Expert Letter: The likely effect of Shell's Reduction Obligation on oil and gas markets and greenhouse gas emissions

1. Introduction

We were invited by Milieudefensie to offer our expert opinion on matters pertaining to the effect of the Reduction Obligation (***RO***) imposed on Shell by the District Court (and challenged by Shell on appeal) on global oil and gas production and greenhouse gas emissions (***GHGs***)—especially but not only the price effect of any withdrawal of oil and gas supply by Shell pursuant to the RO. Our respective expertise in matters relevant to this letter is set out in the Appendix (brief biographies) and our attached CVs. This letter was jointly authored and represents our joint opinion. Our time spent producing this letter has been provided *pro bono*.

In our opinion, the RO would likely reduce global GHGs. The most direct channel through which this reduction is likely to occur is through the price effect, which is the primary subject of this letter. We discuss this first (Section 2). We then discuss the evolution of demand for oil and gas over the longer term, and Shell's ability to influence that demand and the wider market (Section 3). Finally, we outline some other (financial, legal and political) channels through which the judicial imposition of the RO on Shell may reduce GHG emissions (Section 4).

2. The price effect

The price effect is characterised by the following causal chain:

a) Pursuant to the judicial imposition of the RO, Shell must reduce its supply of oil and gas;
b) The reduction in oil and gas supply from Shell decreases the aggregate supply of oil and gas in the respective (global or regional) markets for these fuels;
c) The reduction in aggregate oil and gas supply, all else equal, raises the equilibrium price for these fuels, inducing a contraction in consumption;
d) Given the lower volumes of oil and gas consumed at the new equilibrium price, the global volume of GHGs emitted from the combustion of fossil fuels is reduced.

Shell effectively disputes links (b)–(d) of this causal chain, for example, where it asserts that a reduction in GHG emissions across the world "will not be achieved and, indeed, *cannot* be achieved by the Reduction Obligation" (Shell Statement of Appeal [hereafter "***Shell SOA***"], para 3.2.20, emphasis in original).[1]

However, Shell's argument is incorrect, as we explain here; we first address link (b) and (c) together, followed by link (d).

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[1] We reviewed the English translation of Shell's SOA. We are advised by Milieudefensie that para 3.2.19 in the English translation is equivalent to para 3.2.20 in the Dutch version. Our reference to para 3.2.20 in the text here and subsequently in this letter is intended to refer to the Dutch version. We are unaware of any other discrepancies (relevant to this letter) between the Dutch version and the English translation.

2.1 Market responses to Shell's reduced oil and gas production (links (b) and (c))

The dispute concerning links (b) and (c) concerns the expected direction, and magnitudes, of the responses by oil and gas market participants (producers other than Shell, and consumers) to the reduction in Shell-controlled supply pursuant to the RO.

Shell's argument here is, in its most concise form, that, if the RO is imposed and Shell's supply is reduced, then "The continued demand for oil and gas will need to be met. If the Shell Group does not do so, then others will step in" (Shell SOA, para 3.2.20(c)).

But this claim fails even the most basic principles of economics, which is that supply and demand are related to each other, via price.

First, on supply, it is not necessarily the case that "others will step in" at the same speed, scale, or cost, were Shell to reduce its production of oil and gas by giving up production licenses: other suppliers may be limited in their capacity (e.g., labor or capital) to extract as much oil or gas from the licenses; that capacity could be delayed; or governments that offer the licenses may not re-issue the licenses. In all such cases, the overall supply of oil or gas to the market would be reduced.

Still, Shell believes that the substitution could also happen closer to the point of sale, not at the point of production: "For example: as long as gasoline cars are on the road, a reduction of supply of gasoline by the Shell Group will mean that other companies will supply gasoline to keep these cars running" (Shell SOA, para 3.2.20(c)).

But that example fails to consider how demand is not static. If Shell were to close its gasoline stations (reduce supply), many consumers who regularly used those gasoline stations would now find it less convenient to get gasoline. They may have to travel further to fill their tanks (an added burden, or cost, on their demand), which may prompt them to consider driving less or using other transportation options, such as an electric vehicle (***EV***) they can charge at home. Indeed, as Shell acknowledges, "Consumers would continue to make choices based on cost, availability and security of supply" (Shell SOA, para 2.5.8). Shell's error here is in assuming that those choices can only include fossil fuels, leaving no change in oil or gas demand.[2]

More broadly, any restriction in the supply of oil or gas, whether at the point of extraction or at the point of sale, is going to increase the price of that fuel to consumers. And when prices (and expectations about future prices) go up, consumers change their behaviors, even if only a tiny amount, to mitigate the increase in price. They drive less or at slower (more fuel-efficient) speeds, drive more-efficient cars that they already own, or purchase new, more efficient cars when they next replace a vehicle. Countless economic analyses across the world have shown this basic

[2] Elsewhere in its SOA (e.g., para 2.5), Shell distinguishes between "easy-to-abate" and "hard-to-abate" sectors. Notably, the "ease of abatement" refers in this context to the ease with which consumers can switch away from oil and gas. One of the "easy-to-abate" sectors Shell identifies is "[p]assenger vehicles" (Shell SOA, para 2.5.3). By acknowledging that there are "easy to abate" sectors to which Shell supplies oil and gas, Shell has undercut its own implausible assertion that the entire oil and gas market is characterised by purely inelastic demand. We discuss the issue of "hard-to-abate" sectors later in this section.

dynamic to be true, in studies that assess the price "elasticity" of demand, which is the change in demand as a ratio to change in price.[3] These studies show that demand is affected by a change in price, and therefore is *somewhat* elastic (never perfectly inelastic). Naturally, there is a debate about the *magnitude* of the response (which we address in subsequent paragraphs), but there is no serious debate about the net direction of the effect of a supply reduction, i.e. that there will be less oil and gas consumed than would otherwise be the case.

This relationship between supply and demand, via price, is so basic, so widely understood (including by Shell's own experts[4]), that the burden of proof for claiming otherwise should rest firmly with anyone wishing to assert the contrary. Namely, in this case, the burden of proof should be on Shell to demonstrate that the oil and gas markets are characterised by demand that is completely unresponsive to price and, therefore, to changes in supply. We cannot fathom how they could hope to substantiate this claim. In fact, we are aware of no study that shows demand in oil and gas markets to be perfectly inelastic.

Before turning to link (d) in the causal chain of the price effect, we address three matters of nuance raised by Shell that relate to our claims above.

Infrastructure vs behaviour: A variant of Shell's argument assumes that consumer demand for oil and gas is *entirely* determined by (long-run) changes in infrastructure and technology on the demand side (what it calls "demand-side infrastructure", e.g., at Shell SOA, para 2.5.8), such as EVs and EV charging facilities, and consumers' propensity to purchase and use these. Such demand-side infrastructures are clearly relevant to the demand function for oil and gas (Shell itself admits that it has some control over such demand-side infrastructure, at Shell SOA, para 8.4.5, and we discuss this matter further in Section 3). But they are not the only relevant factors: consumers can and do also adjust their behaviour in response to price signals, *even in the short run*, i.e. within the constraints of existing "demand-side infrastructure", as illustrated by the examples given earlier (e.g., people drive less in response to higher prices).

State vs company supply reductions: Some of the studies relied upon by Milieudefensie and by us in support of our argument about the overall effect of a supply reduction on consumed volumes of oil and gas (and/or on GHGs) pertain to supply restrictions by governments that effectively remove a defined territorial area containing oil and gas resources from the supply function (e.g., by cancelling or ceasing to issue extraction permits in respect of the relevant area). Shell asserts that these studies are not relevant to the present case, which involves a reduction in the supply *controlled by one company*, because in the latter case the same resources could be exploited by another company (e.g., Shell SOA, para 3.2.20(d)). We agree that there is a difference between restricting extraction in a given territorial area and restricting production by an individual company,

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[3] See, as examples: James D. Hamilton, "Understanding Crude Oil Prices" (2009) *The Energy Journal* 30(2): 179–206; Dario Caldara, Michele Cavallo and Matteo Iacoviello, "Oil Price Elasticities and Oil Price Fluctuations" (2019) *Journal of Monetary Economics* 103: 1–20.

[4] The report, "Bedrijfsspecifieke beperking in exploratie en productie en het effect op het wereldwijde verbruik van fossiele energie: Een analyse toegespitst op de positie van Shell", by Professor Machiel Mulder at the University of Groningen's Centre for Energy Economics Research (CEER), described how a decrease in supply leads to an increase in prices and a decrease in consumption whenever other producers are not able to compensate for all the avoided supply.

but do not agree that it is a difference that affects our overall conclusion about the effect of the RO on oil and gas prices, and hence consumption. The literature on supply-side restriction policies has mainly been concerned with restrictions by states, and typically considers the realistic case with an upward sloping supply function (in which each added, marginal unit of supply costs more than the previous unit) and a downward sloping demand function (in which the quantity demanded is negatively related to the price)—see Figure 1, below.[5] A state restriction of extraction permits means companies must go elsewhere—presumably where extraction costs are higher[6]—to extract resources, implying a shift in the supply function (to the left), which leads to higher prices, and lower consumption. But we would also expect that a company-level restriction would lead to higher prices, because extraction costs vary not only due to physical resource-related factors, but also company-related factors. Other companies may not be able to bring Shell's oil and gas projects online for the same cost (or as quickly) as Shell. In short, although controlling extraction licenses and controlling company participation are different policies, they are both policies affecting the cost of oil and gas production. Hence, in general, one would expect restrictions on participation in the market for oil and gas extraction to increase production costs, leading to higher prices and thus lower consumption.

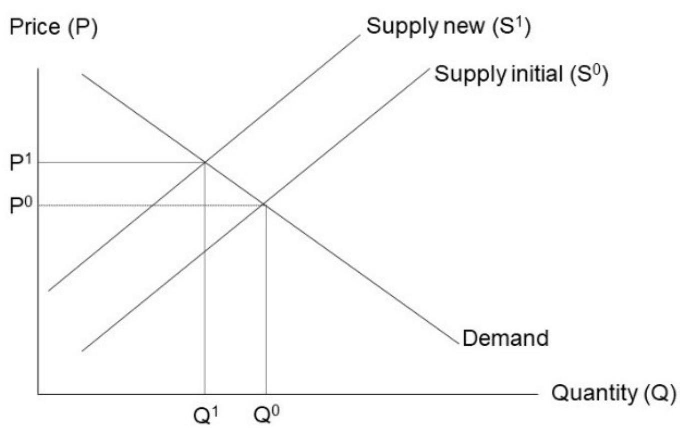

Figure 1: Increase in market equilibrium price and decrease in quantity consumed caused by a decrease in supply.

Easier- vs harder-to-abate sectors: Another argument from Shell is that there are numerous harder-to-abate sectors that will require continued supply of fossil fuels (Shell SOA, para 2.5). Therefore, the argument continues, even if Shell were to stop supplying to these sectors, there would still be a demand for fossil fuels that would be met by other suppliers. There are, indeed, some sectors for which oil demand will hold up in the nearer term, and for which low-carbon alternatives will take longer to come online. This is particularly the case for sectors such as

[5] See, e.g., Geir B. Asheim et al., "The case for a supply-side climate treaty" (2019) *Science* 365: 325–27.
[6] This is a reasonable assumption because producers are already incentivised to produce from fields with the lowest extraction costs, all else equal.

petrochemicals and international transport. That said, none of these sectors is without alternatives (see for example the many publications by the Energy Transitions Commission[7])—and what is defined as 'harder-to-abate' can change over time. Five years ago steel was considered a hard-to-abate sector but innovation and investment in the sector has seen the emergence of clear pathways to a low-carbon transition, focused on Direct Reduction Iron with hydrogen and Electric Arc Furnace technologies.[8]

Due to innovation in clean energy technologies, it is likely that many so called 'hard-to-abate' sectors will develop alternatives in the longer run (and become 'easier-to-abate'). As a result, the remaining demand for oil and gas would become increasingly price elastic. Alternatives would reduce the fossil fuel market size further, leaving only very hard-to-abate sectors with residual demand.[9] The resulting lower levels of demand would likely see higher cost producers increasingly squeezed, and supply predominantly from the larger national oil companies that hold most of the low-cost reserves.[10] It is unlikely that this low residual demand (and smaller market) would provide the same opportunities for international oil companies like Shell.

2.2 The effect on GHG emissions of fuel switching in response to higher oil and gas prices (link (d))

Shell further asserts that the net effect of the RO may be an increase in global GHG emissions because it would slow the switch from coal to natural gas, the combustion of which generates lower GHG emissions than does the combustion of coal (Shell SOA, e.g., para 9.2.13(b)). Before addressing the merits of this claim, it is notable that, in stating this argument, Shell acknowledges that a cut in its supply has an impact on international fuel prices, to which consumers respond (contrary to their claims elsewhere in their SOA, e.g., para 6.4.17 and discussed in Section 2.1, above). If a cut in gas supply from Shell were fully substituted by other producers, leaving the gas price unchanged, then there would be no change in consumers' incentive to switch fuel sources.

Turning to the merits of Shell's point, we agree that increased gas prices are expected to lead to increased demand for close substitutes, and that coal is a substitute for gas. But so is renewable energy, with close to zero emissions. Hence, an expected outcome of a cut in the supply of gas is higher gas prices and *lower* gas consumption, where *some* of the reduction in gas consumption is replaced by increased consumption of coal and renewables. According to the International Energy Agency (***IEA***),[11] on average, coal-to-gas switching reduces emissions by 50% when

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[7] Energy Transitions Commission website, <https://www.energy-transitions.org/publications/>.
[8] For example, see the Green Steel Tracker that provides an overview of low carbon projects in this sector. V. Vogl et al., *Green Steel Tracker*, Version 06/2022 (2021), Stockholm, Dataset, <www.industrytransition.org/green-steel-tracker>.
[9] See for example Dan Welsby, James Price, Steve Pye, and Paul Ekins, "Unextractable fossil fuels in a 1.5 C world" (2021) *Nature* 597(7875): 230–34.
[10] Resource supply curves highlight that much of the lowest cost resource is located in the Middle East, dominated by national oil companies (see, e.g., Welsby et al., "Unextractable fossil fuels in a 1.5 C world"). This is also highlighted in IEA, *The Oil and Gas Industry in Energy Transitions* (Paris: International Energy Agency, January 2020), <https://www.iea.org/reports/the-oil-and-gas-industry-in-energy-transitions>.
[11] IEA, *The Role of Gas in Today's Energy Transitions* (Paris: International Energy Agency, 2019) <https://www.iea.org/reports/the-role-of-gas-in-todays-energy-transitions>.

producing electricity and by 33% when providing heat. Thus, for a cut in gas supply to lead to higher emissions, more than half of the subsequent reduction in gas consumption would need to be offset by increased consumption of coal. With strong policy support for renewables in many countries, and increasingly global concern for local environmental pollution from combustion of coal, this seems unlikely. The IEA points to declining use of coal from 2025, even without any further GHG policies than already implemented or announced (Stated Policies Scenario in *World Energy Outlook*), and additions to global electricity supply are expected to be dominated by renewables by 2030.[12] We also see increasingly ambitious targets for renewable electrification in the EU, most recently with the REPowerEU plan.[13]

Coal is not a close substitute for oil. The potential problem of increased emissions due to fuel switching is thus less relevant for a cut in the supply of oil, except, most notably for switching from oil to electricity in the transport sector. However, as additions to global electricity supply are expected to be dominated by renewables (see previous paragraph), any increase in GHG emissions associated with added electricity demands at the margin would be smaller than the emissions associated with combusting oil-based vehicle fuels.

3. Shell's role in the evolution of demand for oil and gas over the longer-term

Shell makes the claim that it can only reduce its scope 3 emissions[14] by either increasing the sale of low-carbon energy (what it calls "low emission substitution"), the demand for which it claims it cannot control, or by withdrawing the sale of fossil fuel products, which it claims will result in "supplier substitution" (Shell SOA, para 8.4.2). We have already addressed the question of supplier substitution in Section 2. In this section, we discuss the evolution of demand for oil and gas over the longer term, and Shell's ability to influence that demand (i.e., Shell's role in "low emission substitution").

Demand for fossil fuels over the coming decade will not remain constant. In fact, key sectors are more likely to see reduced demand. For example, the trend in EV growth suggests that oil consumption for this sector will experience a strong decline over the next decade. A recent analysis by Bloomberg suggests that a tipping point has been reached in EV sales and that many countries will now see mass adoption in the coming decade.[15] By 2030, the IEA estimates that EVs alone could displace up to 7 mbd of oil production.[16] Many other advances in low carbon technology are emerging across other sectors that are likely to bring structural change to energy demand over the coming decade, notably in green steel production using hydrogen, ammonia in shipping, and electrification of heating in buildings. These changes will likely be reinforced as

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[12]IEA, "Exploring multiple futures: fuels", in *World Energy Outlook 2021* (Paris: OECD Publishing, 2021) DOI: https://doi.org/10.1787/50738f85-en

[13] REPowerEU Plan. COM(2022) 230 final, <https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF>.

[14] That is, the emissions caused when the oil and gas it supplies is combusted by third parties.

[15] Bloomberg, "US Crosses the Electric-Car Tipping Point for Mass Adoption" (2022) <https://www.bloomberg.com/news/articles/2022-07-09/us-electric-car-sales-reach-key-milestone>.

[16] IEA, *Global EV Outlook 2022* (Paris: International Energy Agency, May 2022) <https://www.iea.org/reports/global-ev-outlook-2022>.

climate action accelerates over the coming decade, with suppliers needing to be ready to meet growing demand. The IEA estimates global investment in clean energy transition needs to hit $4.5 trillion in 2030 to achieve its net-zero scenario, a tripling of today's level.[17]

Shell has great potential to accelerate these shifts, influencing demand for fossil fuels over the long term—by investing in low-emissions alternatives to fossil fuels, and by supplying and marketing these to its customers. Shell has the technical know-how, financial clout and marketing channels to help drive change in key sectors, influencing how quickly those sectors transition. Indeed, oil and gas companies such as Shell have positioned themselves as pivotal to the transition, notably in terms of driving forward the hydrogen economy and carbon capture and storage,[18] and investing in EV charging infrastructure. These areas of investment will help drive the transition forward and ultimately influence demand, for example via the 100,000 EV charging points Shell has targeted for the UK by 2030, which is one third of the total UK Government target in 2030.[19] At the global scale, Shell states that "Our aim now is to become one of the largest electric charging solutions providers globally, meeting customer demand at home, at work or on the go".[20] This suggests that Shell clearly has the motivation to influence change, and the technical capability to influence demand so that fossil fuel consumption declines. However, Shell's investment in clean technology has been low, amounting to only a small fraction of its investments in oil and gas.[21]

This commitment by Shell to clean technology investment could be strengthened, and it is our view that the judicial imposition of the RO would likely induce greater commitments of this kind by Shell. Consider, for illustrative purposes, the supply of low-carbon alternatives to fossil fuels in long-distance transport sectors for which electricity-based solutions will be more challenging (as described in Shell SOA para 2.3.8(b)). Shell could shift a larger part of its business to fuels such as sustainable biokerosene or synthetic kerosene for use in aviation, increasing the supply of these lower-emissions alternatives to its customers. If alternatives are supplied and marketed, prices will fall over time, and demand will grow. Whatever specific business decisions Shell makes pursuant to the RO, our more general point is simply that the Court should take account of Shell's role not only as a supplier of oil and gas, but as a potential supplier of low-emissions substitutes, which can influence the evolution of oil and gas demand over the longer term.

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[17] IEA, *World Energy Investment 2022* (Paris: International Energy Agency, June 2022) <https://www.iea.org/reports/world-energy-investment-2022>.

[18] For example, in the UK, see the North Sea Transition Deal, which highlights the key role such companies will play in hydrogen production and carbon capture and storage: BEIS, *North Sea Transition Deal* (UK Department for Business, Energy and Industrial Strategy, March 2021) <https://www.gov.uk/government/publications/north-sea-transition-deal>.

[19] DfT, *Tenfold expansion in chargepoints by 2030 as government drives EV revolution* (UK Department for Transport, March 2022) <https://www.gov.uk/government/news/tenfold-expansion-in-chargepoints-by-2030-as-government-drives-ev-revolution>.

[20] Shell Global, *Electric Vehicle Charging*, <https://www.shell.com/energy-and-innovation/mobility/electric-vehicle-charging.html> (accessed 26 August 2022).

[21] Lewis Fulton and Daniel Sperling, "Oil companies are thinking about a low-carbon future, but aren't making big investments in it yet", *The Conversation* (October 2019); Mei Li, Gregory Trencher, and Jusen Asuka, "The clean energy claims of BP, Chevron, ExxonMobil and Shell: A mismatch between discourse, actions and investments" (2022) *PloS one* 17.2: e0263596.

In addition, and as stated by Shell (SOA, paras 3.3.14 and 8.2.5), a portion of the oil and gas sold by Shell is purchased from other oil and gas producers. Many independent oil and gas producers, of which there are hundreds,[22] rely on a small number of integrated companies[23] like Shell to act as intermediaries to get their products to market. Shell has itself highlighted the important role it plays in providing offtaking and financial services solutions to such independent producers.[24] Accordingly, this is an additional channel through which Shell's business decisions influence the wider market for oil and gas, both in the short and longer term. For example, it is reasonable to assume that if Shell shifted its business model more decisively toward low-emissions solutions, this would (i) depress consumer demand not only for the oil and gas produced by Shell but also the oil and gas produced by independent producers that is on-supplied by Shell (e.g., due to an associated shift in Shell's marketing and distribution strategy), (ii) reduce the supply of oil and gas supplied by those independent producers (due to those independent producers facing higher costs for marketing and distribution), or both (i) and (ii).

The discussion in this section relates to a further concern raised by Shell (SOA, para 2.5.9): that the supply-side action related to the RO will be ineffective unless demand-side action happens in 'tandem'. In order to meet global climate targets, it is not the case that any single entity at a single point in time ought to reduce both supply and demand; rather, it is simply that, *globally*, it is preferable (e.g., more cost-effective) to cut both supply and demand roughly in tandem.[25] For any *single* entity, it may make sense for it to focus on supply, on demand or on both. In any event, Shell's capacity to influence demand over the longer term (as discussed above) underscores the fact that Shell *is* capable of taking both supply actions and demand-influencing actions. Accordingly, the global imperative to tackle both the demand for and supply of fossil fuels is not a valid reason to reject the imposition of the RO on Shell.

4. Additional effects of the RO that may reduce global GHG emissions

Though we have focused on the price effect and, more generally, Shell's role in the evolution of demand for fossil fuels, we wish to highlight a number of additional channels through which the judicial imposition of the RO on Shell may reduce global GHG emissions:

i. A decrease in oil and gas supply due to the increased cost of capital resulting from investors' increased perception of risks associated with the oil and gas industry, as increased risk for higher-cost projects at the margin will decrease consumption;[26]

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[22] See the database of the Global Oil and Gas Exit List (GOGEL), <https://gogel.org/>.

[23] Integrated Oil Companies Stocks List of USA 2022, <https://fknol.com/stock/list/integrated-oil-companies.php>.

[24] "Executive interview with Andrew Smith", Energy Council, <https://energycouncil.com/articles/andrew-smith-shell-trading-supply/>.

[25] Fergus Green and Richard Denniss, "Cutting with Both Arms of the Scissors: the economic and political case for restrictive supply-side climate policies" (2018) *Climatic Change* 150: 73–87.

[26] Bassam Fattouh et al., *Energy Transition, Uncertainty, and the Implications of Change in the Risk Preferences of Fossil Fuels Investors* (Oxford: The Oxford Institute for Energy Studies, 2019); Peter Erickson, et al., "Why Fossil Fuel Producer Subsidies Matter" (2020) *Nature* 578(7793): E1–4.

ii. A decrease in fossil fuel supply due to other courts and tribunals imposing similar restrictions on other fossil fuel production companies, due to the (non-binding, but likely influential) precedent set by the court's decision;[27]

iii. A decrease in fossil fuel supply due to governments in other jurisdictions imposing similar restrictions on other fossil fuel production companies, due to the strengthening of a global moral norm in favour of restricting the supply of fossil fuels.[28]

These effects are difficult to quantify, but we can be confident of their direction, i.e., toward reducing global GHG emissions as a result of decreases in fossil fuel production. It is possible that these effects will be small. But it is also possible that they will be large, with the court's decision potentially catalysing significant changes in the direction of lower emissions. This is because many of the phenomena mentioned here (e.g., market sentiment; norm diffusion) are characterised by complex, non-linear dynamics, such that a change in part of the system (such as a high-profile, major court ruling) could have disproportionate effects on a wide range of emissions-affecting behaviours.[29]

Sincerely,

Peter Erickson, Seattle, 16 September 2022

Fergus Green, London, 16 September 2022

Cathrine Hagem, Oslo, 16 September 2022

Steve Pye, London, 16 September 2022

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[27] Brian J. Preston, "The Influence of the Paris Agreement on Climate Litigation: Legal Obligations and Norms (Part I)" (2021) *Journal of Environmental Law* 33: 1–32; Brian J. Preston, "The Influence of the Paris Agreement on Climate Litigation: Causation, Corporate Governance and Catalyst (Part II)" (2021) *Journal of Environmental Law* 33: 227–56.

[28] Fergus Green, "Anti-fossil fuel norms" (2018) *Climatic Change* 150: 103–16; Fergus Green, "The logic of fossil fuel bans" (2018) *Nature Climate Change* 8: 449–51.

[29] J. Doyne Farmer et al., "Sensitive intervention points in the post-carbon transition" (2019) *Science* 364: 132–4; Ilona M. Otto et al., "Social tipping dynamics for stabilizing Earth's climate by 2050" (2020) *Proceedings of the National Academy of Sciences* 117: 2354–65; Timothy M. Lenton et al., "Operationalising positive tipping points towards global sustainability" (2022) *Global Sustainability* 5.

Appendix: Biographies of Authors

Peter Erickson is a senior scientist at the U.S. Center of the Stockholm Environment Institute. His peer-reviewed studies on how policies, actions, or infrastructure projects increase or decrease greenhouse gas emissions have been published in major scientific journals, including *Nature*, *Nature Climate Change*, *Environmental Research Letters*, and *Climatic Change*. His work on how oil supply affects oil markets and greenhouse gas emissions has been cited by the United States Court of Appeals for the Ninth Circuit and the United States District Court for the District of Columbia. He is also a co-author of the UNEP *Production Gap Report*.

Dr Fergus Green is a Lecturer in Political Theory & Public Policy in the Department of Political Science / School of Public Policy at University College London. He works on ethical, political and governance dimensions of low-carbon transitions. His work on climate-related fossil fuel governance and politics has been published in peer-reviewed journals including *Nature Climate Change*, *Climatic Change*, *Climate Policy* and *Global Environmental Politics*. He has been a chapter co-author of UNEP's *Production Gap Report* since its inception in 2019, and is a member of the Just Transition Taskforce of the Powering Past Coal Alliance.

Dr Cathrine Hagem is Head of Research, Unit for Environmental, Resource and Innovation economics at Statistics Norway. She holds a Dr. Polit degree from the University of Oslo. Her main research interest is environmental and energy economics. She has published over 25 peer reviewed papers. Her papers on restrictions on supply of fossil fuels versus restrictions on demand for fossil fuels in climate policies have been published in *Science*, *Scandinavian Journal of Economics* and *The Energy Journal.* She has been a member of a range of government-appointed commissions (GHG emissions from the agricultural sector; climate change policies; energy and CO_2 taxes; power transmission lines).

Dr Steve Pye is an Associate Professor in energy systems and Deputy Director of the UCL Energy Institute at University College London. His research focuses on the use of energy and integrated assessment models to explore and assess how to decarbonise the UK and global energy system and economy. He has a particular interest in the prospects for fossil fuel producers under climate policy. Steve has published over 50 peer reviewed papers, including in Nature, *Nature Climate Change*, *Nature Energy*, and *Nature Communications*. He is also a regular chapter author on UNEP's *Production Gap Report*. He has a PhD in Energy Engineering from University College Cork.