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Trends in fossil fuel extraction

Implications for a shared effort to align global fossil fuel production with climate limits

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Contents

Key Messages

- Based on current economic trends and without new policy interventions, the projected "baseline" trajectories of global fossil fuel production are vastly divergent from those that would be consistent with limiting warming to 1.5°C and well below 2°C. This discrepancy necessitates the alignment of future production with pathways consistent with the Paris Agreement's temperature goals, and calls into question how countries might cooperate to manage such a decline.

- Today's largest producers are expected to continue dominating the global share of production. Between 2019 and 2030, the largest increases in annual oil production by volume are projected to occur in the United States, followed by Brazil and Iran. The largest increases in annual gas production are projected to occur in the United States, followed by Canada and Saudi Arabia. Annual coal production is projected to increase in only one country: India.

- Over the next two decades, the trajectories of baseline oil and gas production in countries with the highest income level would exceed global pathways consistent with limiting warming to 1.5°C. The same is true for countries with the lowest level of fossil fuel revenue dependence. If not actively and internationally managed, a global wind-down of production in line with international climate goals could therefore be highly inequitable among countries.

Introduction

For decades, countries have been negotiating under the United Nations Framework Convention on Climate Change (UNFCCC) on how to address climate change. These negotiations have produced multiple agreements, including the 2015 Paris Agreement, in which countries agreed to hold global warming below 1.5°C or "well below" 2°C above pre-industrial levels.

Under the Paris Agreement, countries are asked to outline their post-2020 climate actions, known as nationally determined contributions (NDCs), that should also uphold "the principle of equity and common but differentiated responsibilities and respective capabilities, in light of different national circumstances". A recent UNFCCC analysis found that existing NDCs submitted as of 2020 would lead to global emissions being just 0.5% lower in 2030 than in 2010, compared to the 45% reduction needed to keep warming below 1.5°C (Gabbatiss, 2021).

Consequently, actual near- and long-term policies to fulfil the ambitions of the Paris Agreement are urgently needed. Although there was a brief dip in carbon dioxide emissions caused by the COVID-19 pandemic in 2020, global greenhouse gas (GHG) emissions grew in 2019 for the third consecutive year, even as they will need to drop sharply – to zero by mid-century – to meet the Paris Agreement's goals (UNEP, 2020).

At present, most of these emissions – over 75% – are from fossil fuels (SEI et al., 2019). By necessity, reaching net zero emissions therefore requires dramatic reductions in fossil fuel demand and supply. Between now and 2030, for example, annual average decline rates of around 11%, 4% and 3% in global coal, oil and gas production, respectively, would be consistent with limiting warming to below 1.5°C, according to an analysis in the Production Gap Report that is based on mitigation scenarios compiled by the Intergovernmental Panel on Climate Change (SEI et al., 2020). These rates would need to be even faster if carbon dioxide removal methods are not ultimately developed at scale.

Despite this clear implication for a necessary wind-down of fossil fuels in order to meet climate goals, nations have not begun discussing, in earnest, who will produce those dwindling quantities of fossil fuels.

There are many reasons why fossil fuels have not explicitly been addressed by the UNFCCC (Piggot et al., 2018). Nevertheless, the conversation is starting to open up about possible "supply-side" agreements on fossil fuels and climate change, either as part of the UNFCCC or beyond (Asheim et al., 2019; Piggot et al., 2020). For example, a number of countries, including Denmark, France, and New Zealand, have started taking measures to phase out their oil and gas production (Ambrose, 2020). In the United States, President Joe Biden has put a pause on new oil and gas leasing on federal lands and waters, while Vice President Kamala Harris has previously proposed a "first-ever global negotiation of the cooperative managed decline of fossil fuel production" (Barnes, 2020).

The prospect of some type of supply-side agreement raises a number of important questions, including how countries would self-organize, what principles they might use to share the task of winding down coal, oil, and gas production, and whether they would explicitly seek to do so in a way consistent with the ambitions of the Paris Agreement (Piggot et al., 2018; van Asselt, 2014).

The goal of this paper is to contribute to this emerging discussion on why countries might work together to limit fossil fuel extraction. We are motivated both by the importance of managing fossil fuel supply in effective global climate policy (Piggot et al., 2020), and also by the equity implications of a rapid transition away from the commodities – coal, oil, and gas – that some communities (and some countries) depend on for their livelihoods. Indeed, in considering fossil fuel supply as an equity issue, we are building on a rapidly growing literature on equity considerations in the transition away from fossil fuel extraction (Armstrong, 2020; Caney, 2016;

Kartha et al., 2016; Le Billon & Kristoffersen, 2019; Lenferna, 2017; Muttitt & Kartha, 2020; Pye et al., 2020; SEI et al., 2020)

Accordingly, we present a simple analysis on where fossil fuel extraction has happened historically, and where it will continue to occur and expand if current economic trends continue without new policy interventions. By employing some simple scenario analysis, we also demonstrate how the phase-out of fossil fuel production is likely to be inequitable among countries, if not actively and internationally managed. If and how that inequity will be addressed is a question we leave, at least for now, to policymakers, community advocates, and other researchers.

Besides these audiences, our results may also be of interest to non-state actors, including civil society organizations, shareholders, and philanthropists, who are seeking to help move society away from economies based on fossil fuel extraction.

Who are the largest producer countries today and in the near future?

Ample data exist to quantify the levels of coal, oil, and gas that different countries have produced historically (BP, 2020; IEA, 2020a). However, there is less understanding of how much countries will extract in the future.

Here, we compile a picture of expected levels of coal, oil, and gas production given currently foreseen economic trends and absent of new, major policy interventions. These "baseline" levels can then be used to make several observations about who is expanding, who is contracting, and what might instead need to happen to align global fossil fuel production with the Paris Agreement's temperature limits.

For future outlooks of oil and gas production, we rely on the central "base case" scenario from Rystad Energy's widely used UCube database (as of September 2020), which is also used in annual assessments by the International Energy Agency (such as in the IEA's 2020 World Energy Investment and Oil Market Report Series). In this analysis, "oil" includes crude oil, condensate, and natural gas liquids.

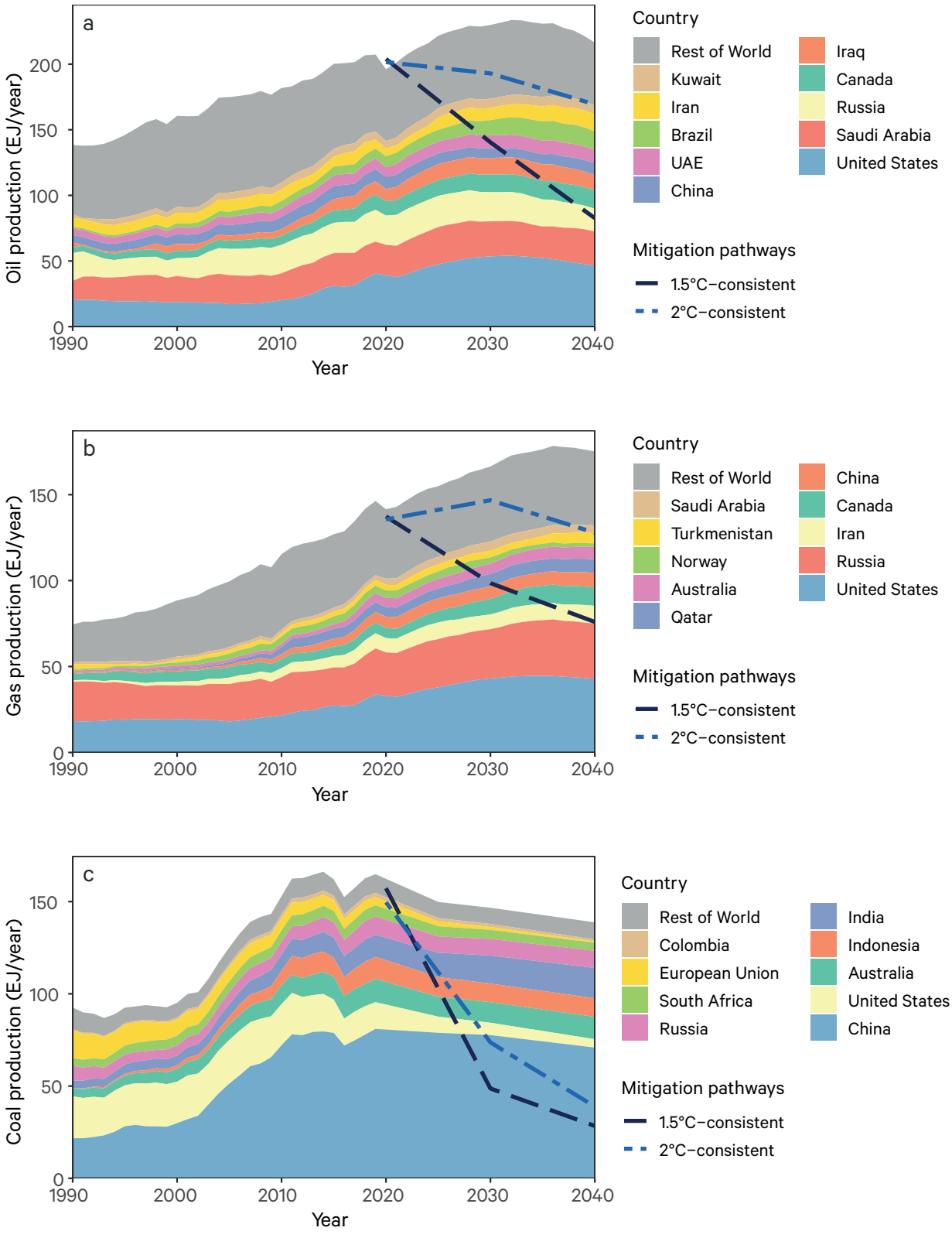
For coal, which is not analysed by Rystad Energy, we rely on the IEA's Stated Policies Scenario (STEPS). This scenario reflects "the impact of existing policy frameworks and today's announced policy intentions", including countries' submitted nationally determined contributions under the Paris Agreement (IEA, 2020b).

Although the Rystad "base case" and IEA STEPS scenarios may not have identical underlying assumptions, they project comparable levels of global oil and gas production (Rystad's estimates of 2030 production are 7% higher for oil and 1% higher for gas). We therefore consider the two data sources to be compatible, at least for our broad purposes here. Hereafter, we refer to both of these scenarios as "baseline".

Figure 1 shows the global projected 2020-2040 baseline levels of oil, gas, and coal production, including a breakdown of national production levels by select major countries to show how each of them contribute to the overall global levels. Given that historical responsibility is one criterion that has been proposed with regards to equitably sharing the remaining carbon budget, we also show historical production back to 1990 in Figure 1.

Also displayed in the figure are the global pathways of oil, gas, and coal production that would be consistent with achieving the Paris Agreement's temperature goals. These pathways are derived from the cost-optimized mitigation scenarios compiled by the IPCC's Special Report

Figure 1. The stacked area charts show 1990-2040 global oil, gas, and coal production (exajoule/year), with country-level contributions shown for the top ten countries based on 2019 production for oil and gas, and for eight major countries plus the European Union for coal. (The countries are plotted in order of decreasing level of 2019 production, starting from the bottom; the colour legends are plotted in the same order). The dashed lines show production pathways consistent with limiting warming to 1.5°C (dark blue) and 2°C (lighter blue) for each fuel. Oil and gas data are from Rystad; coal data are from the IEA (see text for details).



on 1.5°C (IPCC, 2018; Rogelj et al., 2018). They show the median quantities of global oil, gas, and coal that can be produced under a range of modelled future emissions trajectories that limit warming to 1.5°C or 2°C. We follow the approach as outlined in the Appendix of the 2019 Production Gap Report (SEI et al., 2019). Briefly, the "2°C-consistent" pathway was calculated as the median of scenarios that have at least a 66% probability of limiting warming to below 2°C, while the "1.5°C-consistent" pathway was calculated as the median of scenarios with at least a 50% likelihood of limiting warming to below 1.5°C. Both pathways were further constrained to have limited reliance on carbon dioxide removal deployment, given the "multiple feasibility and sustainability constraints" associated with these measures, as noted by the IPCC (IPCC, 2018, p. 19).

A global wind-down of fossil fuel production consistent with staying below 1.5°C or 2°C could also be achieved by a different mix of decline rates for oil, gas, and coal. The median pathways shown in Figure 1 are primarily driven by cost-optimization considerations and depend on many underlying socioeconomic assumptions, such as the levels of carbon capture and storage than can be coupled with fossil fuel or biomass burning, and the expansion of electric or other alternative-fuel vehicles. Furthermore, as Pye et al. (2020) noted, this approach does not take into account the political economy and equity issues of fossil fuel production and use.

Two things are apparent from Figure 1. First, the projected baseline trajectories of oil, gas, and coal production are all higher than each fuel's mitigation pathways for limiting warming to below 1.5°C or 2°C. As quantified here and in the Production Gap Report, under the assumptions of the IPCC mitigation scenarios, the median "1.5°C-consistent" pathway implies an average annual decline rate of around 4% for oil, 3% for gas, and 11% for coal supply between now and 2030. However, baseline oil and gas production levels are projected to each increase by around 2% per year. Although global coal production is projected to slightly decrease, the projected annual decline rate of 1% is far lower than the 11% implied by the 1.5°C-consistent scenario. This means that by 2030, the projected level of global coal production would still be triple the amount consistent with the 1.5°C pathway.

Second, the projected trajectories of production from a handful of major countries would already exceed the pathways consistent with limiting warming to below 1.5°C for each fuel. Between now and 2030, the bulk of production is expected to occur in the following five countries (in decreasing order) for each fuel: Oil – the United States, Saudi Arabia, Russia, Canada, Iraq; Gas – the United States, Russia, Iran, China, and Canada; and Coal – China, India, Australia, Indonesia, and the United States. Thus, today's largest producers are expected to continue dominating the global share of production.

If and as countries begin to discuss how to bring fossil fuel production in line with climate limits, it would also be important to consider who owns and controls production (Heller, 2020). For example, national governments might have a more direct ability to manage production by state-owned companies, but such countries may also rely more heavily on fossil fuel revenues (Bradley et al., 2018; Krane, 2018; Mahdavi, 2014). As noted in the latest Production Gap Report, state-owned enterprises control around 55% of current oil and gas production and well over half of coal production (SEI et al., 2020). Under the baseline scenario explored here, besides ExxonMobil and Shell, the largest companies in terms of total projected 2020-2030 oil and gas production constitute fully or partially state-owned companies in the Middle East, China, and Russia (i.e., Saudi Aramco, the National Iranian Oil Company, Kuwait Petroleum Corporation, PetroChina, and the partially Russia-owned Rosneft and Gazprom).

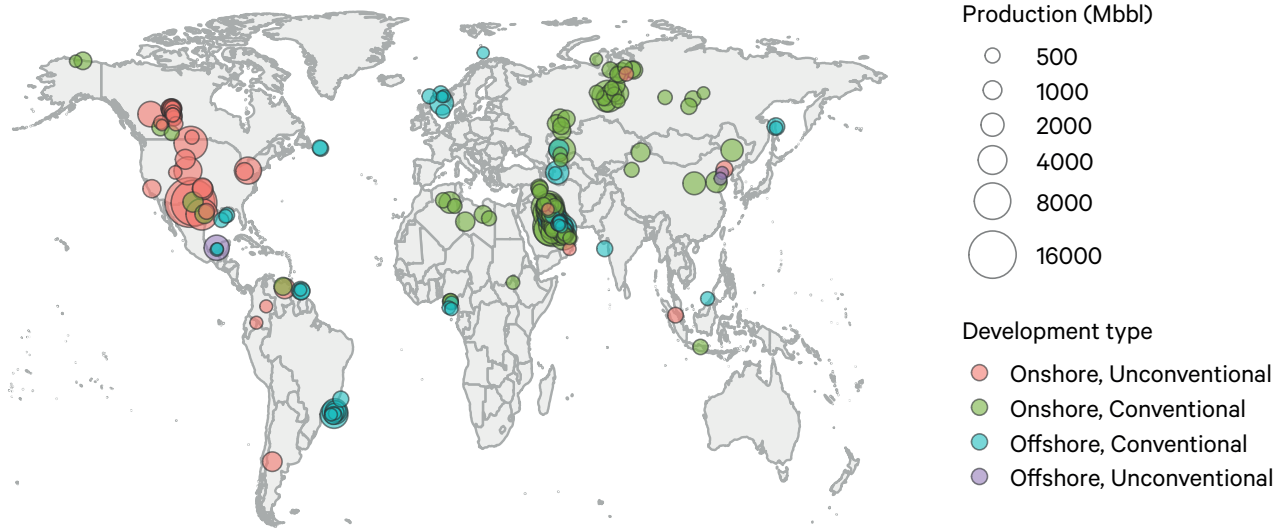
In addition, within each country, fossil fuel production is often concentrated in a few sub-national regions, which can also face different transition challenges. Figure 2 shows the global distribution of the top 200 projects in terms of projected cumulative oil and gas production from 2020 to 2030, along with the type of development. These top 200 oil projects account for 62% of the expected global total, with 15% coming from projects in the United States, 11% in Saudi Arabia,

6% in Russia, and 4% each in Iraq, Canada, and the United Arab Emirates. The largest production hotspots are located in the Permian, Bakken, and Eagle Ford shale basins in the United States; in major conventional oil fields of the Central Arabian basin; and in the Priobskoye conventional oil field in Western Siberia.

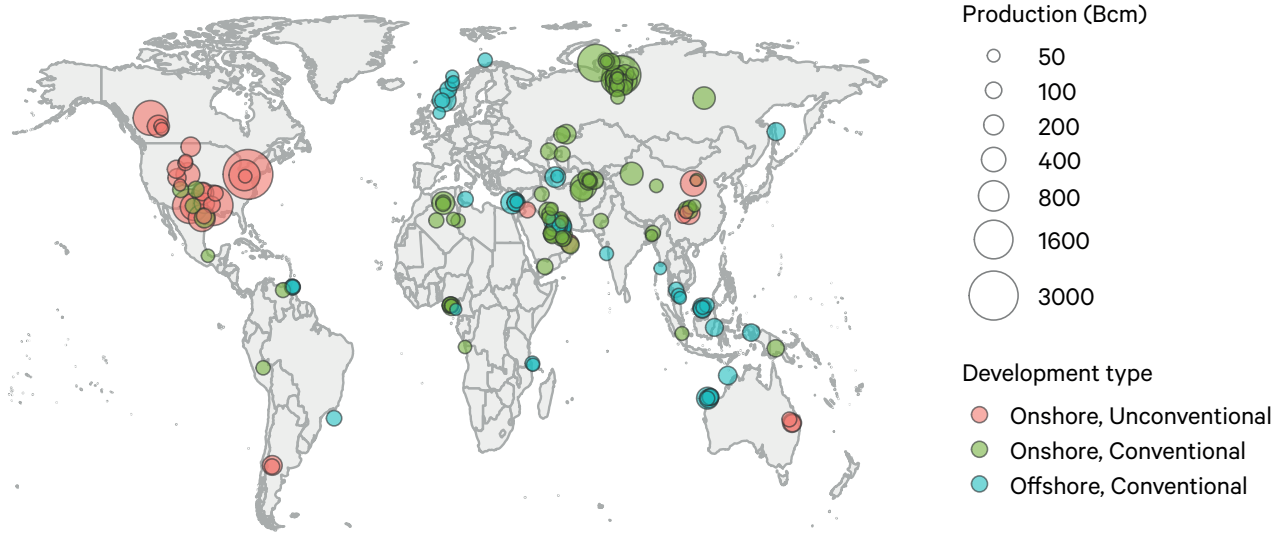
The top 200 gas projects account for 76% of the projected 2020-2030 global total, with 22% coming from projects in the United States, 15% in Russia, and 3-5% each in Iran, Qatar, China, and Canada. The largest hotspots are located in the Marcellus, Haynesville, and Permian shale basins in the United States; in the Yamburg gas field and Yamal Peninsula in Western Siberia; and in the Montney shale play in Canada.

Figure 2. Global distribution of the top 200 oil and gas projects in terms of total cumulative 2020-2030 production (Mbbl = million barrels; Bcm = billion cubic meters). Symbol colours denote the dominant type of development (by production volume) of each project.

a) Top 200 oil projects by cumulative 2020–2030 production



b) Top 200 gas projects by cumulative 2020–2030 production



Where are the largest production increases?

The previous section looked at the largest producers in terms of total projected volume. In this section, we first explore how production may be expanding or contracting in these major producer countries, as well as where the largest increases in production are projected to occur over the next decade. While it may be insightful to focus specifically on production from new, undeveloped fields only[1], we choose to consider changes in production from both existing and new fields in this report. This is because the majority of cumulative oil and gas production between now and 2030 are expected to come from already developed fields in major producer countries, with the exception of the United States, Canada, and Brazil, where production from new fields are expected to also contribute substantially (see Figure S1 in the Appendix).

To that end, Figure 3 shows the projected changes in annual oil, gas, and coal production in 2030, compared to 2019, for the 15 largest producer countries in 2019. Their positions along the x-axis scale with the size of their absolute change, while their positions along the y-axis scale with the size of their relative change.

Figure 3a shows that the United States could see the largest absolute increase in oil production by far (+2,300 million barrels per year, or Mbbl/y). With the exception of Russia and China, today's other top producer countries (Saudi Arabia, Canada, Iraq, the United Arab Emirates, Brazil, Iran, and Kuwait) are also expected to see increased production, ranging between +140 and +690 Mbbl/y. Although 2030 production levels are expected to slightly decrease in Russia and China compared to 2019 levels (by 10-20%), these countries will nonetheless remain in the top ten largest producers in 2030.

For gas (Figure 3b), the United States could also see the largest absolute increase (+260 billion cubic meters per year, or bcm/y), followed by a mix of existing major producers (Canada, Saudi Arabia, Russia, Qatar, and China) with projected increases of around 40-80 bcm/y. Although 2030 production levels are expected to slightly decrease in Norway and Iran compared to 2019 levels, these countries will nonetheless remain in the top ten largest producers in 2030.

In fact, for both oil and gas, the list of top 15 producers in 2030 is expected to remain unchanged compared to 2019.

For coal (Figure 3c), production is expected to decline in all major producing countries and regions except for India, which could see an increase of 27% (+110 million tonnes of coal equivalent per year). Despite this, we reiterate that the projected global decline rate of coal production is still far from commensurate with that needed to stay on track to limiting warming to below 1.5°C (Figure 1).

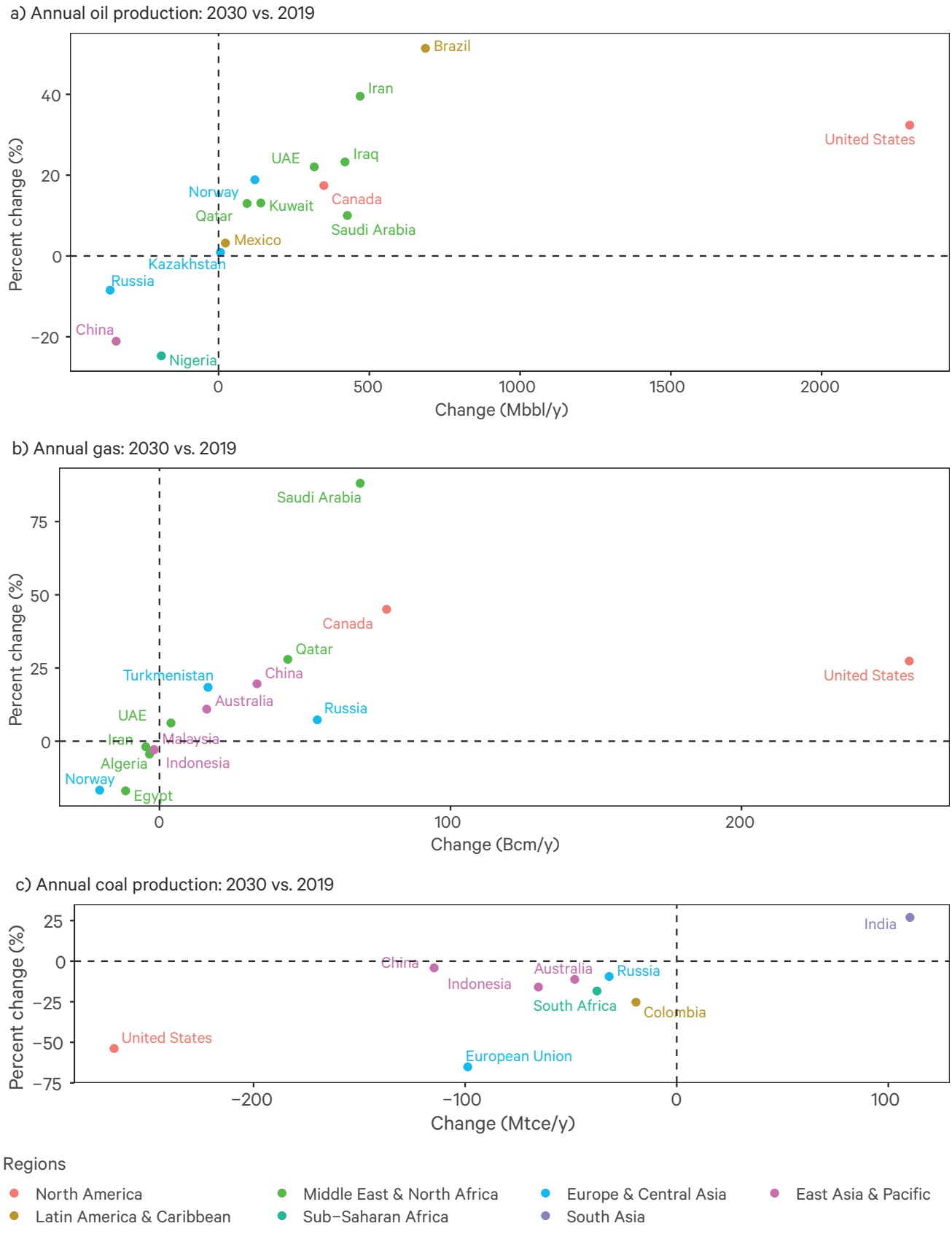
Since oil and gas production are still widely expanding (and there is limited country-level data available for coal from the IEA STEPS scenario), we focus on oil and gas for the rest of this report.

We next explore which countries see the largest projected expansions in oil and gas production, and where these expansions could be coming from. Figure 4 shows 15 countries with the largest projected increases in annual production by volume, when comparing 2030 with 2019; the changes are disaggregated by onshore/offshore and conventional/unconventional development types.

Today's top producers account for the majority of these largest increases, but Figure 4 shows that there are also a few emerging producer countries with rapid projected expansions. Guyana has the 6th largest projected increase in oil production (+410 Mbbl/y) – exclusively from offshore developments, which could make it the 19th largest producer by 2030. For gas, Mozambique, Iraq, and Israel are among the top 10 countries with the largest projected increases.

1 This is because it may be easier to avoid new production than to wind down existing regions that are already dependent on fossil fuel revenues (Muttitt et al., 2016). For example, recent policy commitments by countries including Denmark, France, and New Zealand, have focused specifically on stopping new oil and gas exploration and development (Ambrose, 2020).

Figure 3. Projected changes in annual oil, gas, and coal production in 2030 compared to 2019 for select countries. In each subplot, the x-axis shows absolute changes in units of million barrels (Mbbl) of oil, billion cubic meters (Bcm) of gas, and million tonnes of coal equivalent (Mtce), per year. The y-axis shows percent changes. For oil and gas, countries shown are the top 15 producers in 2019. For coal, all projections available from the IEA World Energy Outlook at the individual country level (plus the European Union) are shown. Symbol colours denote different regions (see legend).



As can be seen in Figure 4, the types of development driving oil and gas expansion vary from country to country. In the United States and Canada, increases in annual oil and gas production are primarily driven by onshore unconventional development. Conversely, increases in oil production in offshore conventional fields underlie much of the expansion projected in Brazil, Guyana, Saudi Arabia and the United Arab Emirates, while those in onshore conventional fields underlie much of the expansion projected in Iran and Iraq. For gas, increases in annual production in Saudi Arabia, Qatar, and Mozambique are mainly driven by offshore conventional development.

On a global level, onshore unconventional development drives 71% of the projected increase in annual oil production, and 67% of the projected increase for gas, with offshore conventional development primarily accounting for the rest.

Implications for aligning fossil fuel production with climate limits

Under the baseline scenarios analysed here, the trajectories of future global fossil fuel production are vastly divergent from those that would be consistent with limiting warming to 1.5°C and well below 2°C. This discrepancy necessitates the alignment of future production with pathways consistent with the Paris Agreement's temperature goals, and calls into question how countries might cooperate to manage such a decline.

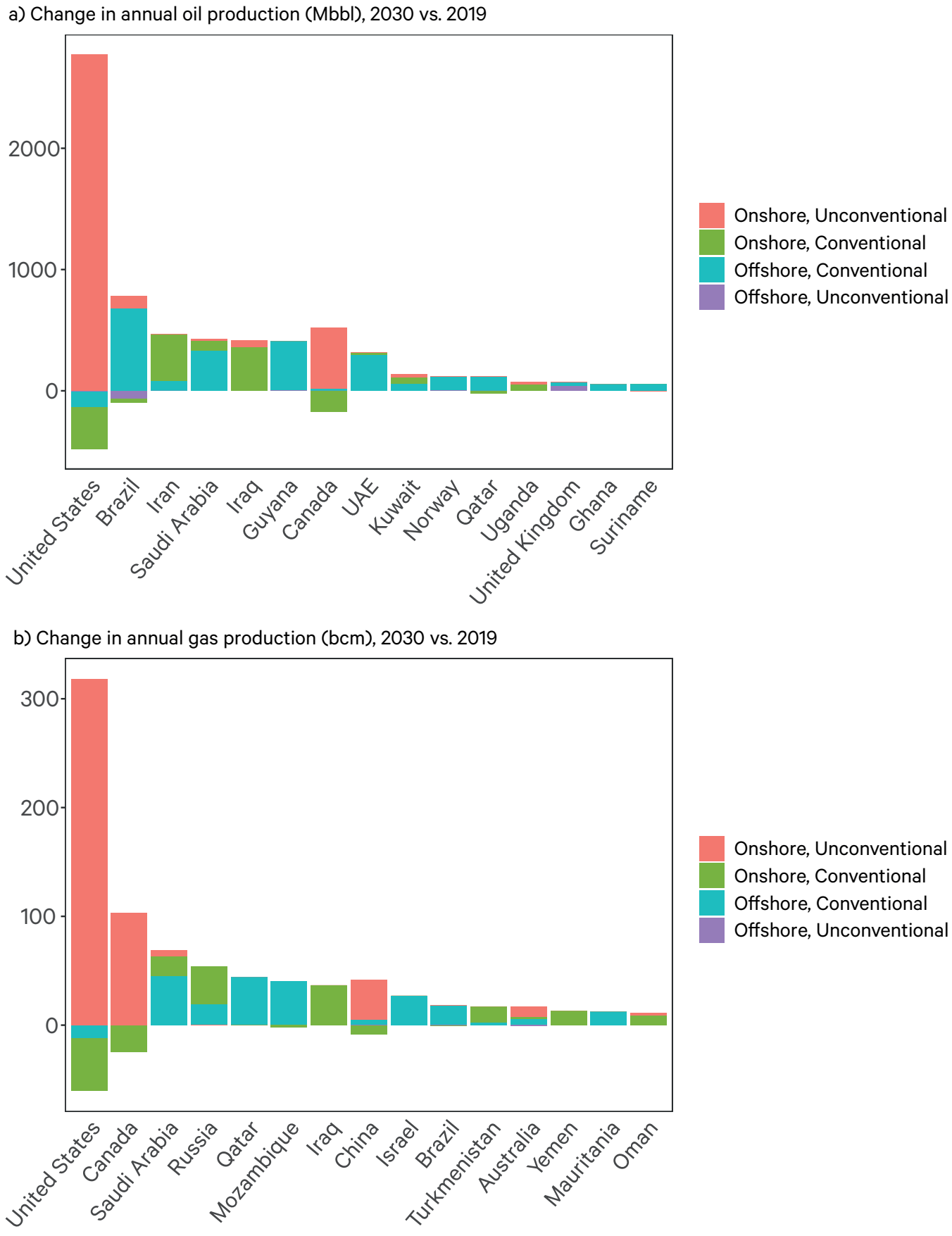
While equity has long been a cornerstone of international climate policymaking, what equity means with respect to fossil fuel production has been less studied and discussed. Nevertheless, there are compelling reasons to consider equity and differentiated responsibilities in any cooperative effort to limit global warming (Fleurbaey et al., 2014).

Furthermore, a number of scholars have begun exploring approaches and principles for sharing a limited budget of fossil fuel extraction, many of whom have emphasised the importance of considering equity principles (Armstrong, 2020; Caney, 2016; Kartha et al., 2016; Le Billon & Kristoffersen, 2019; Lenferna, 2017; Muttitt & Kartha, 2020; Pye et al., 2020). For example, Caney (2016) proposed three criteria for defining an equitable allocation: a country's level of development, its historical responsibility in terms of past extraction and benefits accrued, and the availability of other resources for development. Muttitt and Kartha (2020) proposed five principles, which include considering which countries are least dependent on extraction and have the greatest capacity to transition.

It is beyond the scope of this analysis to evaluate the different principles of international cooperation that have been proposed. Instead, we provide a simple analysis to highlight the equity implications of production under the baseline scenario presented above, which is absent of new policy interventions. Using the same data as in Figure 1, we aggregate the projected baseline trajectories of national oil and gas production into different groups according to two indicators: (1) a country's income level; and (2) a country's relative dependence on fossil fuel revenues, measured as the percentage of total gross domestic product (GDP) compared to other producer countries (see footnote[2] and Table S1 in the appendix for further details). While simplified, these two indicators nonetheless capture the broad challenge that an equitable global transition will

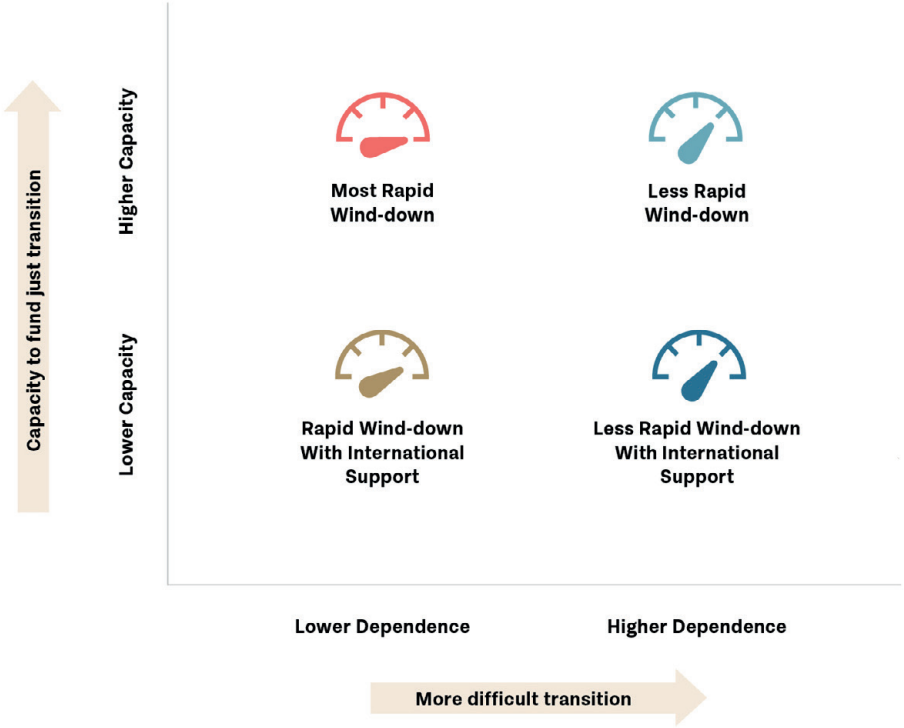
2 Data sources and methods for country indicators are as follows: (1) Income classification as of 2020 by the World Bank, downloaded from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups); (2) Dependence on fossil fuel revenues. This metric relies on 2018 data on oil and gas rents as percentages of GDP from the World Bank (downloaded from https://data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS and https://data.worldbank.org/indicator/NY.GDP.NGAS.RT.ZS). Some researchers have suggested that gross national income (GNI) might provide a better metric given that a non-trivial share of fossil fuel revenues could be expatriated in some countries. However, recent data on fossil fuel rents as % of GNI are not readily available for all countries. In this analysis, countries are grouped into "low" (less than 50th percentile), "medium" (50th-90th percentile), or "high" (more than 90th percentile) dependence based on how their values compare to all other countries for a given fuel (see Table S1 in the appendix for details). This is a simplistic approach that only represents the dependence of a given country relative to other producer countries for each fuel. For a summary of approaches to evaluating the extractives (including oil and gas) dependence of countries, see Hailu and Kipgen (2017).

Figure 4. Changes in annual oil and gas production – when comparing 2030 with 2019 – for 15 countries with the largest projected increases by volume, shown by different field types (including from both existing and new fields).



require, and recognizes that countries' transitional challenges differ widely depending on their level of dependence on fossil fuel production and their capacity to diversify and support a transition, as summarized in Figure 5.

Figure 5. How capacity and dependence can influence the pace of winding down fossil fuel production and need for international support. (This figure is reproduced from the 2020 Production Gap Report (SEI et al., 2020), where it was adapted from Muttitt and Kartha (2020)).



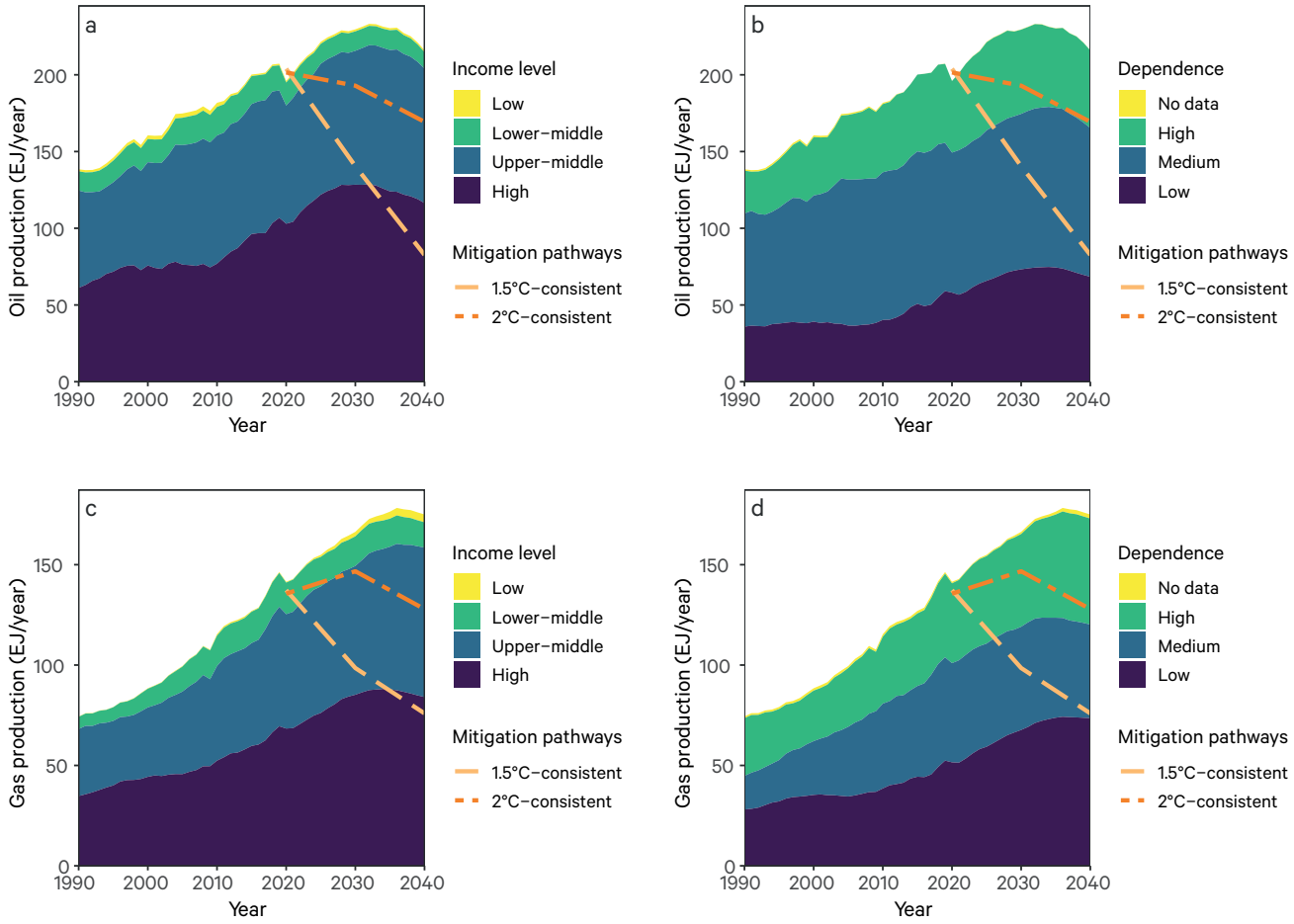
As the left side of Figure 6 (panels a and c) shows, if total oil and gas production continued along baseline projections, countries with the highest levels of income would exceed global pathways for production consistent with limiting warming to 1.5°C or 2°C over the next two decades, effectively leaving no oil and gas production for countries with lower levels of income.

Similarly, the right side of Figure 6 (panels b and d) shows that when countries are grouped by their levels of relative dependence on fossil fuel revenues, the majority of production is projected to occur in countries with low or medium dependence. The aggregated production trajectory from these countries would already exceed global pathways consistent with limiting warming to 1.5°C.

We note that in Figure 6, the order of the stacked area charts representing each group's production trajectories highlights a particular comparison. Alternatively, the reversed ordering, as shown in Figure S2 in the Appendix, offers complementary insights. For example, the baseline trajectories of oil and gas production in countries with relatively high and medium dependencies would also exceed the global pathways consistent with limiting warming to 1.5°C by 2030. While these countries may need international support and a longer timeframe to transition away from fossil fuels, they will nonetheless also need to align their future production with international climate goals.

These two representations epitomize two starkly different global approaches to winding down production: one at the expense of the poorer and/or more dependent countries, and the other at the expense of those that are wealthier and less dependent. Consequently, these charts show why it may be important to consider international equity in discussions about if and how countries would cooperate on limiting fossil fuel production. For example, if it was considered

Figure 6. The stacked area charts show global 1990-2040 oil (a, b) and gas (c, d) production (exajoule/year) with country-level data grouped by income or relative revenue dependence as described in the legends. The dashed lines show production pathways consistent with limiting warming to 1.5°C (light orange) and 2°C (dark orange).



inequitable for the relatively wealthy and least fossil-fuel-dependent countries to produce a majority of the limited oil and gas that can be produced under low-carbon pathways, these countries would need to take leadership roles in the transition, phasing out their own fossil fuel production at rates that are even faster than the global averages.

Conclusions

Our analysis finds that the trajectories of baseline oil, gas, and coal production are in excess of pathways consistent with limiting warming to 1.5°C and well below 2°C, if current economic trends and existing policies continue. These results are in line with previous analyses that have explored production plans and projections by governments (SEI et al., 2020) or by companies (Grant & Coffin, 2019), and further strengthens the case for why new policy interventions are needed to wind down global coal, oil, and gas demand and supply in line with the Paris Agreement's temperature limits.

Between 2019 and 2030, the largest increases in annual oil production are projected to occur in existing major producer countries including the United States, Brazil, and Iran. The largest increases in annual gas production would be in the United States, followed by Canada and Saudi Arabia. The list of top 10 oil and gas producers in 2030 are expected to remain unchanged compared to 2019.

From a policy perspective, having a shared understanding around baseline levels and distributions of future fossil fuel production could be an important first step for countries seeking to work together to find more equitable outcomes. As a parallel example, reference greenhouse gas emissions levels have served many uses over time (Clapp & Prag, 2012; Erickson & Broekhoff, 2017; Hausfather & Peters, 2020).

In this report, we also demonstrate that when countries are grouped by two fairness criteria – their capacity to transition or their relative dependence on fossil fuel revenues – the projected production pathways from the wealthiest or the least-dependent countries alone would already exceed global pathways consistent with limiting warming to 1.5°C over the next few decades.

It is too early to say how this type of information may play a role in international discussions around limiting fossil fuel production. Nevertheless, there is clearly a case to be made, based on simple equity principles, that countries with more capacity to transition and lower dependence on fossil fuel revenues should wind down the fastest. Our analysis shows that current trends are moving in the opposite direction. Therefore, if not actively and internationally managed, a phase-out of fossil fuel production in line with the ambitions of the Paris Agreement could be highly inequitable among countries.

The information we present here may also be useful to civil society groups seeking to highlight the expansion of fossil fuel production and, in so doing, help hold governments accountable for their role (including in support of fossil fuel companies) for the projected over-production of fossil fuels.

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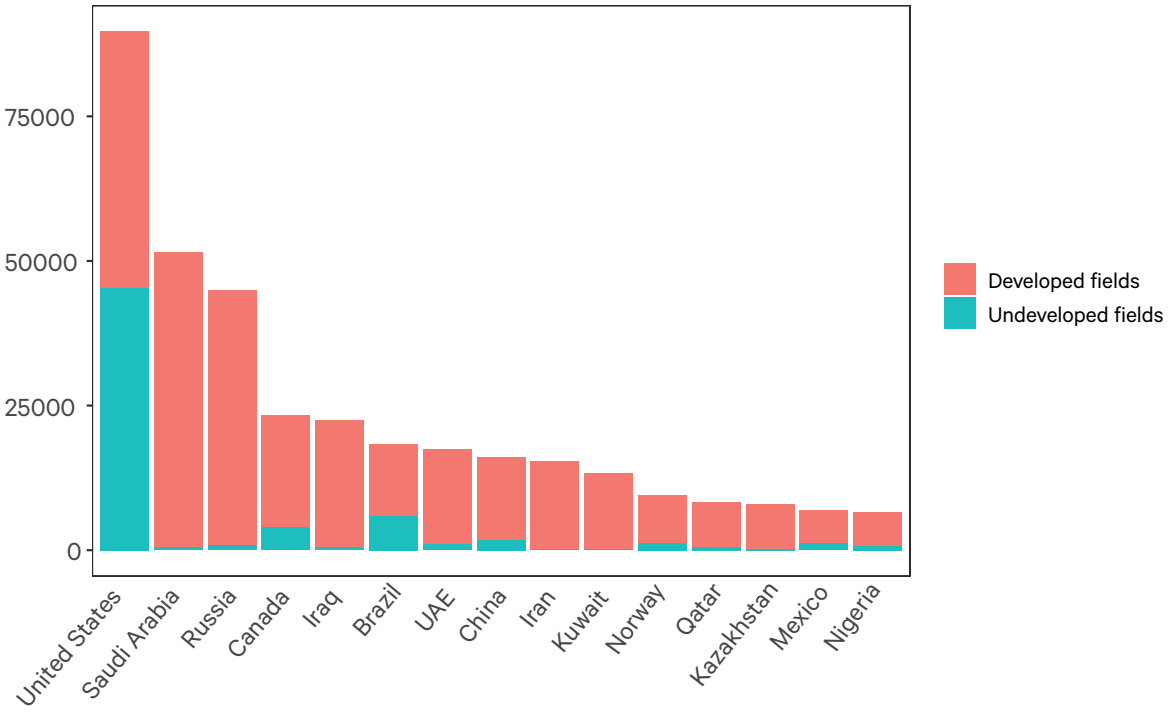
Appendix

Figure S1. Total oil and gas production from developed fields versus that from new, undeveloped fields (as of September 2020). The stacked bar charts show the sum of projected production from 2020 to 2030 for the top 15 countries.

a) 2020–2030 cumulative oil production (Mbbl)



b) 2020–2030 cumulative gas production (bcm)

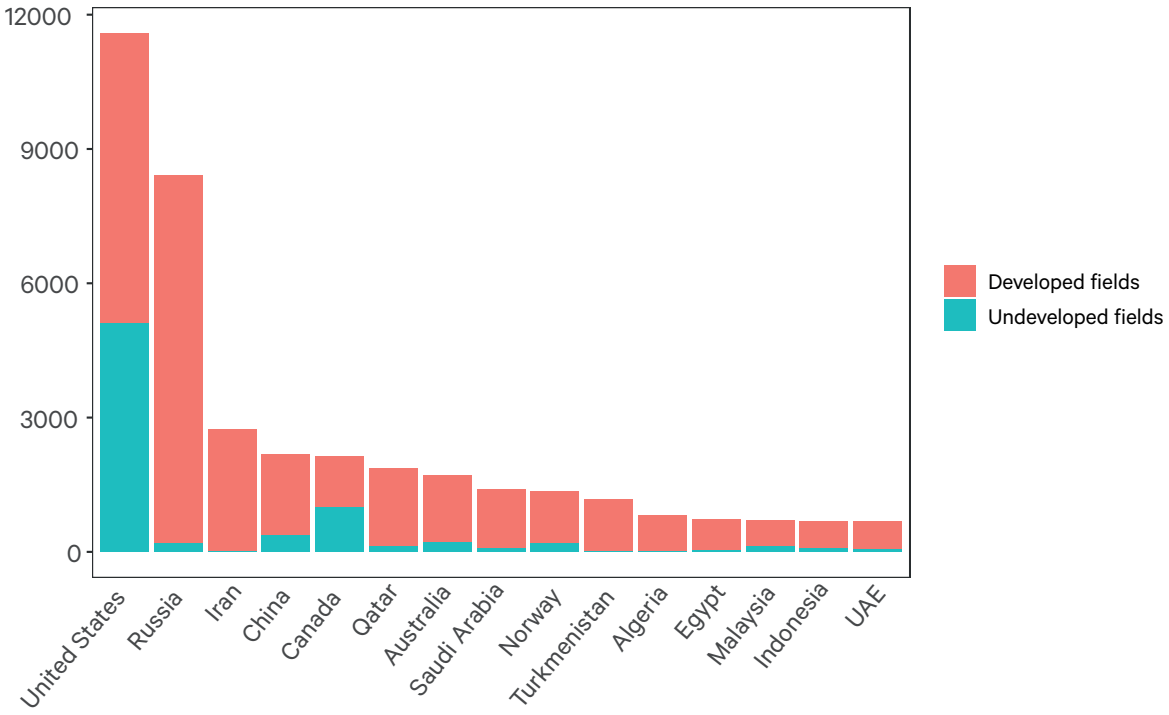


Table S1. The "dependence" of countries on their oil or gas revenues are classified relative to how a given country's value compares to all other countries for a given fuel. The threshold values for each classification are shown in the table below. This is a simplistic approach that only represents the dependence of a given country relative to other producer countries for each fuel. For a summary of approaches to evaluating the extractives (including oil and gas) dependence of countries, see Hailu and Kipgen (2017).

	Oil revenue % of GDP	Gas revenue % of GDP
Low (less than 50th percentile)	< 0.6%	< 0.2%
Medium (50-90th percentile)	0.6-25%	0.2-3.7%
High (more than 90th percentile)	> 25%	> 3.7%

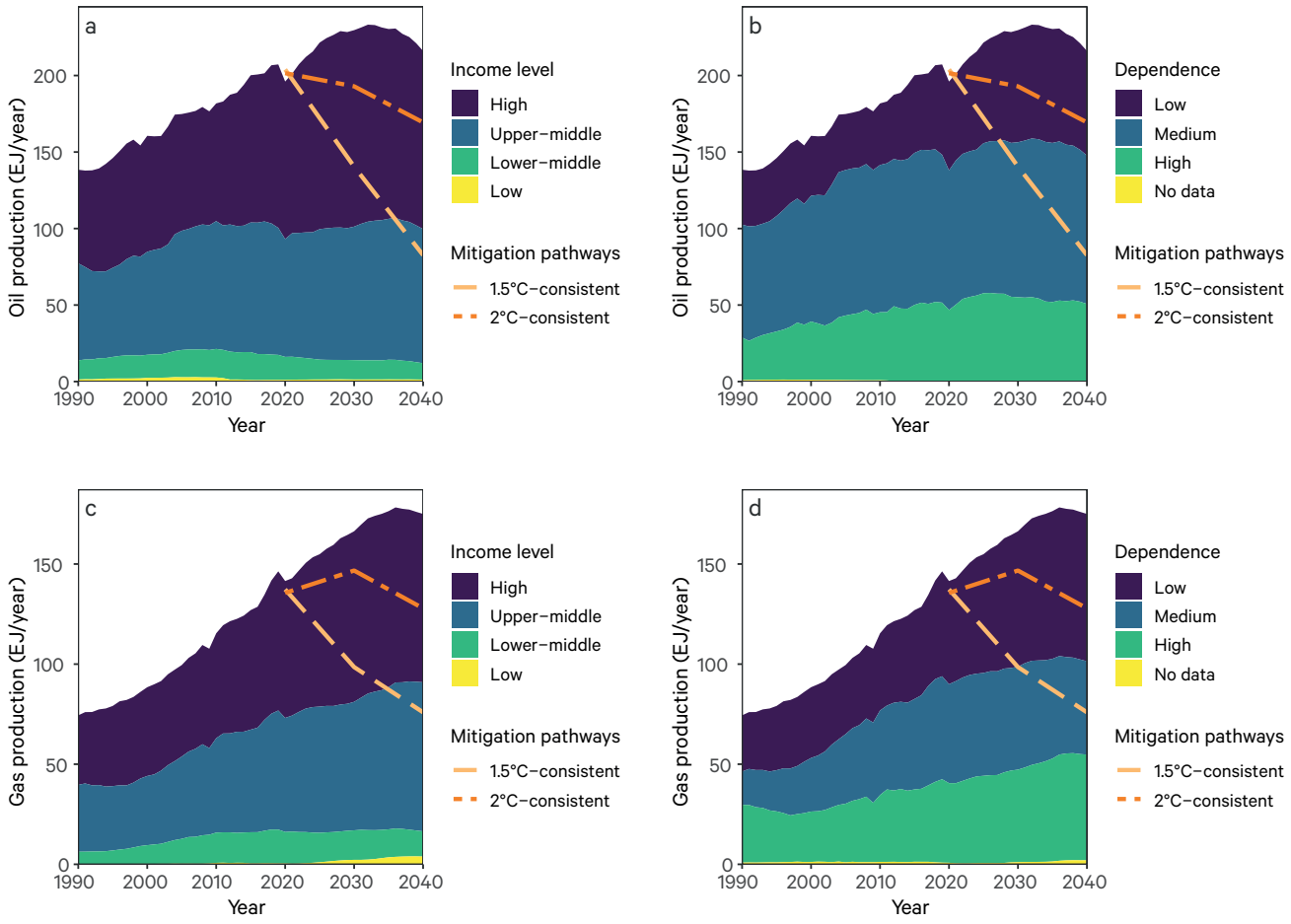


Figure S2. As in Figure 6 – but with reversed ordering of the country groups – the stacked area charts show global 2000-2040 oil (a, b) and gas (c, d) production (exajoule/year) with country-level data grouped into different aggregates as described in the legends. The dashed lines show production pathways consistent with limiting warming to 1.5°C (light orange) and 2°C (dark orange).

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