media/shared-media/documents/climate-change-resilience.pdf))
- Chevron 2018d Renewable energy Chevron (Retrieved from [www.chevron.com/corporate-responsibility/climate-change/renewable-energy](http://www.chevron.com/corporate-responsibility/climate-change/renewable-energy))
- Clean Energy Fuels Corporation 2017 Bp and clean energy partner to expand U.S. renewable natural gas transportation fueling capabilities; BP to acquire clean energy's upstream rng business and sign long-term rng supply agreement with clean energy Clean Energy Fuels Corporation (Retrieved from [www.cleanenergyfuels.com/press-room/bp-clean-energy-partner-expand-u-s-renewable-natural-gas-transportation-fueling-capabilities-bp-acquire-clean-energy-s-upstream-rng-business-sign-long-term-rng-supply-agreement/](http://www.cleanenergyfuels.com/press-room/bp-clean-energy-partner-expand-u-s-renewable-natural-gas-transportation-fueling-capabilities-bp-acquire-clean-energy-s-upstream-rng-business-sign-long-term-rng-supply-agreement/))
- CNOOC 2012 Sustainability report China National Offshore Oil Corporation (Retrieved from [www.cnooc.com.cn/data/upload/nb2012en.pdf](http://www.cnooc.com.cn/data/upload/nb2012en.pdf))
- CNOOC 2016 Sustainability report, our quality energy for your blue sea and sky. China National Offshore Oil Corporation (Retrieved from [www.cnooc.com.cn/attach/0/1706190943580169753.pdf](http://www.cnooc.com.cn/attach/0/1706190943580169753.pdf))
- CNOOC 2017a Annual report (Retrieved from [www.cnooc.com.cn/attach/0/1806141618435805115.pdf](http://www.cnooc.com.cn/attach/0/1806141618435805115.pdf))
- CNOOC 2017b Cnooc limited environmental, social and governance report (Retrieved from [www.cnoocld.com/col/col7601/index.html](http://www.cnoocld.com/col/col7601/index.html))
- CNOOC 2017c Sustainability report China National Offshore Oil Corporation (Retrieved from [www.cnooc.com.cn/attach/0/1805101714161002148.pdf](http://www.cnooc.com.cn/attach/0/1805101714161002148.pdf))
- CNOOC 2018 Environmental protection Press release (Retrieved from [www.cnooc.com.cn/col/col6451/index.html](http://www.cnooc.com.cn/col/col6451/index.html))

- CNPC 2017 Annual report China National Petroleum Corporation (Retrieved from [www.cnpc.com.cn/en/2014enbvfg/201504/469c5c60316a49bd8f75f461417eab33/files/e20c8207fff2405396f34075b67f3f8f.pdf](http://www.cnpc.com.cn/en/2014enbvfg/201504/469c5c60316a49bd8f75f461417eab33/files/e20c8207fff2405396f34075b67f3f8f.pdf))
- CNPC 2018a Climate change (Retrieved from [www.cnpc.com.cn/en/climate/common\\_index.shtml](http://www.cnpc.com.cn/en/climate/common_index.shtml))
- CNPC 2018b Controlling carbon emissions China National Petroleum Corporation (Retrieved from [www.cnpc.com.cn/en/fuelingtheLowcarbonconomy/201408/31b9feb6c8a44ae49588e8c350ab6b62.shtml](http://www.cnpc.com.cn/en/fuelingtheLowcarbonconomy/201408/31b9feb6c8a44ae49588e8c350ab6b62.shtml))
- CNPC 2018c Energy saving and emission reduction China National Petroleum Corporation (Retrieved from [www.cnpc.com.cn/en/energy/energy\\_index.shtml](http://www.cnpc.com.cn/en/energy/energy_index.shtml))
- Council N R et al 2004 *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs* (Washington, DC: National Academies Press)
- Crolius S 2018 Japan, Saudi Arabia explore trade in hydrogen, ammonia (Retrieved from [www.ammoniaenergy.org/japan-saudi-arabia-explore-trade-in-hydrogen-ammonia/](http://www.ammoniaenergy.org/japan-saudi-arabia-explore-trade-in-hydrogen-ammonia/))
- Dhahran 2018 Renewable best practice Saudi Aramco (Retrieved from [www.saudiaramco.com/en/news-media/news/2018/sharing-renewable-best-practices-joint-ventures](http://www.saudiaramco.com/en/news-media/news/2018/sharing-renewable-best-practices-joint-ventures))
- Eckert V 2018 German solar battery maker Sonnen secures shell cash to expand Reuters (Retrieved from [www.reuters.com/article/us-sonnen-batteries-funding/german-solar-battery-maker-sonnen-secures-shell-cash-to-expand-idUSKCN11O0DO](http://www.reuters.com/article/us-sonnen-batteries-funding/german-solar-battery-maker-sonnen-secures-shell-cash-to-expand-idUSKCN11O0DO))
- Eni 2018a Development of green investments Eni (Retrieved from [www.eni.com/en\\_IT/sustainability/climate-change-and-new-forms-of-energy/commitment-to-renewable-energy.page](http://www.eni.com/en_IT/sustainability/climate-change-and-new-forms-of-energy/commitment-to-renewable-energy.page))
- Eni 2018b Eni for 2017: Path to decarbonization (Retrieved from [www.eni.com/docs/en\\_IT/enicom/sustainability/EniFor-2017-Decarbonization.pdf](http://www.eni.com/docs/en_IT/enicom/sustainability/EniFor-2017-Decarbonization.pdf))
- Eni 2018c Eni will invest 7 billion in Italy over the next four years, including 1 billion in green activities Eni (Retrieved from [www.eni.com/en\\_IT/media/2018/04/eni-will-invest-7-billion-in-italy-over-the-next-four-years-including-1-billion-in-green-activities](http://www.eni.com/en_IT/media/2018/04/eni-will-invest-7-billion-in-italy-over-the-next-four-years-including-1-billion-in-green-activities))
- Eni 2018d Renewable energy and environmental R&D center Eni (Retrieved from [www.eni.com/en\\_IT/innovation/our-skills/renewable-energy-and-environmental-rd-center.page](http://www.eni.com/en_IT/innovation/our-skills/renewable-energy-and-environmental-rd-center.page))
- Equinor 2016a Convergent energy and power receives strategic investment from Statoil Energy Ventures Convergent Energy and Power (Retrieved from [www.globenewswire.com/news-release/2016/12/05/1254219/0/en/Convergent-Energy-Power-Receives-Strategic-Investment-From-Statoil-Energy-Ventures.html](http://www.globenewswire.com/news-release/2016/12/05/1254219/0/en/Convergent-Energy-Power-Receives-Strategic-Investment-From-Statoil-Energy-Ventures.html))
- Equinor 2016b Statoil launches USD 200 m new energy investment fund Equinor (Retrieved from [www.equinor.com/en/news/launches-usd200m-new-energy-investment-fund.html](http://www.equinor.com/en/news/launches-usd200m-new-energy-investment-fund.html))
- Equinor 2017a 2017 annual report and form 20-f (Retrieved from [www.equinor.com/content/dam/statoil/documents/annual-reports/2017/statoil-annual-report-20f-2017.pdf](http://www.equinor.com/content/dam/statoil/documents/annual-reports/2017/statoil-annual-report-20f-2017.pdf))
- Equinor 2017b Evaluating conversion of natural gas to hydrogen (Retrieved from [www.equinor.com/en/news/evaluating-conversion-natural-gas-hydrogen.html](http://www.equinor.com/en/news/evaluating-conversion-natural-gas-hydrogen.html))
- Equinor 2017c Sustainability report (Retrieved from [www.equinor.com/content/dam/statoil/documents/sustainability-reports/statoil-sustainability-report-2017.pdf](http://www.equinor.com/content/dam/statoil/documents/sustainability-reports/statoil-sustainability-report-2017.pdf))
- Equinor 2018a Equinor acquires minority shareholding in Scatec Solar ASA Equinor (Retrieved from [www.equinor.com/en/news/2018-11-15-solar.html](http://www.equinor.com/en/news/2018-11-15-solar.html))
- Equinor 2018b New energy solutions Equinor (Retrieved from [www.equinor.com/en/what-we-do/new-energy-solutions.html](http://www.equinor.com/en/what-we-do/new-energy-solutions.html))
- ExxonMobil 2016 ExxonMobil and fuel cell energy progressing one-of-a-kind carbon capture fuel cell solution ExxonMobil (Retrieved from <https://energyfactor.exxonmobil.com/news/fuel-cell-site/>)
- ExxonMobil 2017 2016 corporate citizenship report (Retrieved from <https://corporate.exxonmobil.com/en/Community-engagement/sustainability-report>)
- ExxonMobil 2018a 2018 energy and carbon summary ExxonMobil (Retrieved from [https://corporate.exxonmobil.com/-/media/Global/Files/energy-and-carbon-summary/2018-Energy-and-Carbon-Summary\\_archive.pdf](https://corporate.exxonmobil.com/-/media/Global/Files/energy-and-carbon-summary/2018-Energy-and-Carbon-Summary_archive.pdf))
- ExxonMobil 2018b Cogeneration ExxonMobil (Retrieved from <https://corporate.exxonmobil.com/en/technology/energy-efficiency/cogeneration/overview>)
- ExxonMobil 2018c ExxonMobil announces greenhouse gas reduction measures ExxonMobil (Retrieved from <https://news.exxonmobil.com/press-release/exxonmobil-announces-greenhouse-gas-reduction-measures>)
- ExxonMobil 2018d Innovating energy solutions: research and development highlights ExxonMobil (Retrieved from <https://corporate.exxonmobil.com/en/energy/research-and-development/innovating-energy-solutions/research-and-development-highlights>)
- Felix B 2018 Total buys stake in U.S. battery developer Ionic Materials Reuters (Retrieved from [www.reuters.com/article/us-total-batteries/total-buys-stake-in-u-s-battery-developer-ionic-materials-idUSKBN1HP2B4](http://www.reuters.com/article/us-total-batteries/total-buys-stake-in-u-s-battery-developer-ionic-materials-idUSKBN1HP2B4))
- Fletcher L, Crocker T, Smyth J and Marcell K 2018 Beyond the cycle: Which oil and gas companies are ready for the low-carbon transition? *CDP Report*
- Gazprom 2016 Gazprom group's sustainability report 2016 (Retrieved from [www.gazprom.com/f/posts/44/307258/sustainability-report-2016-en.pdf](http://www.gazprom.com/f/posts/44/307258/sustainability-report-2016-en.pdf))
- Gazprom 2017a PJSC Gazprom annual report (Retrieved from [www.gazprom.com/f/posts/60/709300/gazprom-annual-report-2017-eng.pdf](http://www.gazprom.com/f/posts/60/709300/gazprom-annual-report-2017-eng.pdf))
- Gazprom 2017b PJSC Gazprom environmental report 2017 (Retrieved from [www.gazprom.com/f/posts/60/709300/gazprom\\_ee\\_2017\\_2.pdf](http://www.gazprom.com/f/posts/60/709300/gazprom_ee_2017_2.pdf))
- Gazprom 2018a Energy saving press release (Retrieved from [www.gazprom.com/nature/energy-conservation/](http://www.gazprom.com/nature/energy-conservation/))
- Gazprom 2018b Energy saving (Retrieved from [www.gazprom.com/nature/energy-conservation/](http://www.gazprom.com/nature/energy-conservation/))
- Gazprom 2018c Gazprom becomes first Russian energy company to conduct independent audit of greenhouse gas emissions press release (Retrieved from [www.gazprom.com/press/news/2018/june/article435686/](http://www.gazprom.com/press/news/2018/june/article435686/))
- GCxN 2018 Shell and NREL launch cleantech incubator: Shell gamechanger accelerator powered by NREL GlobeNewswire (Retrieved from <https://globenewswire.com/news-release/2018/09/20/1574024/0/en/Shell-and-NREL-Launch-Cleantech-Incubator-Shell-GameChanger-Accelerator-Powered-by-NREL.html>)
- Geman B 2018 Oil and power giants form new carbon capture group Axios (Retrieved from [www.axios.com/carbon-capture-energy-advance-center-bp-chevron-2b63c8b7-caa3-4c34-8f66-54fd8c135b45.html](http://www.axios.com/carbon-capture-energy-advance-center-bp-chevron-2b63c8b7-caa3-4c34-8f66-54fd8c135b45.html))
- Gheorghiu I 2018 Sunpower becomes biggest US solar panel builder with SolarWorld purchase Utility Dive (Retrieved from [www.utilitydive.com/news/sunpower-becomes-biggest-us-solar-panel-builder-with-solarworld-purchase/538815/](http://www.utilitydive.com/news/sunpower-becomes-biggest-us-solar-panel-builder-with-solarworld-purchase/538815/))
- Global Carbon Project 2016 Global methane budget 2016 Global Carbon Project (Retrieved from [www.globalcarbonproject.org/methanebudget/16/files/GCP\\_MethaneBudget\\_2016.pdf](http://www.globalcarbonproject.org/methanebudget/16/files/GCP_MethaneBudget_2016.pdf))



- Global CCS Institute 2010 Feasibility study of ccs-readiness in guangdong (gdccsr): 2010 Annual Report (Retrieved from <http://hub.globalccsinstitute.com/publications/feasibility-study-ccs-readiness-guangdong-gdccsr-2010-annual-report/>)
- Graves L 2016 Oil and gas still the main focus for adnoc press release (Retrieved from [www.thenational.ae/business/oil-and-gas-still-the-main-focus-for-adnoc-1.140288](http://www.thenational.ae/business/oil-and-gas-still-the-main-focus-for-adnoc-1.140288))
- Habboush M 2018 Saudi arabia plans up to \$7 billion of renewable energy projects this year Bloomberg (Retrieved from [www.bloomberg.com/news/articles/2018-01-16/saudi-arabia-plans-up-to-7-billion-of-renewables-this-year](http://www.bloomberg.com/news/articles/2018-01-16/saudi-arabia-plans-up-to-7-billion-of-renewables-this-year))
- Hanley E S, Deane J and Gallachir B 2018 The role of hydrogen in low carbon energy futures a review of existing perspectives *Renew. Sustain. Energy Rev.* **82** 3027–45
- Hashemian M 2017 Replacing gasoline with cng as fuel generates \$37b revenues for iran: official Shana (Retrieved from [www.shana.ir/en/newsagency/279261/Replacing-Gasoline-with-CNG-as-Fuel-Generates-37b-Revenues-for-Iran-Official](http://www.shana.ir/en/newsagency/279261/Replacing-Gasoline-with-CNG-as-Fuel-Generates-37b-Revenues-for-Iran-Official))
- Hauff J, Bode A, Neumann D and Haslauer F 2014 *Global Energy Transitions: a Comparative Analysis of Key Countries and Implications for the International Energy Debate* (Berlin: World Energy Council, Weltnergerierat) ([www.atkearney.com/documents/10192/5293225/Global+Energy+Transitions.pdf/220e6818-3a0a-4baa-af32-8bfb64f4a6b](http://www.atkearney.com/documents/10192/5293225/Global+Energy+Transitions.pdf/220e6818-3a0a-4baa-af32-8bfb64f4a6b))
- Hydrogen Council 2017 Hydrogen scaling up: a sustainable pathway for the global energy transition *Hydrogen Roadmap Europe* (Bietlot: Hydrogen Council)
- Hydrogen Council 2018 Global hydrogen coalition quadruples size in 18 months Hydrogen Council (Retrieved from <http://hydrogencouncil.com/council-quadruples-size/>)
- IPCC 2014 Summary for policymakers *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press) (Retrieved from [www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc\\_wg3\\_ar5\\_summary-for-policymakers.pdf](http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf))
- IRENA 2018 Global energy transformation: a roadmap to 2050 *Int. Renewable Energy Agency, Abu Dhabi*
- ITM Power 2018 World's largest hydrogen electrolysis in shell's rhineland refinery ITM Power (Retrieved from [www.itm-power.com/news-item/worlds-largest-hydrogen-electrolysis-in-shells-rhineland-refinery](http://www.itm-power.com/news-item/worlds-largest-hydrogen-electrolysis-in-shells-rhineland-refinery))
- K-Pulse 2018a Koc launches renewable energy dashboard *K-Pulse* **5** 28–31 (Retrieved from [www.kpc.com.kw/press/KPCPublications/KPulse/KPulse-en-issue-5.pdf](http://www.kpc.com.kw/press/KPCPublications/KPulse/KPulse-en-issue-5.pdf))
- K-Pulse 2018b Koc signs \$213.36 million contract to build 3 giant tankers *K-Pulse* **5** 32–5 (Retrieved from [www.kpc.com.kw/press/KPCPublications/KPulse/KPulse-en-issue-5.pdf](http://www.kpc.com.kw/press/KPCPublications/KPulse/KPulse-en-issue-5.pdf))
- Kenning T 2018 Scatec and equinor complete 162 mw solar project in ceará, brazil' PV Tech (Retrieved from [www.pv-tech.org/news/scatec-and-equinor-complete-162mw-solar-project-in-ceara-brazi](http://www.pv-tech.org/news/scatec-and-equinor-complete-162mw-solar-project-in-ceara-brazi))
- Körner A, Tam C, Bennett S and Gagné J 2015 Technology roadmap-hydrogen and fuel cells *Int. Energy Agency (Paris, France)*
- KPC 2017 Brightness in integration, annual report 2017 Kuwait Petroleum Corporation (Retrieved from [www.kpc.com.kw/press/KPCPublications/AnnualReports/AnnualRep2017-eng.pdf](http://www.kpc.com.kw/press/KPCPublications/AnnualReports/AnnualRep2017-eng.pdf))
- KPC World and Bouresly A M 2016 Knpc draws up detailed plans to meet the needs of local market for petroleum products *KPC World* **77** 15
- Lacey S 2017 Bp jumps back into solar with a \$200 million investment in europes biggest project developer Greentech Media (Retrieved from [www.greentechmedia.com/articles/read/bp-jumps-back-into-solar](http://www.greentechmedia.com/articles/read/bp-jumps-back-into-solar))
- Lambert F 2017 First look at shell's new electric car charging stations being deployed at its gas stations Electrek (Retrieved from <https://electrek.co/2017/09/27/shell-new-electric-car-charging-gas-stations/>)
- Lane J 2014 Saudi aramco invests in siluria: will bio rescue ocm and put the roi back into gtl? Biofuels Digest (Retrieved from [www.biofuelsdigest.com/bdigest/2014/08/20/saudi-aramco-invests-in-siluria-will-bio-rescue-ocm-and-put-the-roi-back-into-gtl/](http://www.biofuelsdigest.com/bdigest/2014/08/20/saudi-aramco-invests-in-siluria-will-bio-rescue-ocm-and-put-the-roi-back-into-gtl/))
- Mahdi W and Mazneva E 2018 Russians, saudis may go beyond oil alliance with lng project Bloomberg (Retrieved from [www.bloomberg.com/news/articles/2018-02-14/russia-saudis-may-go-beyond-their-oil-alliance-with-lng-deal](http://www.bloomberg.com/news/articles/2018-02-14/russia-saudis-may-go-beyond-their-oil-alliance-with-lng-deal))
- Makvandi M 2018 Using solar energy lighting system at the national drilling company National Iranian Oil Company (Retrieved from <http://nioc.ir/portal/Home/ShowPage.aspx?Object=NEWSID=2d001dd3-7240-4909-b58e-a3db8994809c LayoutID=caffb005-7022-4586-b08e-b6dbd9df0e2e CategoryID=40295507-1e70-49ec-af82-e5eeba6870bc>)
- Mandala A 2018 Italy's eni aims for oil industry first with carbon neutral goal Reuters (Retrieved from [www.reuters.com/article/us-eni-carbon/italys-eni-aims-for-oil-industry-first-with-carbon-neutral-goal-idUSKBN1JS14R/](http://www.reuters.com/article/us-eni-carbon/italys-eni-aims-for-oil-industry-first-with-carbon-neutral-goal-idUSKBN1JS14R/))
- McGlade C and Ekins P 2015 The geographical distribution of fossil fuels unused when limiting global warming to 2 c *Nature* **517** 187
- MexicoNow 2018 Mexican biofuel producer builds usd 100 million ethanol plant in veracruz Mexico Now (Retrieved from <https://mexiconow.com/index.php/article/3604-mexican-biofuel-producer-builds-us-100-million-ethanol-plant-in-veracruz>)
- NGV Global 2017 The natural green choice of asia pacific 7th ANGVA Biennial Int. Conf. and Exhibition (Retrieved from [www.ngvglobal.org/events/angva-2017-natural-gas-vehicles-the-natural-green-choice-of-asia-pacific/](http://www.ngvglobal.org/events/angva-2017-natural-gas-vehicles-the-natural-green-choice-of-asia-pacific/))
- NIOC 2017 Iran, frances sofgaz sign gas recovery contract National Iranian Oil Company (Retrieved from <http://en.nioc.ir/Portal/home/?news/81365/71248/214550/Iran-Frances-Sofgaz-sign-gas-recovery-contract->)
- NIOC 2018 Preparing a comprehensive carbon atlas for the first time in the oil industry press release (Retrieved from [www.nioc.ir/portal/Home/ShowPage.aspx?Object=NewsID=a1f1e142-7498-492e-8456-bf0f4fb813d9 LayoutID=20a876d6-9507-46b8-b7e3-22d2b08e5711 CategoryID=40295507-1e70-49ec-af82-e5eeba6870bc](http://www.nioc.ir/portal/Home/ShowPage.aspx?Object=NewsID=a1f1e142-7498-492e-8456-bf0f4fb813d9 LayoutID=20a876d6-9507-46b8-b7e3-22d2b08e5711 CategoryID=40295507-1e70-49ec-af82-e5eeba6870bc))
- Offshore Energy Today 2017 Corvus energy system to power two havila psvs Offshore Energy Today (Retrieved from [www.offshoreenergytoday.com/corvus-energy-system-to-power-two-havila-psvs/](http://www.offshoreenergytoday.com/corvus-energy-system-to-power-two-havila-psvs/))
- OGCI 2018 A catalyst for change Oil and Gas Climate Initiative (Retrieved from <http://oilandgasclimateinitiative.com/policy-and-strategy/>)
- Oil and Gas Climate Initiative 2015 Ogci climate investments announces venture day towards zero methane emissions Oil and Gas Climate Initiative (Retrieved from <https://oilandgasclimateinitiative.com/oil-gas-ceos-jointly-declare-action-climate-change/>)
- Oil and Gas Climate Initiative 2018a Ogci at work Oil and Gas Climate Initiative (Retrieved from [https://oilandgasclimateinitiative.com/wp-content/uploads/2018/09/OGCI\\_Report\\_2018.pdf](https://oilandgasclimateinitiative.com/wp-content/uploads/2018/09/OGCI_Report_2018.pdf))
- Oil and Gas Climate Initiative 2018b Oil and gas climate initiative sets first collective methane target for member companies Oil and Gas Climate Initiative (Retrieved from <https://oilandgasclimateinitiative.com/oil-and-gas-climate-initiative-sets-first-collective-methane-target-for-member-companies/>)
- Oil and Gas Climate Initiative 2018c Oil and gas climate initiative welcomes chevron, exxonmobil and occidental petroleum into its international membership Oil and Gas Climate Initiative (Retrieved from <https://oilandgasclimateinitiative.com/oil-and-gas-climate-initiative-welcomes-chevron-exxonmobil-and-occidental-petroleum-into-its-international-membership/>)
- Parnell J 2018 Exxonmobil signs 250 mw texan solar ppa PV Tech (Retrieved from [www.pv-tech.org/news/exxonmobil-signs-250mw-texan-solar-ppa](http://www.pv-tech.org/news/exxonmobil-signs-250mw-texan-solar-ppa))
- PDO 2016 Sustainability report 2016 Petroleum Development Of Oman (Retrieved from [www.pdo.co.om/en/news/publications/Publications%20Doc%20Library/PDO%20AR%202016%20Annual%20Report.pdf](http://www.pdo.co.om/en/news/publications/Publications%20Doc%20Library/PDO%20AR%202016%20Annual%20Report.pdf))



- PDO 2017 Sustainability report 2017 Petroleum Development Of Oman (Retrieved from [www.pdo.co.om/en/news/publications/Publications%20Doc%20Library/\\_Annual-report-2018-04-BothSN.pdf](http://www.pdo.co.om/en/news/publications/Publications%20Doc%20Library/_Annual-report-2018-04-BothSN.pdf))
- Pemex 2016 Sustainability report 2016 (Retrieved from [www.pemex.com/en/responsibility/sustainable/Documents/20171123\\_IS\\_2016\\_ENG\\_FINAL\\_assurance%20letter.pdf](http://www.pemex.com/en/responsibility/sustainable/Documents/20171123_IS_2016_ENG_FINAL_assurance%20letter.pdf))
- Petrobras 2017a Annual report Petrobras (Brazilian Petroleum Corporation) (Retrieved from [www.investidorpetrobras.com.br/en/annual-reports/integrated-report/annual-report](http://www.investidorpetrobras.com.br/en/annual-reports/integrated-report/annual-report))
- Petrobras 2017b Sustainability report Petrobras (Brazilian Petroleum Corporation) (Retrieved from [www.investidorpetrobras.com.br/en/annual-reports/integrated-report/sustainability](http://www.investidorpetrobras.com.br/en/annual-reports/integrated-report/sustainability))
- Petrobras 2018 Annual report Petrobras (Brazilian Petroleum Corporation) (Retrieved from [www.investidorpetrobras.com.br/en/annual-reports/integrated-report/annual-report](http://www.investidorpetrobras.com.br/en/annual-reports/integrated-report/annual-report))
- Petronas 2017 Annual report 2017 (Retrieved from [www.petronas.com/ws/sites/default/files/2018-08/petronas-annual-report-2017\\_0.pdf](http://www.petronas.com/ws/sites/default/files/2018-08/petronas-annual-report-2017_0.pdf))
- PitPoint 2017 Pitpoint acquires hydrogen refueling station in antwerp PitPoint (Retrieved from [www.pitpoint.nl/en/pitpoint-acquires-hydrogen-refueling-station-antwerp/](http://www.pitpoint.nl/en/pitpoint-acquires-hydrogen-refueling-station-antwerp/))
- Power Technology 2018 Miraah solar thermal project (Retrieved from [www.power-technology.com/projects/miraah-solar-thermal-project/](http://www.power-technology.com/projects/miraah-solar-thermal-project/))
- Raízen 2018 Annual report 2017/2018 (Retrieved from [www.raizen.com.br/relatorioanual/en/](http://www.raizen.com.br/relatorioanual/en/))
- Ramady M 2018 *Saudi Aramco 2030: Post IPO Challenges* (Berlin: Springer)
- Reuters 2012 Cnooc, spanish firm in solar power joint venture-source (Retrieved from [www.reuters.com/article/cnooc-isofoton-solar/cnooc-spanish-firm-in-solar-power-joint-venture-source-idUSL4E8D24RZ20120202](http://www.reuters.com/article/cnooc-isofoton-solar/cnooc-spanish-firm-in-solar-power-joint-venture-source-idUSL4E8D24RZ20120202))
- Roselund C 2018 Gip launches renewable energy developer, acquires 4.7 gw of sunpower assets PV Magazine (Retrieved from [www.pv-magazine.com/2018/09/04/gip-launches-renewable-energy-developer-acquires-4-7-gw-of-sunpower-assets/](http://www.pv-magazine.com/2018/09/04/gip-launches-renewable-energy-developer-acquires-4-7-gw-of-sunpower-assets/))
- Rosneft 2017a Rosneft annual report 2017 (Retrieved from [www.rosneft.com/upload/site2/document\\_file/a\\_report\\_2017\\_eng.pdf](http://www.rosneft.com/upload/site2/document_file/a_report_2017_eng.pdf))
- Rosneft 2017b Rosneft sustainability report 2017 (Retrieved from [www.rosneft.com/upload/site2/document\\_file/RN\\_SR2018\\_eng\\_web\\_1.pdf](http://www.rosneft.com/upload/site2/document_file/RN_SR2018_eng_web_1.pdf))
- Royal Dutch Shell 2017a Management day (Retrieved from [www.shell.com/media/news-and-media-releases/2017/management-day-2017-shell-updates-company-strategy.html](http://www.shell.com/media/news-and-media-releases/2017/management-day-2017-shell-updates-company-strategy.html))
- Royal Dutch Shell 2017b Shell onshore operating principles in action in north america: methane fact sheet (Retrieved from [www.shell.us/energy-and-innovation/shale-gas-and-oil/methane-fact-sheet.html](http://www.shell.us/energy-and-innovation/shale-gas-and-oil/methane-fact-sheet.html))
- Royal Dutch Shell 2017c Shell signs agreement with sbi bio energy inc Royal Dutch Shell (Retrieved from [https://docs.wixstatic.com/ugd/00eea8\\_1084c68adad74eea84f413d96e99093d.pdf](https://docs.wixstatic.com/ugd/00eea8_1084c68adad74eea84f413d96e99093d.pdf))
- Royal Dutch Shell 2018a New energies Royal Dutch Shell (Retrieved from [www.shell.com/energy-and-innovation/new-energies.html](http://www.shell.com/energy-and-innovation/new-energies.html))
- Royal Dutch Shell 2018b Quest carbon capture and storage Royal Dutch Shell (Retrieved from [www.shell.ca/en\\_ca/about-us/projects-and-sites/quest-carbon-capture-and-storage-project.html](http://www.shell.ca/en_ca/about-us/projects-and-sites/quest-carbon-capture-and-storage-project.html))
- Royal Dutch Shell 2018c Shell announces methane emissions intensity target for oil and gas assets Royal Dutch Shell (Retrieved from [www.shell.com/media/news-and-media-releases/2018/shell-announces-methane-emissions-intensity-target.html](http://www.shell.com/media/news-and-media-releases/2018/shell-announces-methane-emissions-intensity-target.html))
- Royal Dutch Shell 2018d Shell energy transition report (Retrieved from [www.shell.com/energy-and-innovation/the-energy-future/shell-energy-transition-report.html](http://www.shell.com/energy-and-innovation/the-energy-future/shell-energy-transition-report.html))
- Royal Dutch Shell 2018e Shell windenergy Royal Dutch Shell (Retrieved from [www.shell.us/energy-and-innovation/shell-windenergy.html](http://www.shell.us/energy-and-innovation/shell-windenergy.html))
- Royal Dutch Shell 2018f Sustainability report 2017 (Retrieved from <https://reports.shell.com/sustainability-report/2017/>)
- Saadi D 2018 Adnoc to boost carbon capture in oilfields by six-fold over the next 10 years The National Business (Retrieved from [www.thenational.ae/business/energy/adnoc-to-boost-carbon-capture-in-oilfields-by-six-fold-over-the-next-10-years-1.696251](http://www.thenational.ae/business/energy/adnoc-to-boost-carbon-capture-in-oilfields-by-six-fold-over-the-next-10-years-1.696251))
- Saini D 2017 *Enhancing Aspects of Geologic CO2 Storage: Synergy between Enhanced Oil Recovery and Storage* (Berlin: Springer)
- Sapp M 2013 Gazprom subsidiary to invest \$100 million in biodiesel for eu export Biofuel Digest (Retrieved from [www.biofuelsdigest.com/bdigest/2013/08/28/gazprom-subsiary-to-invest-100-million-in-biodiesel-for-eu-export/](http://www.biofuelsdigest.com/bdigest/2013/08/28/gazprom-subsiary-to-invest-100-million-in-biodiesel-for-eu-export/))
- Saudi Aramco 2017 Unmatched opportunity, saudi aramco annual review 2017 (Retrieved from [www.saudiaramco.com/en/who-we-are/overview/annualreview](http://www.saudiaramco.com/en/who-we-are/overview/annualreview))
- Saudi Aramco 2018 Sustainable business operations (Retrieved from [www.saudiaramco.com/en/home/our-business/sustainable-production.html](http://www.saudiaramco.com/en/home/our-business/sustainable-production.html))
- Scatec Solar 2018 Scatec solar secures a 117 mw solar project in argentina together with equinor Scatec Solar (Retrieved from [www.scatecsolar.com/Investor/Stock-exchange-notice/Scatec-Solar-secures-a-117-MW-solar-project-in-Arentina-together-with-Equinor](http://www.scatecsolar.com/Investor/Stock-exchange-notice/Scatec-Solar-secures-a-117-MW-solar-project-in-Arentina-together-with-Equinor))
- Stoker L 2018 Shell targets southeast asia c&i solar markets with cleantech solar deal PV Tech (Retrieved from [www.pv-tech.org/news/shell-targets-southeast-asia-ci-solar-markets-with-cleantech-solar-deal](http://www.pv-tech.org/news/shell-targets-southeast-asia-ci-solar-markets-with-cleantech-solar-deal))
- Stothard M 2016 Total aims to be 20% low-carbon by 2035 Financial times (Retrieved from [www.ft.com/content/04985ba4-21c8-11e6-aa98-db1e01fab0c0](http://www.ft.com/content/04985ba4-21c8-11e6-aa98-db1e01fab0c0))
- The Motorship 2015 Corvus battery technology receives statoil investment The Motorship (Retrieved from [www.motorship.com/news101/ships-equipment/corvus-battery-technology-receives-statoil-investment](http://www.motorship.com/news101/ships-equipment/corvus-battery-technology-receives-statoil-investment))
- Total 2016 Total presents proposed new organization to achieve its ambition to become the responsible energy major Total (Retrieved from [www.total.com/en/media/news/press-releases/total-presents-proposed-new-organization-achieve-its-ambition-become-responsible-energy-major](http://www.total.com/en/media/news/press-releases/total-presents-proposed-new-organization-achieve-its-ambition-become-responsible-energy-major))
- Total 2017a Integrating climate into our strategy (Retrieved from [www.total.com/sites/default/files/atoms/files/integrating\\_climate\\_into\\_our\\_strategy\\_eng.pdf](http://www.total.com/sites/default/files/atoms/files/integrating_climate_into_our_strategy_eng.pdf))
- Total 2017b Total expands its energy efficiency business with the acquisition of greenflex Total (Retrieved from [www.total.com/en/media/news/press-releases/total-expands-its-energy-efficiency-business-with-the-acquisition-of-greenflex](http://www.total.com/en/media/news/press-releases/total-expands-its-energy-efficiency-business-with-the-acquisition-of-greenflex))
- Total 2017c Total partners with eren renewable energy to expand its renewable business Total (Retrieved from [www.total.com/en/media/news/press-releases/total-partners-eren-renewable-energy-expand-its-renewable-business](http://www.total.com/en/media/news/press-releases/total-partners-eren-renewable-energy-expand-its-renewable-business))
- Total 2018a 2017 registration document including the annual financial report Total (Retrieved from [www.total.com/sites/default/files/atoms/files/2017-en-accessible.pdf](http://www.total.com/sites/default/files/atoms/files/2017-en-accessible.pdf))
- Total 2018b Electric vehicle charging solutions: total acquires g2mobility and forms partnership with nexans Business Wire (Retrieved from [www.businesswire.com/news/home/20180920005258/en/Total-S.A.-UK-Regulatory-Announcement-Electric-Vehicle](http://www.businesswire.com/news/home/20180920005258/en/Total-S.A.-UK-Regulatory-Announcement-Electric-Vehicle))
- Total 2018c Integrating climate into our strategy Total (Retrieved from [www.total.com/sites/default/files/atoms/files/total\\_climat\\_2018\\_en.pdf](http://www.total.com/sites/default/files/atoms/files/total_climat_2018_en.pdf))

- Total 2018d Solar: the focus of our renewable energy ambition Total (Retrieved from [www.total.com/en/energy-expertise/exploration-production/solar-power/solar-the-focus-of-our-renewable-energy-ambition](http://www.total.com/en/energy-expertise/exploration-production/solar-power/solar-the-focus-of-our-renewable-energy-ambition))
- Total 2018e Total energy ventures: innovating with start-ups Total (Retrieved from [www.total.com.au/en/making-energy-better/worldwide-projects/total-energy-ventures-innovating-start-ups](http://www.total.com.au/en/making-energy-better/worldwide-projects/total-energy-ventures-innovating-start-ups))
- Total 2018f Total enters into an agreement for the proposed acquisition of direct energie to accelerate its ambition in gas and electricity in france and belgium Total (Retrieved from [www.total.com/en/media/news/press-releases/total-enters-agreement-proposed-acquisition-direct-energie-accelerate-its-ambition-gas-and](http://www.total.com/en/media/news/press-releases/total-enters-agreement-proposed-acquisition-direct-energie-accelerate-its-ambition-gas-and))
- Total 2019 Biotfuel: developing second-generation biofuels (Retrieved from [www.total.com/en/energy-expertise/projects/bioenergies/biotfuel-converting-plant-wastes-into-fuel](http://www.total.com/en/energy-expertise/projects/bioenergies/biotfuel-converting-plant-wastes-into-fuel).)
- U.S. Department of Energy 2017 Fuel cell technologies market report 2016 U.S. Department of Energy (Retrieved from [www.energy.gov/sites/prod/files/2017/10/f37/fcto\\_2016\\_market\\_report.pdf](http://www.energy.gov/sites/prod/files/2017/10/f37/fcto_2016_market_report.pdf))
- U.S. Environmental Protection Agency 2017 Understanding global warming potentials U.S. Environmental Protection Agency (Retrieved from [www.epa.gov/ghgemissions/understanding-global-warming-potentials](http://www.epa.gov/ghgemissions/understanding-global-warming-potentials))
- Valle S 2018 Big oil aims to exploit brazil's sun and wind along with crude Bloomberg (Retrieved from [www.bloomberg.com/news/articles/2018-09-10/big-oil-aims-to-exploit-brazil-s-sun-and-wind-along-with-crude](http://www.bloomberg.com/news/articles/2018-09-10/big-oil-aims-to-exploit-brazil-s-sun-and-wind-along-with-crude))
- Victor D G, Hults D R and Thurber M C 2012 *Oil and Governance: State-Owned Enterprises and the World Energy Supply* (Cambridge: Cambridge University Press)
- Wesoff E 2014 Glasspoint wins \$53 m from oman, shell, vcs for solar enhanced oil recovery Greentech Media (Retrieved from [www.greentechmedia.com/articles/read/glasspoint-wins-53m-from-oman-shell-vcs-for-solar-enhanced-oil-recovery](http://www.greentechmedia.com/articles/read/glasspoint-wins-53m-from-oman-shell-vcs-for-solar-enhanced-oil-recovery))
- Weston D 2018 Borssele iii and iv reaches financial close Windpower Offshore (Retrieved from [www.windpoweroffshore.com/article/1486358/borssele-iii-iv-reaches-financial-close](http://www.windpoweroffshore.com/article/1486358/borssele-iii-iv-reaches-financial-close))
- Willuhn M 2018 Momentum builds for perovskite tandems, 25%+ efficiency achieved PV Magazine (Retrieved from [www.pv-magazine.com/2018/06/15/momentum-builds-for-perovskite-tandems-25-efficiency-achieved/](http://www.pv-magazine.com/2018/06/15/momentum-builds-for-perovskite-tandems-25-efficiency-achieved/))
- Wind Power 2018 Wind energy market actors Wind Energy Market Intelligence (Data retrieved from [www.thewindpower.net/players\\_en.php](http://www.thewindpower.net/players_en.php))
- Zhong M and Bazilian M D 2018 Contours of the energy transition: investment by international oil and gas companies in renewable energy *Electr. J.* **31** 82–91