How ambitious are oil and gas companies' climate goals?

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The oil and gas industry is a leading emitter of greenhouse gases and faces an existential threat from the transition to a low-carbon economy. This has not escaped the attention of the investors that own oil and gas companies. These investors seek to understand what oil and gas companies are doing about climate change and, in particular, how these companies' long-term emissions targets compare with international climate goals. In this paper, we present a forward-looking method of estimating the lifecycle carbon emissions intensity of oil and gas producers based on their public disclosures, and we use it to compare companies' targets with international climate goals. The sector is not on target. Recent trends in emissions intensity have been mostly flat. Many companies are yet to set emissions targets or provide insufficient clarity on them. Of those that have, most targets are either too shallow or too narrow. Encouragingly though, a few companies have set long-term emissions targets that would bring their GHG intensity close to, and in two cases below, international climate goals by mid-century.

The energy sector is at the forefront of the transition to a low-carbon economy. This poses an existential threat to oil and gas (O&G) companies, whose main business is supplying fossil fuels. In 2019, the O&G sector supplied 55% of global primary energy,(*1*) while it was responsible for 56% of all energy-related CO2 emissions and 40% of total greenhouse gas (GHG) emissions.(*2*) Publicly traded O&G companies are investor-owned and constitute a significant share of many investment portfolios. Prior to the Covid19 pandemic, the combined equity valuation of publicly listed O&G companies was US$5.6 trillion, or about 6% of global market capitalisation[a]. Investors in these companies are therefore taking an increasingly keen interest in climate change,(*3*) in particular seeking to understand the so-called 'transition

[a] Data from FTSE Russell.

risks' faced by O&G companies[b].(*4*) Besides risk management, some investors also have an ethical mandate to ensure their investments do not undermine international climate goals.

One way to understand company positioning and performance on climate change is to use Environmental, Social and Governance (ESG) ratings. These ESG ratings have a traditional focus on companies' managerial practices, for example whether companies have established a climate change policy. While measures of company inputs/effort can be useful, they do not inform investors about what ultimately matters for climate change, i.e. GHG emissions. For this, investors tend to rely on estimates of companies' current carbon footprint, in particular GHG intensity.(*5*, *6*) However, typical carbon footprinting methods have several limitations. First, they are often limited in scope to companies' operational emissions, whereas the majority of emissions can occur either further up the value chain or, as in O&G, further down (see below). Second, emissions are often normalised by company revenue when calculating intensity, but revenue is both volatile and difficult to project into the long run, compared with measures of physical production.(*7*) Third and most importantly, by relating to current emissions they provide limited information about companies' future emissions and therefore about companies' preparedness to undergo a transition.

In this paper, we present a method of estimating forward-looking, lifecycle GHG intensities of public O&G producers and comparing them with scenarios that limit global warming to different levels, e.g. 1.5°C. This is with a view to answering the question; how do companies' climate targets compare with international goals, notably those of the 2015 UN Paris Agreement on climate change? We seek to provide an independent means of evaluating the growing number of company claims to be 'Paris-aligned'[c]. We also analyse covariates of companies' GHG intensities, which paves the way to assess the potential of strategies such as reducing operational emissions and shifting to gas.

Our method is based on GHG intensities so that we can control for the obvious role of company size in determining emissions. This creates a challenge, however, as keeping temperatures to 2°C or below requires staying within an absolute CO2 emissions budget.(*8*) We follow the Sectoral Decarbonization Approach (SDA) in reconciling an intensity approach with an absolute emissions budget.(*7*, *9*) An energy model is run within an absolute emissions budget to obtain projections of emissions and activity/production by sector. Dividing the former by the latter gives sectoral GHG intensity pathways, which are used as benchmarks against which to compare companies' own transition pathways. Note that our approach otherwise differs from the SDA in specific ways (see Methods).

[b] Other sources of risk to O&G companies and their investors include the risks associated with supply and demand shocks due to climate change's physical impacts (physical risk), and financial liabilities stemming from companies' historical emissions (liability risk), as exemplified by a rising number of court cases, and fuelled by advances in attribution science.(*32*, *33*)

[c] For example, Royal Dutch Shell: "With this approach [Shell's climate targets], we want to contribute to achieving a net-zero world, where society stops adding to the amount of greenhouse gases (GHGs) in the atmosphere. This supports the most ambitious goal to tackle climate change laid out in the Paris Agreement: to limit the rise in average global warming to 1.5°Celsius."(*34*)

Our lifecycle measure of companies' GHG intensity includes not only their operational (Scope 1 and 2) emissions, but also emissions down the value chain from use of sold products (Scope 3, category 11), i.e. burning O&G for energy in buildings, electricity, industry and transport. Emissions are normalised by energy sales/supply and compared with global primary energy supply, including coal, O&G, nuclear, renewable electricity and biofuels. We present a method of sourcing emissions and energy sales conveniently yet consistently using companies' public disclosures. Our assessment includes company emissions disclosures up to September 2020 and emissions reduction targets announced by January 1st 2021.

We show that, as a group, the world's 52 largest public O&G producers are far from being aligned with limiting global warming to 2°C or below using this methodology and performance indicator. Recent trends in GHG intensity have been mostly flat. Some companies are yet to set emissions targets and some others provide limited clarity on what they cover and how they will reduce company-wide emissions. Of those that have set assessable targets, most targets are either too shallow (i.e. the percentage cut is too low) or too narrow (i.e. key emissions sources, notably from use of sold products, are excluded from the target). Encouragingly, some companies have set long-term emissions targets covering most/all company emissions, including targets labelled as 'net zero'. The most ambitious of these would see the companies in question bring their GHG intensity below the low-carbon benchmarks by 2050: Occidental Petroleum under the 1.5°C benchmark, and Royal Dutch Shell under the 2°C benchmark. For these companies, attention turns to the strategies underpinning the targets.

The state of company emissions disclosure and current emissions intensity

Our emissions intensity metric is: Scope 1 and 2 GHG emissions, plus GHG emissions from use of externally sold energy products (Scope 3, Category 11), per unit of energy sales. This captures the vast majority of O&G producers' lifecycle emissions.(*2*)

We focus on the world's top 50 public O&G producers by market capitalisation. These are companies in the ICB 'Oil and Gas Producers' sector, including upstream exploration and production (E&P) companies, integrated O&G companies involved not only in E&P but also in downstream refining, distribution and retail, as well as a few specialist downstream companies. Since 2017, the list of companies in the top 50 has naturally been subject to some fluctuation. We include new entrants to the top 50 since 2017, as well as retaining companies that have fallen outside the top 50, resulting in a total of 52 companies included in our analysis.

Table 1 takes these 52 O&G producers and surveys the state of emissions disclosure by scope. The vast majority of public O&G producers (45 out of 52) now publish data on their Scope 1 and 2 emissions. However, only 23 companies disclose an estimate of their Scope 3 use of sold product emissions and these estimates are based on different and often incomparable methods, because, in a largely voluntary disclosure regime, companies enjoy considerable latitude in choosing how to measure them (e.g. what organisational boundary to choose and which products to include).

Table 1. Disclosure of emissions and emissions targets by the world's top 52 public O&G producers (emissions disclosures up to September 2020 and targets announced by Jan 1st 2021). Disclosures are disaggregated by scope of emissions.

			Historic emissions data disclosure			Emissions target disclosure		
Company Name	**Mkt cap ($bn)***	**Assessment period**	**Scope 1**	**Scope 2**	**Scope 3****	**Scope 1**	**Scope 2**	**Scope 3****
Saudi Aramco	1,747.41	2018-2018	●	●				
Exxon Mobil	236.31	2014-2018	●	●		●	●	
Chevron	191.63	2014-2019	●	●	●	●	●	
Royal Dutch Shell	183.28	2017-2019	●	●	●	●	●	●
Total	119.89	2014-2019	●	●	●	●	●	●
Reliance Industries	117.54	a) & b)	●	●			x	
BP	86.84	2014-2019	●	●	●	●	●	●
Gazprom	76.95	2014-2019	●	●	●		x	
CNOOC	59.97	2016-2019	●	●				
Rosneft Oil	58.66	2014-2019	●	●	●	●	●	
Equinor	55.42	2014-2019	●	●	●	●	●	●
ConocoPhillips	53.67	2014-2019	●	●	●	●	●	
Lukoil	49.85	2016-2019	●				x	
NovaTek	47.58	2014-2019	●	●		●		
Eni	45.33	2014-2019	●	●	●	●	●	●
Petrobras	40.50	2014-2019	●	●	●	●	●	
Phillips 66	38.55	2014-2019	●	●				
Suncor Energy	37.87	2014-2019	●	●	●	●	●	
PTT	35.94	2014-2017	●	●	●		x	
EOG Resources	35.62	2014-2018	●			●	●	
Valero Energy	30.05	2014-2018	●	●		●	●	
Ecopetrol	29.39	2014-2019	●	●			x	
Marathon Petroleum	29.39	2014-2018	●	●		●	●	
Formosa Petrochemical	28.67	a)	●	●			x	
Neste	27.31	2014-2019	●	●	●	●	●	●
Canadian Natural Resources	26.98	2014-2018	●	●			x	
Occidental Petroleum	24.82	2014-2018	●	●	●	●	●	●
TATNEFT	19.93	2016-2019	●			●	●	
Repsol	19.26	2016-2019	●	●	●	●	●	●
Pioneer Natural Resource	18.30	2016-2018	●			●	●	
Oil & Natural Gas	17.64	2016-2018	●	●				
Woodside Petroleum	16.97	2014-2019	●	●	●	●	●	
Hess	15.86	2014-2019	●	●	●			
Imperial Oil	15.08	2014-2019	●	●		●		
OMV	14.05	2016-2019	●	●	●	●	●	●
China Petroleum & Chemical	13.74	2017-2019	●	●		●	●	
ENEOS	13.39	2016-2019	●	●	●	●	●	●
Concho Resources	12.70	2017-2019	●					
INPEX	11.82	2018-2019	●	●	●		x	
Galp Energia	10.68	2017-2019	●	●	●	●	●	●
Diamondback Energy	10.20	2015-2018	●					
SK Innovation	9.46	b)	●	●			x	
Petrochina	9.08	2019-2019	●	●				
Santos	8.69	2014-2019	●	●	●	●	●	
Cenovus Energy	7.97	2014-2019	●	●		●	●	
Noble Energy	7.51	2014-2019	●	●	●		x	
Cabot Oil & Gas	7.34	a)						
Marathon Oil	7.00	2014-2018	●	●				
Devon Energy	6.71	2014-2018	●	●			x	
HollyFrontier	6.51	2016-2019	●	●				
Apache	6.32	2014-2018	●	●			x	
Ovintiv	1.42	2014-2018	●	●				

* Averaged over four quarters from September 2019 to September 2020. When data were not available for all quarters, a company's market cap was estimated using the available quarters.

** Only refers to Scope 3 Category 11: emissions from use of sold product (as per Greenhouse Gas Protocol)

a) No assessment due to insufficient O&G-specific emissions disclosure

b) No assessment due to insufficient energy sales disclosure

● Absolute emissions and/or emissions intensity disclosure available

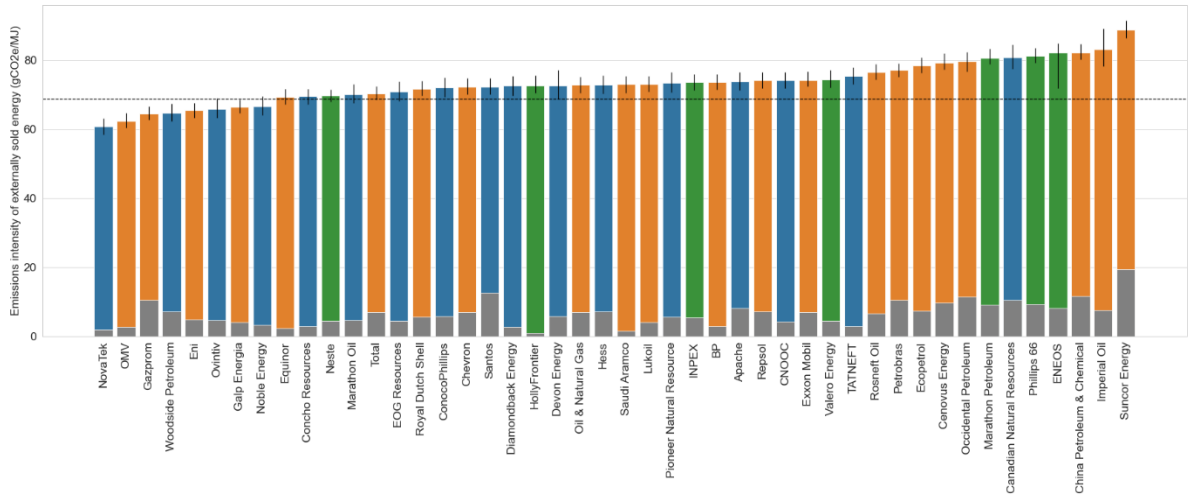
x Company has set some form of Scope 1 and/or 2 target but the scope of the target is too narrow to estimate company-wide future emissions or the target is formulated insufficiently precisely.
● Scope 3 covered by target does not apply to all externally sold energy
● The target covers some form of Scope 3 use of sold product emissions, but is incompatible with our methodology (e.g. missing base year emissions, expressed against a business-as-usual scenario, or includes avoided emissions)

As a result, we developed a bottom-up method of calculating Scope 3 use of sold product emissions on a consistent basis using companies' energy sales/production data. The method is similar to that employed in ref. (*10*) and is described in more detail in the Methods and Supplementary Methods. Scope 3 use of sold product emissions are estimated by applying product-specific emissions factors to externally sold volumes of a wide range of energy products. Similarly, the energy value of companies' sales is estimated by applying net calorific values to those sales. Electricity is converted to primary energy using the Physical Energy Content Method (PECM; see (*11*)), applying average thermal power plant efficiencies. This method is applied to all companies, i.e., we do not use companies' own disclosed Scope 3 use of sold product emissions.

Figure 1 plots company GHG intensities in 2018. This establishes companies' current position (2018 being the most recent year for which data are widely available) and compares that with an estimate of the GHG intensity of global primary energy supply. We are able to source 2018 data for 46 companies. The remaining six companies disclosed insufficient data on either their emissions, production or sales to be included. The average GHG intensity in 2018 was 73.3 gCO2e/MJ on an unweighted basis and 72.9 gCO2e/MJ weighted by energy sales. This implies 424 and 421 kgCO2e/barrel of oil equivalent (boe) respectively assuming an average barrel of oil contains 5,779 MJ of energy (*12*, *13*). Intensities ranged from 60.7 gCO2e/MJ (NovaTek) to 88.7 gCO2e/MJ (Suncor Energy). Disaggregating results by sub-sector, we estimate an overall emissions intensity of 71.1 gCO2e/MJ for O&G E&P (N=17), compared with 74.0 gCO2e/MJ for integrated O&G (N=22). This accords with expectations, since integrated O&G companies have energy-intensive refining and distribution businesses to add to their E&P businesses, though the sample sizes are small and the difference is not statistically significant. We estimate an overall emissions intensity of 76.3 gCO2e/MJ for 'Other O&G' producers, most of which are specialist Refining & Marketing companies (N=7).

Most O&G producers' GHG intensities are above the global energy sector average, although eight are below. The global energy sector average includes coal, which raises the average, but more importantly it includes biofuels, nuclear and renewables, which reduce the average. Compared with data on GHG intensity at the field level,(*14*) public O&G producers' operational GHG intensity shows less variation, possibly due to diversification of production across regions. Companies' GHG intensities are clearly dominated by Scope 3 use of sold product emissions. Scope 1 and 2 emissions account for only 8.5% of companies' overall intensity on average (standard deviation 4.2%; range 1.3-21.9%; mean of E&P companies 7.6%; mean of integrated companies 9.4%).

Figure 1. Lifecycle GHG intensities of the world's top public O&G producers in 2018. Estimates include companies' Scope 1 and 2 emissions, plus Scope 3 emissions from use of externally sold energy products. Scope 1 and 2 emissions for each company are shaded grey. The remainder of company emissions are from Scope 3 use of sold products. The error bars represent uncertainty about Scope 3 emissions from use of sold products, using upper- and lower-bound effective carbon emissions factors. The dotted line represents the estimated GHG intensity of primary energy supply in 2018 (data from IEA/EDGAR). Bars are colour-coded according to GICS sub-industry (blue=E&P, orange=integrated, green=other).



Although emissions from fossil fuel combustion are generally well understood, we perform sensitivity analysis using upper- and lower-bound effective carbon emissions factors(*15*) to re-calculate company GHG intensities. The error bars in Figure 1 show the results of this analysis. Uncertainty stemming from Scope 3 use of sold product emissions is relatively small. The uncertainty is highly correlated across companies because it stems from uncertainty about carbon embodied in generic fuel types. It is largest for companies selling relatively large quantities of bitumen and/or coal. There is additional uncertainty about companies' Scope 1 and 2 emissions, which does not tend to be quantified in company disclosures.

Comparing companies' targets with the Paris Agreement goals

Twenty-eight out of 52 companies (54%) have disclosed a quantitative emissions target and accompanying emissions/energy data sufficient to project their transition pathways into the future. These targets are disclosed on various bases and we explain how we convert them to a common intensity metric in the Methods and Supplementary Methods. Table 1 shows that some other companies have disclosed targets, but not in a form that can be independently assessed in terms of company-wide emissions. For example, these companies do not define the scope of emissions or organisational boundary to which the target applies, or targets are expressed relative to an unquantifiable baseline. Henceforth all emissions reductions are measured relative to the 2018 level.

On an unweighted average basis, companies are targeting reducing their GHG intensity by 16.6% by their end target year (which varies). On the same unweighted average basis, the end target year for achieving this is 2038, i.e. most end targets are relatively long-term. Sixteen companies also have intermediate targets, including most of those with end targets after 2030. The median target equates to just a 6.4% reduction in GHG intensity by the end target

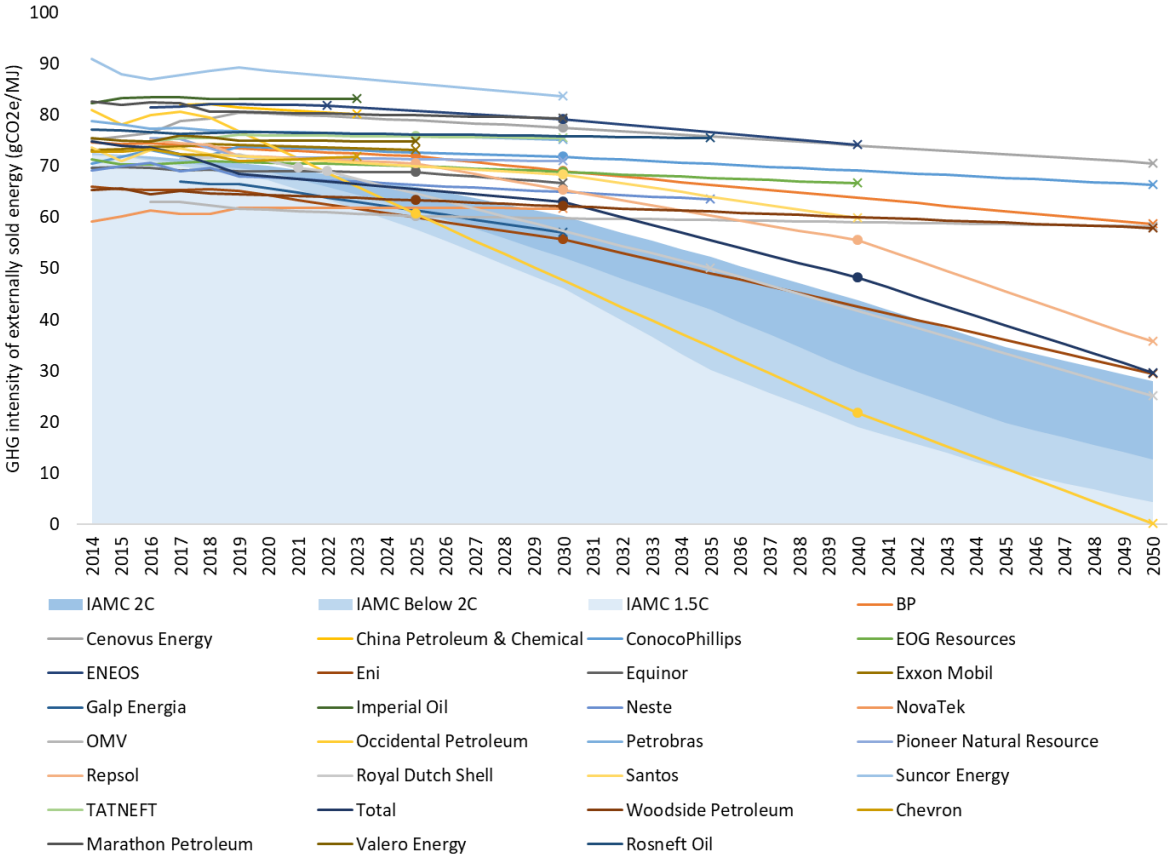
year, however. The distribution is thus heavily skewed by ambitious targets, which have been set by six companies: Occidental Petroleum (a 100% reduction in GHG intensity by 2050, i.e. net zero emissions by our measure), Royal Dutch Shell (-65% by 2050), Total (-58% by 2050), Eni (-55% by 2050), Repsol (-52% by 2050), and BP (-20% by 2050).

Figure 2 compares companies' transition pathways with three decarbonisation scenarios for the energy sector, which are derived from the IPCC/IAMC 1.5°C Scenario Explorer:(*16*, *17*) a 2°C benchmark, a Below 2°C benchmark and a 1.5°C benchmark. Taking the 1.5°C benchmark as our example, GHG intensity falls by 33% by 2030 and 94% by 2050. Decomposing the intensity measure, absolute GHG emissions fall by 43% by 2030 and 93% by 2050, within which methane emissions, small relative to CO2, initially fall faster (by 64% by 2030, but only 83% by 2050). Primary energy supply decreases by 15% by 2030 but increases by 4% by 2050. See the Methods for further details.

Only one company plans to reduce its GHG intensity below the 1.5°C benchmark by 2050: Occidental Petroleum. One further company plans to bring its GHG intensity under the 2°C benchmark by 2050: Royal Dutch Shell. No other company has set an emissions target ambitious enough to beat the 2°C benchmark by 2050 (although Eni, Repsol and Total come close) and most are far from that. Collectively, the world's top public O&G producers are not aligned with the Paris Agreement temperature goals.

Companies' targets fail to align with 2°C or below for one of two reasons: either the targeted reduction is insufficient, or the targeted reduction does not apply to all company emissions. This particularly concerns companies whose targets only cover their Scope 1 and (mostly) Scope 2 emissions, and do not address the dominant emissions from Scope 3 use of sold products (c.f. Table 1). Some of these targets limited to Scope 1 and 2 are described by the companies themselves as 'net zero' targets. Put another way, these companies plan to decrease the GHG intensity of their operations, but not to diversify into low-carbon forms of energy, or deploy carbon capture, utilisation and storage. The companies with ambitious targets all include Scope 3 use of sold products in their targets.

Figure 2. Estimated transition pathways for the 28 companies with emissions targets and sufficient emissions/energy data. End targets are marked with a cross, intermediate targets with a dot. Companies without targets are not shown. These are superimposed on three benchmark, temperature-constrained pathways for the GHG intensity of primary energy supply, using scenario data from the IPCC/IAMC 1.5°C Scenario Explorer.

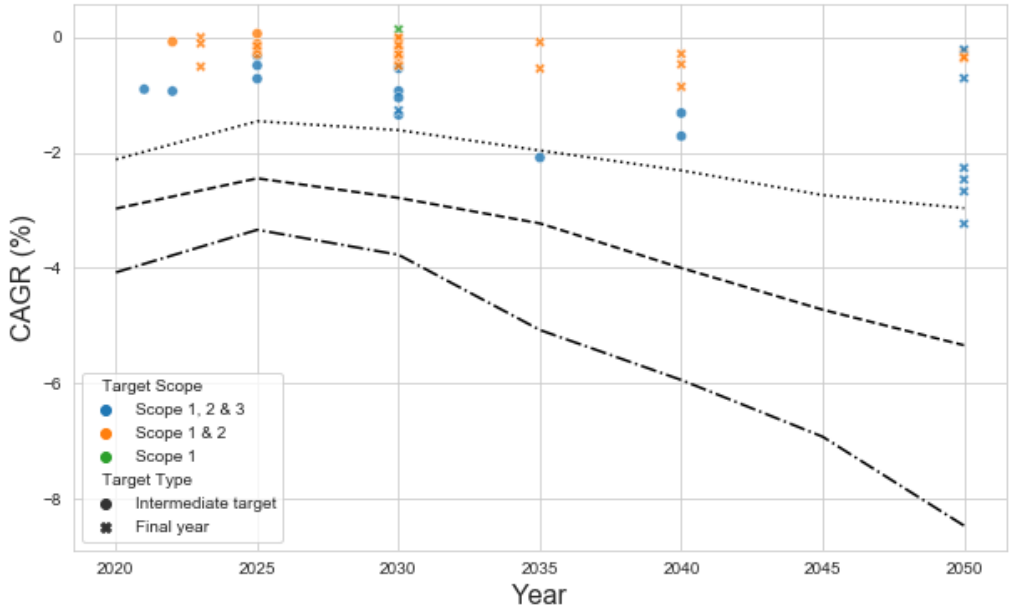


Another way to look at these data is in terms of the compound annual growth/reduction rate (CAGR) of GHG intensity (Figure 3). CAGR is a familiar concept in financial appraisal. In this context, it describes the average speed at which companies would need to reduce their GHG intensity in order to keep pace with the low-carbon transition. The CAGR required to bring the average company's GHG intensity down to the 2°C benchmark in 2050 is -3.0% (measured from the unweighted average company GHG intensity in 2018 of 73.3 gCO2e/MJ). The corresponding CAGR required to meet the Below 2°C benchmark is -5.3%, while for 1.5°C it is -8.5%. In contrast, the CAGR of the targets we assess is mostly much slower. Excluding Occidental Petroleum, the unweighted average CAGR of company targets is just 0.7%. Some of the longer-term targets that cover Scope 3 use of sold product emissions imply faster CAGRs of -2% or better. Moreover, if companies do not meet the benchmarks until 2050, then unless their absolute energy sales are falling fast enough (e.g. due to falling market share), companies' cumulative absolute emissions between now and 2050 will be above the corresponding benchmark carbon budget.

Decarbonisation in line with the Paris Agreement goals appears even more challenging when looking at recent trends in GHG intensity. On an unweighted average basis, GHG intensities declined by just 0.1% per annum between 2014 and 2019 (n.b. these data are for an

unbalanced panel of companies, given varying degrees of historical emissions disclosure). European companies (excl. Russia) decreased their GHG intensity by -0.5% p.a. on average, whereas GHG intensities were approximately flat outside Europe (+0.02% p.a. on average). For the same period, the largest average reduction was -1.8% p.a. (Total), whereas the largest increase was 1.4% p.a. (Cenovus Energy).

Figure 3. Implied emissions CAGRs. The scenario lines indicate the implied CAGR for the unweighted average company GHG intensity in 2018 to reach the respective scenarios in a given year. Companies without targets are not shown in the figure. Occidental Petroleum is excluded as it targets reducing GHG intensity to zero, thus its CAGR is not defined.



Factors related to companies' current GHG intensity

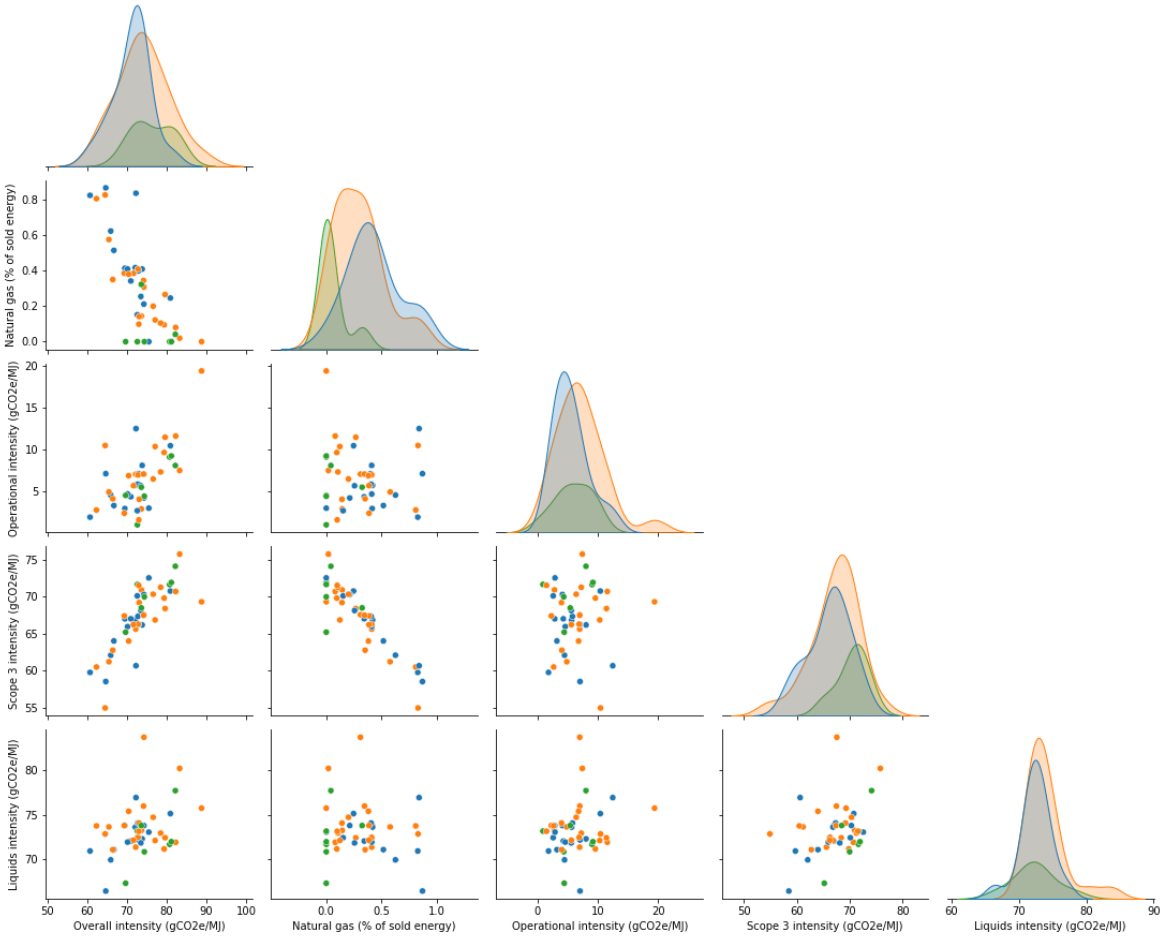
Companies' future emissions intensity is a product of (i) their current emissions intensity and (ii) their emissions targets. Figure 4 analyses the relationship between companies' 2018 GHG intensity and several potential covariates that we were able to systematically collect.

Product mix: As companies' GHG intensities are dominated by Scope 3 use of sold product emissions, product mix matters. Lifecycle GHG intensity is strongly negatively correlated with the share of natural gas in companies' sales/production (Pearson's r=-0.76, p=6.3E-10). Lifecycle GHG intensity is positively correlated with companies' GHG intensity of liquids (Pearson's r=0.37, p=0.01), because liquids emit a wide range of CO2 per unit of energy when burned (from 63.1 gCO2/MJ for LPG to 80.7 gCO2/MJ for Bitumen). Companies' GHG intensity of liquids is therefore determined by the mix of liquids they sell. These results are consistent with the strategy of reducing emissions through shifting the product portfolio towards lower-carbon liquids and gas.(*18*)

Operational emissions: The second strongest association we find is between lifecycle and operational (i.e. Scope 1 and 2) GHG intensity (Pearson's r=0.63, p=3.1E-06). Naturally this

implies that O&G companies can also reduce their lifecycle GHG intensity by reducing their operational GHG intensity, albeit the effect is more limited. Operational GHG intensity is not significantly associated with Scope 3 GHG intensity, the share of gas in the product mix, or the GHG intensity of liquids. Hence operational GHG intensity does not appear to be related to product mix, at least as it affects emissions intensity. This is consistent with the analysis of the International Energy Agency, which suggests that the median operational GHG intensities of oil and gas are similar,(*19*) although any correlation between operational GHG intensity and product mix may be masked by (i) aggregation to the company level and (ii) noise in the data.

Figure 4. Pairwise correlations between covariates of GHG intensity. Each cell in the matrix explores the correlation between two factors. The distributions of the data are plotted on the diagonal. Data points are colour-coded according to GICS sub-industry (blue=E&P, orange=integrated, green=other). The same data are shown broken down by region in the Supplementary Results Figure 4.



Regional and size effects: As shown in Supplementary Results Table 1, we find a significant association between companies' home country (i.e. the country in which the company is listed) and lifecycle GHG intensity using a Kruskal-Wallis rank sum test (p=0.03). This could reflect the geographical nature of reserves (e.g. Canadian oil sands), markets or regulation. It

is consistent with evidence of considerable cross-country variation in the GHG intensity of oil production(*14*) and refining(*20*). We do not find any association between company size (as measured by both free float and non-free float market cap) or type and lifecycle GHG intensity.

Factors related to companies' GHG emissions targets

We do not find a significant association between whether a company has set a target (yes/no) and company region, however target strength, measured in terms of the size of planned emissions reductions, is significantly associated with company region (Kruskal-Wallis rank sum test, p=0.02). Most of the largest planned emissions reductions are by European companies (see Supplementary Results Figure 5).

Whether a company has set a target (yes/no) is associated with company size as measured by free float market cap (Kruskal-Wallis rank sum test, p=0.01), but target strength is not significantly associated with size. Hence, bigger companies are more likely to set targets than smaller ones, but when it comes to target strength there is no significant difference.

We do not find a significant association between target-setting and the percentage of gas in the product mix, the emissions intensity of liquids sold, operational emissions intensity, Scope 3 use of sold product emissions intensity, or companies' lifecycle GHG intensity in 2018. One might have expected companies that are better positioned to transition to low-carbon energy by virtue of their business model and position in the sector to be more likely to set emissions targets, but our data do not show that.

Summary, limitations and future research agenda

Investors are increasingly focused on the climate strategies of public O&G companies. We have developed a quantitative method of assessing O&G producers' emissions targets and comparing them with international climate goals as simulated by IPCC energy models. The method translates commonly disclosed emissions and production/sales data into a consistent estimate of companies' lifecycle GHG intensity and is forward-looking. To facilitate comparisons between companies of different size, the method is intensity-based, but the low-carbon scenarios comply with absolute emissions budgets.(*7*) Although climate goals are increasingly common among O&G producers, few would bring about a significant reduction in companies' lifecycle GHG intensity.

Further analysis indicates that changing the relative proportions of energy products in companies' energy sales portfolio – away from liquids with high GHG intensity towards liquids with low GHG intensity and especially gas – is a tool to decarbonise in the short to medium term. However, in the longer term shifting to gas will not be enough, as the GHG intensity of primary energy supply falls below the GHG intensity of natural gas in low-carbon scenarios. Operational emissions reductions, including in relation to methane and flaring, can have some effect, but when GHG intensity is measured on a lifecycle basis the potential appears to be more limited. Instead, in order to reduce GHG intensity at a pace consistent with decarbonisation of primary energy in 2°C scenarios and below, O&G producers would need to pursue additional strategies such as investing in renewable energy, or carbon capture, utilisation and storage (*21*). For example, Occidental Petroleum's target is underpinned by a

strategy to deploy Direct Air Capture of atmospheric CO2,(*22*) while Royal Dutch Shell's target is based in large part on a strategy of diversifying into renewables.(*23*)

A number of caveats and limitations apply to our research. Among the more important are the following:

- Whilst GHG intensity is a valid metric for a wide range of decarbonisation strategies, including diversification into renewables and also specialisation in carbon capture, utilisation and storage, decarbonisation of energy sold is not the only path O&G producers can take to cut emissions. For some companies, stopping investment in O&G production and returning cash to shareholders may be better. The effectiveness of this approach can only be tracked using absolute emissions, but with absolute emissions one loses the capacity to compare companies' intensities. Even if a company does pursue a strategy to exit from energy, our approach can still help to separate out companies that plan to meaningfully reduce their emissions intensity from companies that do not, facilitating a more focused engagement with the latter companies on what they are doing instead and why. A two-part test may be appropriate, whereby companies can be aligned with climate goals either based on their GHG intensity/decarbonisation goals as set out in this paper, or their absolute GHG emissions/plans to wind down O&G production. Benchmarking changes in absolute emissions is potentially problematic, as these changes are largely determined by company size. However, this could be achieved by allocating each company a proportion of the emissions budget in the target year based on its current market share. To claim alignment with a climate goal, the company would set a target to reduce its absolute emissions to this level. This is an item for future work, since we are yet to see O&G companies declare harvest/wind-down strategies (only one company, Eni, has a long-term, absolute emissions target covering Scope 3 use of sold products and it also has an intensity target that we can work with).

- We have been confronted with a series of decisions on the scope of our analysis. We aggregate oil and gas products, because many companies we assess produce both and changing the product mix is a viable strategy for many. However, this can be contested given that oil and gas products serve rather different markets. We treat all oil producers as comparable, including upstream E&P companies and integrated companies. Again, this is contestable. However, our analysis indicates that there are only modest differences between E&P and integrated companies' GHG intensities (on various measures). We compare O&G producers to an emissions benchmark for all primary energy, including coal, nuclear, renewable electricity and biofuels. This is certainly challenging for O&G producers to achieve but reflects the fundamental shift in the primary energy mix in low-carbon scenarios. We include Scope 3 use of sold product emissions in our GHG intensity measure, because that is where the vast majority of lifecycle emissions come from. Future work could focus just on O&G companies' Scope 1 and 2 emissions. Currently, energy models tend not to provide projections of the O&G industry's Scope 1 and 2 emissions alone, however.

- Our method makes future projections based on companies' stated emissions targets. However, companies need to back up their targets with viable strategies and thus it will be important to look at our data alongside complementary analyses, such as those of companies' governance/management practices(*9*) and their proved reserves and new capital expenditure.(*24*)
- Our method relies on the accuracy of company emissions disclosures. Although these disclosures are often independently audited, they have been questioned in various respects.(*25*, *26*) In O&G, a particular concern is possible under-reporting of methane emissions.(*27*) A systematic, like-for-like comparison of company disclosures with data from alternative sources such as asset-level data has yet to be undertaken and would be of value.
- Disclosure frameworks/regimes currently allow companies to choose their organisational boundaries for emissions accounting (principally financial/operational control versus equity share). With a choice of consolidation approach and relatively small shifts in asset ownership, companies can influence both their emissions and emissions intensity.

Methods

About the Transition Pathway Initiative

This research is an output of the Transition Pathway Initiative (TPI). TPI is a global, investor-led initiative to assess companies' progress on the transition to a low-carbon economy. The results are published open-access at http://www.transitionpathwayinitiative.org, which also contains further information about the initiative.

Company sampling procedure

The TPI company database has been amassed by first selecting sectors of the economy with high aggregate GHG emissions and high emissions intensity, including O&G production. Then, in each sector, the largest publicly listed companies are selected on the basis of their free-float market capitalisation/value, which is a proxy for investor exposure, i.e. for the importance of a company to the portfolio of an average investor in world equities. Although the O&G sector contains a number of large state-owned enterprises, few of these are relevant to equities investors.

The Sectoral Decarbonization Approach

TPI's assessment of corporate GHG emissions draws on the SDA.(*7*) The SDA translates emissions targets made at the international level (for example under the 2015 Paris Agreement to the UN Framework Convention on Climate Change) into appropriate benchmarks, against which the performance of individual companies can be compared.

The SDA is built on the principle of recognising that different sectors of the economy (e.g. oil and gas production, electricity generation and automobile manufacturing) face different challenges arising from the low-carbon transition, including where emissions are

concentrated in the value chain, and how costly it is to reduce emissions. Other approaches to translating international emissions targets into company benchmarks have applied the same decarbonisation pathway to all sectors, regardless of these differences.(*28*)

Therefore the SDA takes a sector-by-sector approach, comparing companies within each sector against each other and against sector-specific benchmarks, which establish the performance of an average company that is aligned with international emissions targets.

Our application of the SDA involves the following steps:

1. A global carbon budget is established, which is consistent with international emissions targets, for example keeping global warming below 2°C. Carbon budgets are set using climate modelling.
2. The global carbon budget is allocated across time and to different industrial sectors. This is done using an integrated economy-energy model. These models usually allocate emissions reductions by sector according to where it is cheapest to reduce emissions and when (i.e. the allocation is cost-effective). Cost-effectiveness is, however, subject to some constraints, such as political and public preferences, and the availability of capital. This step is therefore driven primarily by economic and engineering considerations, but with some awareness of political and social factors.
3. Sectoral emissions are normalised by a relevant measure of sectoral activity (e.g. physical production, economic activity). This results in a *benchmark* pathway for emissions intensity in each sector, against which companies can be compared. Assumptions about sectoral activity need to be consistent with the emissions modelled and are therefore taken from the same energy modelling. There is a preference for physical production as the activity measure, since it is less volatile than financial measures like revenue, and can be projected into the long term with fewer assumptions.
4. Companies' recent and current emissions intensity is calculated and their future emissions intensity can be estimated based on emissions targets they have set. Together these establish emissions intensity pathways for companies. Note that unlike ref. (*7*), companies' pathways do not necessarily converge on the sectoral emissions intensity in 2050 – this depends on what targets companies have actually set.
5. Companies' emissions intensity paths are compared with each other and with the relevant sectoral benchmark paths.

The SDA is primarily intended as a test of the level of ambition of company targets and may be less reliable as a predictor of companies' future emissions intensity, since companies may under- or over-deliver on their targets. Further discussion of this point is provided in ref. (*9*).

Applying the SDA to oil and gas production

In applying the SDA to any sector, we must establish (i) the scope of emissions to include and (ii) an appropriate measure of sectoral activity/production. Choosing (i) typically involves

making a trade-off between comprehensiveness (i.e. including as many lifecycle emissions as possible) and data availability. In O&G production, investors' interest in transition risk justifies including not only Scope 1 and 2 emissions, but also emissions down the value chain from use of sold products (Scope 3, category 11), which account for the vast majority of lifecycle emissions from O&G.(*29*) Other sources of value-chain or Scope 3 emissions exist, but these are relatively trivial for O&G producers and we ignore them on the grounds that company disclosure is limited (see Table 1). On (ii), O&G companies are primarily energy suppliers (the other main market is petrochemicals), so an appropriate measure of activity is aggregate energy supply. This is defined as total net calorific energy supply from all fuels, including hydrocarbons, biomass and waste, plus any energy supplied by O&G companies as electricity generated from fossil fuels, nuclear or renewables. The transition to a low-carbon economy requires a wholesale shift of the energy system away from fossil fuels.

At the company level, we need to measure energy supply in a way that enables upstream and downstream O&G companies to be compared consistently. For this, we establish the concept of 'assessed product', a.k.a. energy sold externally, which includes primary, refined, finished and traded O&G products (excluding derivatives trading), as well as other energy (e.g. renewable electricity). See the Supplementary Methods for further information about assessed product (especially Supplementary Methods Figure 1).

In summary, our emissions intensity metric is: Scope 1, 2 and 3 (use of sold product) GHG emissions from energy products sold externally in units of grams of CO2 equivalent (gCO2e) per mega joule (MJ).

Benchmark scenarios

Projections of GHG emissions and production are obtained from the IPCC/IAMC 1.5°C Scenario Explorer hosted by IIASA.(*16*, *17*) Companies are compared with three benchmark scenarios linked to the goals of the 2015 UN Paris Agreement on climate change (specifically Article 2):

1. A *1.5°C scenario*, comprising scenarios classified by the IPCC as Below 1.5°C (limiting peak warming to below 1.5°C throughout the 21st century with 50–66% likelihood) and 1.5°C with low overshoot (limiting median warming to below 1.5°C in 2100 and with a 50–67% probability of temporarily overshooting that level earlier).
2. A *Below 2°C scenario*, comprising scenarios classified by the IPCC as 1.5°C with high overshoot (limiting median warming to below 1.5°C in 2100 and with a greater than 67% probability of temporarily overshooting that level earlier) and lower 2°C (limiting peak warming to below 2°C throughout the 21st century with greater than 66% likelihood).
3. A *2°C scenario*, comprising scenarios classified by the IPCC as higher 2°C (keeping peak warming to below 2°C throughout the 21st century with 50-66% likelihood).

For each benchmark scenario, we obtain the following data points from the scenario database:

- Emissions|CO2|Energy: CO2 emissions from energy use on supply and demand side (IPCC category 1A, 1B) (Mt CO2/yr);
- Emissions|CH4|Energy: CH4 emissions from energy use on supply and demand side, including fugitive emissions from fuels (IPCC category 1A, 1B) (Mt CH4/yr);
- Primary energy: total primary energy consumption (direct equivalent) (EJ/yr);
- Final Energy|Non-Energy Use: final energy consumption by the non-combustion processes (EJ/yr).

Energy-related CO2 and CH4 emissions are added together to give total energy-related GHG emissions (CH4 emissions are converted to CO2 using a 100-year Global Warming Potential of 28). Dividing total energy-related GHG emissions by primary energy gives the GHG intensity of primary energy. We adjust primary energy by deducting from total primary energy consumption the share of final energy consumption by non-combustion processes (e.g. plastic and petrochemical production).

While pure E&P companies only sell primary energy, integrated companies provide some of their externally sold energy products in the form of final energy. For some types of final energy, primarily electricity, this distinction is important due to large energy losses in conversion (see Supplementary Methods). For liquid fuels, however, the losses in conversion are small.(*30*)

The IPCC/IAMC 1.5°C Scenario Explorer provides multiple scenarios within each of the above benchmark categories. This multiplicity comes from different energy models run with different assumptions. For consistency, we only consider the subset of models that produce scenarios in all three benchmark categories, namely AIM/CGE, IMAGE and REMIND. Having excluded other models, we then calculate, for each benchmark category above, the weighted average GHG intensity of primary energy. That is, we first average all emissions intensity scenarios produced by each model individually, and then average across the three models, with each model given 1/3 weight. Table 2 summarises emissions and energy data for the benchmark scenarios.

Table 2. Emissions and energy data for the benchmark scenarios. Note intensities are calculated at the model/scenario level before averaging. Initial year of IAMC database is 2010.

	2018	2025	2030	2035	2040	2045	2050
	Emissions|CO2|Energy (Mt CO2/yr)						
2°C	34281.1	32878.9	29635.9	25347.5	21567.3	17520.1	14762.8
Below 2°C	33527.8	28307.5	22809.2	18145.9	13474.7	9512.3	6430.8
1.5°C	32185.4	25500.2	19137.0	12251.9	8003.0	4599.7	1874.9
	Emissions|CH4|Energy (Mt CO2e/yr)						
2°C	3276.7	2475.3	1955.5	1459.0	1101.9	920.8	828.1
Below 2°C	3162.8	2043.3	1497.0	1107.0	849.0	708.1	610.0
1.5°C	3196.6	1682.2	1146.2	867.7	709.3	617.7	545.8
	Primary Energy excl. non-energy (EJ/yr)						
2°C	532.4	535.4	524.0	512.8	519.2	535.4	564.1

Below 2°C	526.7	490.8	460.7	454.9	469.3	497.4	529.3
1.5°C	518.0	471.1	441.2	439.7	468.7	504.0	537.0
	GHG intensity (gCO2e/MJ)						
2°C	71.0	66.0	60.2	52.2	43.7	34.6	27.9
Below 2°C	68.9	61.5	52.1	41.9	29.8	19.8	12.6
1.5°C	69.2	57.7	46.1	30.2	19.0	10.5	4.3

Calculating company emission intensities

Company emissions intensity data are sourced from their public disclosures. The data sources include company reports, e.g. their annual and sustainability reports, company websites, and responses to the annual CDP (formerly Carbon Disclosure Project) questionnaire. Disclosed emissions data tend to come in one of two forms:

1. *Emissions intensity data*: some companies disclose their recent and current emissions intensity and some companies have also set future emissions targets in intensity terms.

2. *Absolute emissions data*: some companies disclose their recent and current emissions on an absolute (i.e. un-normalised) basis. Some companies similarly set future emissions targets in terms of absolute emissions. This raises the particular question of what to assume about those companies' future production. We assume company production increases at the same rate as the sector as a whole (i.e. this amounts to an assumption of constant market share), using sectoral growth rates from the IEA.(*31*) While companies' market shares are unlikely to remain constant, there is no obvious alternative assumption that can be made, which treats all companies consistently.

The length of companies' emissions intensity paths will vary depending on how much information companies provide on their emissions, as well as the time horizon for their emissions targets.

Companies disclose emissions using different organisational boundaries. There are two high-level approaches: the equity approach and the control approach, and within the control approach there is a choice of financial or operational control. Companies are free to choose which organisation boundary to set in their voluntary disclosures and there is variation between companies assessed in this paper. We accept emissions reported using any of the above approaches to setting organisational boundaries, as long as: (i) the boundary that has been set appears to allow a representative assessment of the company's emissions intensity; (ii) the same boundary is used for reporting company emissions and production, so that a consistent estimate of emissions intensity is obtained. At this point in time, limiting the assessment to one particular type of organisational boundary would severely restrict the breadth of companies we can assess.

The Supplementary Methods contains more information about how company emissions intensities are calculated.

Data sources and validation

538 The preliminary assessment of each company goes through a company review stage, in which
539 the company is contacted with a draft of our assessment and invited to check the veracity of
540 the disclosed data being used, as well as being requested to answer specific queries in some
541 cases. Companies may propose corrections, but they must be supported by publicly available
542 data and cannot be altered on the basis of data that are only communicated privately to us.
543 The response rate for the sample of companies in this paper was 58%.

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Contributions

The methodology was designed by all authors, led by S.D. and D.G.. V.J. analysed the data with input from S.D., D.G. and J.N.. S.D. and V.J. drafted the paper with input from D.G. and J.N.

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Competing interests

The authors declare no competing interests.