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The Paris-compliant company: Measuring transition performance against the Paris goals using a strict science-based approach

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The achievement of the Paris climate goals of well-below 2 degrees of warming requires that companies align their emissions with this goal. To measure whether companies are compliant with the Paris Agreement targets we propose several strict conditions specifying what an emissions allocation methodology requires before it can be classified as Paris-Compliant, and then examine the current methodologies for their compliance with these conditions. Our conditions focus on the need for a common ambitious base year for all companies that is consistent with an underlying decarbonisation pathway aligned with the Paris goals. Additionally we propose five operationalisation requirements to ensure companies can declare they are on a Paris Compliant Pathway and that any re-alignment pathway strictly adheres to the Paris-compliant carbon budget. Applying example Paris-Compliant Pathways and associated metrics to ten high emission energy companies and eight cement companies, we find that none are currently Paris-compliant, with every year of delayed action increasing their required rate of decarbonisation and hence the exposure of billions of investment dollars to transition risk. Applying our proposed method ensures the Paris carbon budget will be met and that progress can be tracked accurately, which is imperative for companies and stakeholders to align their decision-making with the Paris Agreement.

Introduction

There is international agreement that to avoid the worst effects of climate change, global temperature increases must be limited to 'well below 2°C above pre-industrial levels' [1]. Stabilising global temperatures in line with this primary objective of the Paris Agreement requires net emissions of greenhouse gases to decline rapidly and reach net zero by around 2050[2]. Companies have an important role to play in achieving these goals [3]. They contribute to greenhouse gas emissions directly, through their operations (Scope 1 or 2 emissions), and indirectly, through upstream and downstream emissions (Scope 3), such as those associated with the use of their products [4, 5]. Business strategy, investments, innovation, and lobbying practices may also affect emissions [6].

Despite evidence of increasing commitment to strengthen global action, most businesses globally are failing to significantly reduce their greenhouse gas emissions [7], an issue exacerbated by a lack of emission regulations in many countries. Continued business inaction on emissions reductions will render the goals of the Paris Agreement unachievable. Consequences of allowing climate change to continue include considerable economic and financial risk for most companies [8], while evoking ethical concerns for the resulting impacts to the lives of global communities disconnected in space and time from the emission source [9-11].

Addressing climate change requires an increased awareness of climate risk by company executives, the support of regulators, investors, and other stakeholders to ensure firms are managed in a way that they can remain profitable through the transition [12], and a sense of shared responsibility for firms to reduce their emissions [13]. Fortunately, pressure for companies to take account of their greenhouse gas emissions and associated climate risk has been growing over the last few decades [15-17]. The recently formed Task Force on Climate-Related Financial Disclosures (TCFD) has spurred an enormous growth in efforts for companies to report on climate risk. Most recently, Larry Fink, the CEO of the largest asset manager in the world, BlackRock, in his annual letter to clients asked them to "disclose a business plan aligned with the goal of limiting global warming to well below 2ºC, consistent with achieving net zero global greenhouse gas emissions by 2050" [18].

For companies to produce an effective business plan for addressing their Paris-Compliance requires a consistent and defensible framework for translating this global goal into specific targets for all companies in all sectors [19]. This includes the construction of science-based, fair, and company-specific greenhouse-gas emission metrics that assess a firms' alignment to this mutually agreed climate target.

A number of methodologies for converting global climate targets to company-specific emissions trajectories have been developed [13, 20, 21, 22]. It is now increasingly common for companies to set climate targets through the Science Based Targets initiative, which as of August 2021 boasted over 1,700 companies "taking action" through this initiative, a tripling in less than two years [25, 26]. Emission reduction targets, or specifically, Paris-compliant emission reduction levels, are instrumental in evaluating the performance of companies against these climate goals. Yet, until recently, it was uncommon for science-based methodologies to be used by sustainability rating agencies to measure a firm's climate performance [21].

This paper first proposes two conditions that must be met before an allocation method can be considered Paris Compliant, and one desirable condition. Secondly, we specify five further requirements on how a Paris-Compliant methodology must be *operationalised* to ensure the combined emissions of all companies stay within the Paris carbon budget. A company can follow many different emissions reduction pathways, but only a limited number will be Paris-Compliant. We refer to any such emissions reduction pathway for a given corporation as a Paris Compliant Pathway (PCP) if it applies a methodology that meets our allocation conditions and adheres to our operationalisation requirements.

Thirdly, we propose metrics that evaluate the performance of a company against its chosen PCP and ultimately its compliance with the Paris climate goals. Finally, we apply our

PCP approach to major companies from two very different economic sectors, the data-rich Australian electricity industry, and the data-poor global cement production industry, all of which have billions of dollars of assets potentially at risk of stranding [29], to demonstrate the use of our assessment conditions on real companies and industries.

A strict methodology for assessing companies' Paris compliance

Translating the goals of the Paris Agreement to the company specific carbon budgets and PCPs requires a budget allocation methodology. We propose two necessary conditions that must be met for any allocation methodology to be suitable for assessing Paris Compliance, and one desirable condition. First, the underlying global or regional decarbonisation pathway(s) used by the methodology must be consistent with the goals of the Paris Agreement, peaking of global emissions as soon as possible, and holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels [30].

Second, the base year from which progress is measured should be set in 2015 or prior and needs to be consistent with the underlying decarbonisation pathway (of condition 1), consistent with the "enhanced action prior to 2020" section of the Durban Platform for Enhanced Action CP.21 (2015) referred to in the Paris Agreement (Paris Agreement, Article 4, Part 8) and the pathways outlined in the IPCC special report on 1.5ºC [2]. Base years have been shown to clearly have a significant influence on a company's carbon budget [31]. If companies are not evaluated against a common, and ambitious, base year, it is not possible to compare their actions-to-date against climate goals or against the progress of other companies, and virtually impossible to ensure actions are on target with the Paris goals. Technically speaking there are and will continue to be global emission reduction pathways that are consistent with a "well-below" 2°C temperature goal, that start in 2016 or later. However, these pathways are requiring faster decarbonisation rates with every year of global inaction. More importantly allowing base years of 2016 or later either allows the global carbon budget to be exceeded or unfairly reduces the established carbon budget of those companies who have been taking appropriate action since (or before) the Paris Agreement was signed.

Finally, a desirable, but not necessary condition is that the methodology should account for "common but differentiated responsibilities" in addressing climate change [32], meaning that companies in developed nations have a greater responsibility in mitigating climate change than companies in developing countries. The methodology should be clear on how it allocates the budget amongst companies in different countries.

Applying these conditions we evaluate four allocation methodologies that have a version of their approach published since 2015: the Sectoral Decarbonisation Approach (SDA) [13, 33], Greenhouse gas Emissions per Unit of Value Added (GEVA) [20; 33], the Absolute Contraction Approach (ACA) [33] and the Context-based Carbon Metric method developed by the Centre for Sustainable Organisations (CSO) [22] (Table1).

Condition	**ACA**	**GEVA**	**SDA**	**CSO**
1) Underlying decarbonisation pathway consistent with "well-below 2C"	Yes Eligible scenarios selected as per process detailed in SBTi foundations for target setting (2) (An emission scenario envelope derived from Huppmann et al. (2018); for well-below 2°C, and 1.5°C.	No Unclear, but 50% GHG reductions between 2010-2050.	Yes - IEA Beyond 2°C Scenario (IEA B2DS) - 50% chance of limiting global average temperature rise to 1.75°C above pre-industrial levels.	Yes - SSP1-1.9 CMIP6; 1.345°C (CSO, 2021) - CERC-LED-OECD; 1.5°C.
2) Base year 2015 or prior	No. 2020 (note they also allow from earlier years with a higher target for SMEs; i.e. 50% from 2018 in 2035 or 42% from 2020 to 2035). The scenario identified in condition 1 starts from 2020.	Yes 2010 only	Yes Depends on IEA scenario: - 2014 for IEA B2DS (ETP, 2017)	Yes 2015 (CSO, 2021)
3) Desirable: Differentiated resp.	No Equal absolute reduction target for all companies (2.7%/yr for 1.5°C and 4.2%/yr for 2°C); grandfathering	No Allocation depends on economic contributions to global GDP; grandfathering	No Allocation based on initial carbon intensity and market share; grandfathering Minor equity consideration in terms of accounting for different capabilities of sectors and geographical location (geographical location only partially; accounted for in market share, not for intensity)	Yes - SSP 1-1.9 CMIP6 for global. - CERC-LED-OECD for companies in OECD.

Table 1: The application of our three conditions of Paris-Compliance to four allocation methodologies: the Sectoral Decarbonisation Approach (SDA), Greenhouse gas Emissions per Unit of Value Added (GEVA), the Absolute Contraction Approach (ACA) and the Context-based Carbon Metric method developed by the Centre for Sustainable Organisations (CSO).

The SDA was the first method adopted and co-developed by the Science Based Targets initiative (an initiative by the Carbon Disclosure Project, World Wide Fund for nature, UN Global Compact, and World Resources Institute) in 2015. The SDA takes a sectoral approach using the International Energy Agency's (IEA) decarbonisation pathways [23] and allocates sectoral budgets to companies based on their initial emission intensities, i.e., emissions (CO_2) per activity (such as kWh of electricity, or tonnes of steel), and their market share. Initially, companies in "other industries" (for which sectoral pathways were not available) were suggested to use the Greenhouse gas Emissions per unit of Value Added (GEVA) method [13], which allocates the carbon budget to companies according to their economic activity. However, the Science Based Targets initiative has moved away from this approach and is instead suggesting the Absolute Contraction Approach (ACA) for these companies, applying an equal percentage of emission reductions to every company. The Context-based Carbon metric Centre for Sustainable Organisations methodology is similar to the GEVA method, setting targets based on economic activity (contribution to GDP), but updates yearly with actual GDP figures to ensure it remains consistent with a Paris-Compliant carbon budget. From Table 1, we find that the SDA and Context-based Carbon Metric by the CSO are the only two methods that meet our two conditions, whilst the CSO also meets the desirable condition of differentiated responsibilities, with companies in developed countries required to decarbonise much faster than those in developing countries.

As several Paris-Compliant pathways will be available for any company to evaluate its performance against, there needs to be transparency in terms of the three conditions of Paris-Compliance, specifically, i.e., what allocation method is used, the base year of the pathway(s) of the underlying method, the scenario that this method is consistent with (e.g. IEA B2DS or the SSP1-1.9), and whether they encourage differentiated responsibilities.

Once a Paris-Compliant methodology is selected and an emission reductions pathway is calculated using this methodology, some additional operationalisation requirements must also be met for a company to claim it is on a Paris-Compliant Pathway (PCP). The first operationalisation requirement is that when applying a methodology that relies on the assumption of a future variable, e.g., projected market share, to calculate the emission reduction pathways and carbon budget, the allocation must be adjusted as soon as the information for the realised variable is available. For example, if market share was an input variable and was projected to calculate the carbon budget in advance, the carbon budget should be adjusted every time the market share differs from the projection.

The second operationalisation requirement is that if a company does not meet the emissions reductions of their PCP in any year, they must reconstruct a “re-alignment” PCP that adheres to all the conditions above while maintaining the company’s carbon budget. This will mean that any company which fails to reduce their emissions sufficiently in any year must increase their reductions in subsequent years to compensate. In short, if a company has not met its target, a “re-alignment” pathway should be defined to make up for the action deficit. Finally, whilst some methods use carbon intensity measures, it is important that corresponding absolute emission pathways and carbon budgets are always calculated [13; 31]. Ultimately, the absolute cumulative emissions determine whether the Paris goals are met of holding warming to less than 2 degrees above pre-industrial levels.

Finally, there are three additional minor operationalisation requirements concerning special circumstances. In the case of a merger or acquisition the combined company must reduce its emissions as if both companies have been one company since the base year. In the case of new companies, a defensible approach must also be applied. For example, a new company has five years to establish their market share and emissions, following which they must then align their reductions to a constant reduction rate that achieves net zero as required by the chosen methodology for their sector. Thirdly, to avoid unnecessary application of the methodology to progressive and new clean companies, if a company have for the last five years recorded emissions that are less than 0.1% of their national sector's emissions, they will be regarded as Paris-Compliant.

As way of example, although the SDA meets our conditions for Paris-Compliance the Science Based Targets initiative (SBTi), which operationalises the SDA method, deviates from our operationalisation requirements in several key areas. Firstly, the SBTi allows for flexibility in setting the base year, and thus does not account for the emissions of all companies from a common base year that is consistent with the underlying decarbonisation pathway. Second, the SBTi does not strictly require a revision of the target when the company has not met its target or has deviated from its projected market share used to set the target. The need to account for the "action deficit" this might cause is acknowledged in principle by the updated SBTi guidance, with companies that are not on track required to "explain why and the strategy for addressing these deficits in the future" [34]. However, the SBTi still allows companies to set a base year beyond 2014, and even if a company sets a target in 2014, there is no clarity on how to accurately include any deficits it incurs since this base year, or account for changes in their actual vs projected market share, in their target recalculation.

Accordingly, we propose here our own example Paris-Compliant Pathways (PCP's) that hold true to each of our allocation conditions, and operationalisation requirements, and therefore allow us to demonstrate their importance to ensuring compliance. For this purpose, we create a "base" PCP for a given company, founded on a Paris-Compliant allocation method, in this case the SDA, using the company's initial emissions intensity and projected market (PM) share, or actual market (AM) share where available, from the common base year (2014). This sets the company's "base" Paris-Compliant Pathway for the firm, which has an associated company carbon budget (based on actual market share to date and projected market share). If a company deviates from its "base" PCP in any one year, a "re-alignment" PCP is calculated that would guide the company on how to stay within its carbon budget. In assessing a company's progress, we present the PCP using carbon intensity, $PCP_{intensity}$, as well as using cumulative absolute emissions, $PCP_{emissions}$. Both represent the exact same pathways, but both are required to ensure that absolute emissions are tracked.

Figure 1a and b presents several new emissions intensity pathways for an individual company experiencing a deviation from their PCP. The base year of the PCP is 2014 as this reflects the inception of the IEA B2DS. Our "base" PCP is defined using the company's actual market share for the years to date (2014-2019) and projected market share (here, beyond 2019). This allows us to account for discrepancies between realised emissions and those that would have been produced if following the base PCP since 2014. Given the company has deviated from its PCP, we illustrate two potential "re-alignment" PCPs that the company could follow to compensate for the lack of progress since 2014 and stay within its CCB. Through this example we show that decarbonisation rates in the next 5 years have a significant effect on the decarbonisation rates required between 2025 and 2050 if the company is to remain "Paris-Compliant".

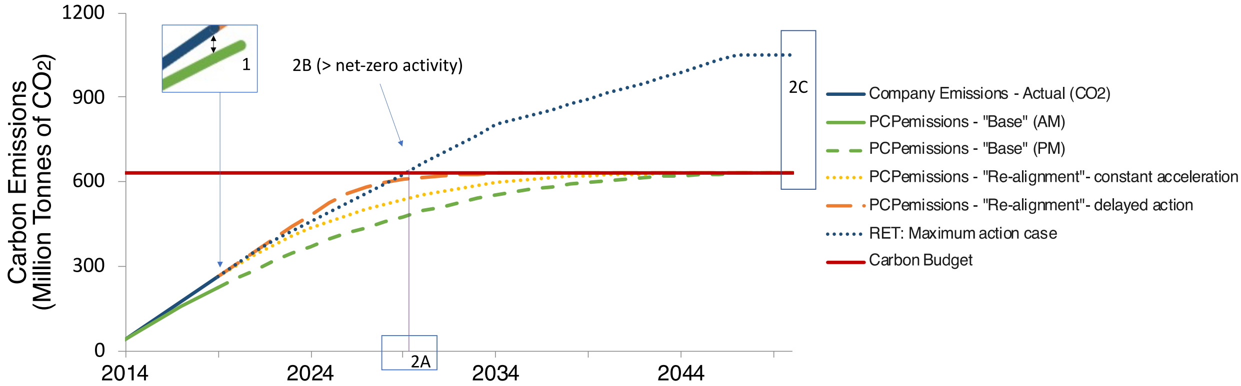
New metrics for gauging companies' transition performance

Having defined what a Paris-Compliant emission reduction pathway is, we can now establish metrics to measure a company's performance against a Paris-Compliant Pathway. There are two recent initiatives that assess a company's transition performance using the SDA method: 1) The Transition Pathway Initiative (TPI) [27]; and 2) Assessing low-Carbon Transitions (ACT) [28]. These two initiatives include a wide variety of qualitative and quantitative metrics to assess a companies' performance. Acknowledging the importance of the variety of metrics, we focus on the quantitative metrics that measure how a companies' carbon emissions align with Paris-compliant decarbonisation pathways. From a climate perspective, only actual emissions determine whether a Paris-compliant carbon budget is met. Unfortunately, for the quantitative metrics, the TPI and ACT both inherit similar shortcomings to those of the SBTi when using the SDA as a benchmark, with additional issues of their own, which we outline in more detail in the Supplementary Materials.

We propose three new metrics, mostly focused on absolute emissions ($PCP_{emissions}$), for evaluating the Paris-Compliance of companies. "Metric 1 - Performance to Date" measures current performance since the base year, "Metric 2 - Projected Performance" provides indicators for the implications of continuing business as usual, and "Metric 3 - Re-alignment Decarbonisation Rate" gives the re-alignment factor required for the company to return to a climate-safe pathway. For measuring Metric 1 - Performance to date we compare a company's cumulative emissions to date against its $PCP_{emissions}$, where $PCP_{emissions}$ are defined as the cumulative emissions that would have been emitted since 2014 had it followed its "base" $PCP_{emissions}$. For Metric 2 – Projected Performance we estimate a reference emission pathway based on a projection, and estimate three sub-metrics: 2a) the "Estimated Year to Finish" (EYF), the year the company carbon budget would be exceeded, 2b) their projected (carbon positive) production in the EYF, and 2c) the exceedance of the company carbon budget as a multiple in the year the company's PCP must become net-zero (around 2050 for the electric utilities sector). The carbon budget is defined as the total emissions a company can emit before it must achieve net-negative carbon intensities (the International Energy Agency B2DS allows for temporary overshoot of the carbon budget). For Metric 3 we quantify two re-alignment options (as shown in Figure 1c) that provide a measure of how much faster a company will need to decarbonise relative to the rate in its original $PCP_{intensity}$.

Figure 1 demonstrates our three metrics for AGL, an Australian electricity provider. The actual CO_2 emissions (black line) of the company since 2014 exceeded their Climate-safe Emission Pathway (green line) by a factor of 1.12 in 2019. For our electric utility sample, we have actual asset data and can estimate a reference pathway where the company continues to operate its assets until the expected closure date and then replaces their assets with a zero-carbon alternative, which we refer to as "maximum action pathway". Under this scenario, the company would exceed its carbon budget in about a decade (2031) (metric 2a), whilst still producing 34.2 million MWh (with positive carbon intensities). Thus, the company will need to retire this production capacity if it wants to remain within its carbon budget. If this projected pathway is followed, emissions will be 166% of the company's carbon budget by 2050 (Metric 2c). Note that for other sectors with limited availability, we can project emissions using, for example, the geometric growth of emission intensity from 2014-2019, which we have done for our sample of cement companies in Figure 2 (Fig e, f). Companies themselves are encouraged to release projections of their emission pathways.

a



b

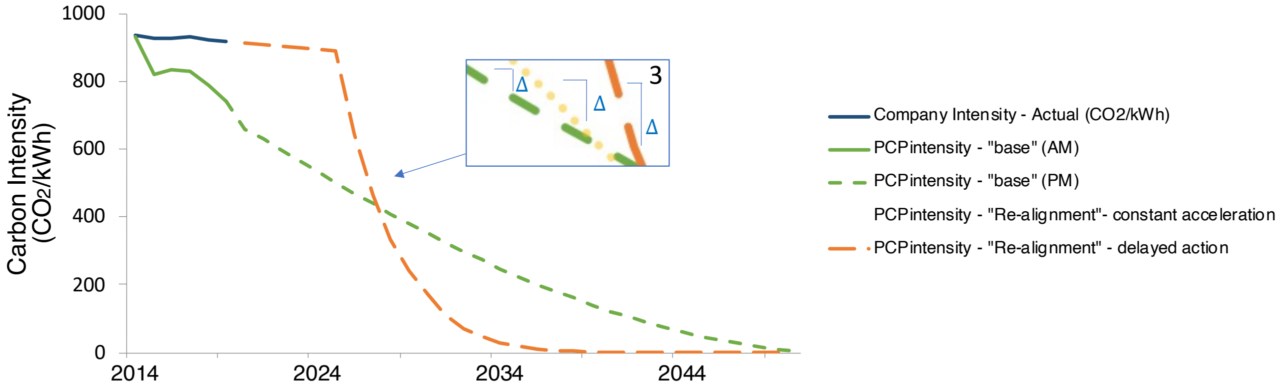


Fig. 1 | Paris Compliant Pathways and transition performance metrics for the largest Australian electric utility company (AGL). Both **Panel a** and **Panel b** show the same "base" Paris Compliant Pathway using the Sectoral Decarbonisation Approach on an existing company's initial intensity (2014) and actual market share (green line) and projected market share (dashed green line). It also shows two possible "re-alignment" PCP's the company could follow to stay within its carbon budget: a PCP featuring a constant "accelerated" decarbonisation rate which commences immediately (dotted yellow line); and a PCP which follows a "maximum action pathway" for the next 5 years, followed by a new accelerated decarbonisation rate (long-dashed orange line). **Panel a** also illustrates Metric 3 which measures the difference in decarbonisation rates between the "base" $PCP_{intensity}$ and the "re-alignment" $PCP_{intensity}$. **Panel b** shows Metric 1 and metric 2. Metric 1 measures the performance since the base year (cumulative emissions since the base year 2014 relative to the Climate-safe Emissions Pathway). Metric 2 is composed of three sub-metrics; 2A is the estimated year that the company carbon budget will be fully emitted based on a "maximum action pathway" of future cumulative emission projections, all assuming constant market-share, where the operation of assets continue until closure date and are replaced by a zero-carbon alternative, which we refer to as "maximum action pathway" (short dash); 2B is the amount of activity in place under the maximum action pathway at the EYF with a positive emission intensity; 2C is the emissions under the maximum action pathway in 2050 compared to the carbon budget.

If the company takes immediate action (in this case, in 2020) to re-align its trajectory to stay within its carbon budget to 2051 (the year the company should go carbon negative to follow its PCP), it will need to decarbonise its operations 1.46 times more rapidly than had it followed its PCP since the base year of 2014 (Table 2, Figure 2). If the company delays re-alignment and continues its current decarbonisation pathway until 2025, it will need to decarbonise 3.15 times more rapidly post-2025 than if it had followed its "base" PCP since 2014. This demonstrates the impact of delayed action especially in the early years, as inaction can lead to unachievable levels of decarbonisation. This increased pace of change will be highly disruptive forcing the company to accelerate the retirement of carbon-intensive assets and more rapidly mobilize capital for low-carbon assets. Earlier emission reductions would allow for a slightly more gradual decarbonisation (Fig 1c). These results are summarised in Table 2.

Metric	**Value for company**	
1: Cumulative Emissions emitted since base year relative to emissions allowed under the Climate-safe Emission Pathway (%/absolute))	117%/38MtCO_2	
2: The potential for stranding of existing assets (using a "maximum action pathway") A: Estimated Year to Finish (EYF) Carbon Budget B: Production Activity with greater than net-zero emission intensity in EYF C: The level of exceedance of the company's carbon budget by 2050 (percentage of company's carbon budget)	 2031 34.2 million MWh 166%	
3: Adjusted decarbonisation rate required to be climate-safe (compared to rate if followed "base" $PCP_{intensity}$)	**2020-2025**	**2025 - 2051**
i) constant acceleration	1.46x	1.46x
ii) delayed action ("maximum action pathway" in next 5 years)	0.08x	3.15x

Table 2: Calculated transition performance metrics for company in Figure 1.

Figure 2 demonstrates the application of the metrics to the 10 largest Australian electricity utilities and eight cement companies from various countries, showing the scale of the decarbonisation challenge. In 2019, all electric utility companies currently exceeded their PCP (Fig 2a), and if the companies followed a "maximum action pathway", from 2019 onwards, all companies are expected to exceed their total carbon budget before 2030 (Fig 2b) and exceed their carbon budget by between 2 and 4 times in the year 2050 (Extended Data Figure 1). The cement companies are slightly more aligned with their PCP, yet all eight companies have exceeded their PCP to date (Fig 2d), are expected to exceed their carbon budget by 2042 (Fig 2e).

As a result of their failure to follow their PCP, all electric utility and cement companies in our sample face a requirement to increase the rate of decarbonisation between 1.1 and 2.6 times faster than required had they followed their base PCP (Metric 3; Fig 2c, f). This metric is a measure of the extent to which a firm's present decarbonisation trajectory is misaligned with the Paris Agreement, as defined by the PCP. Any further exceedance of the PCP beyond 2019 will increase this rate even further.

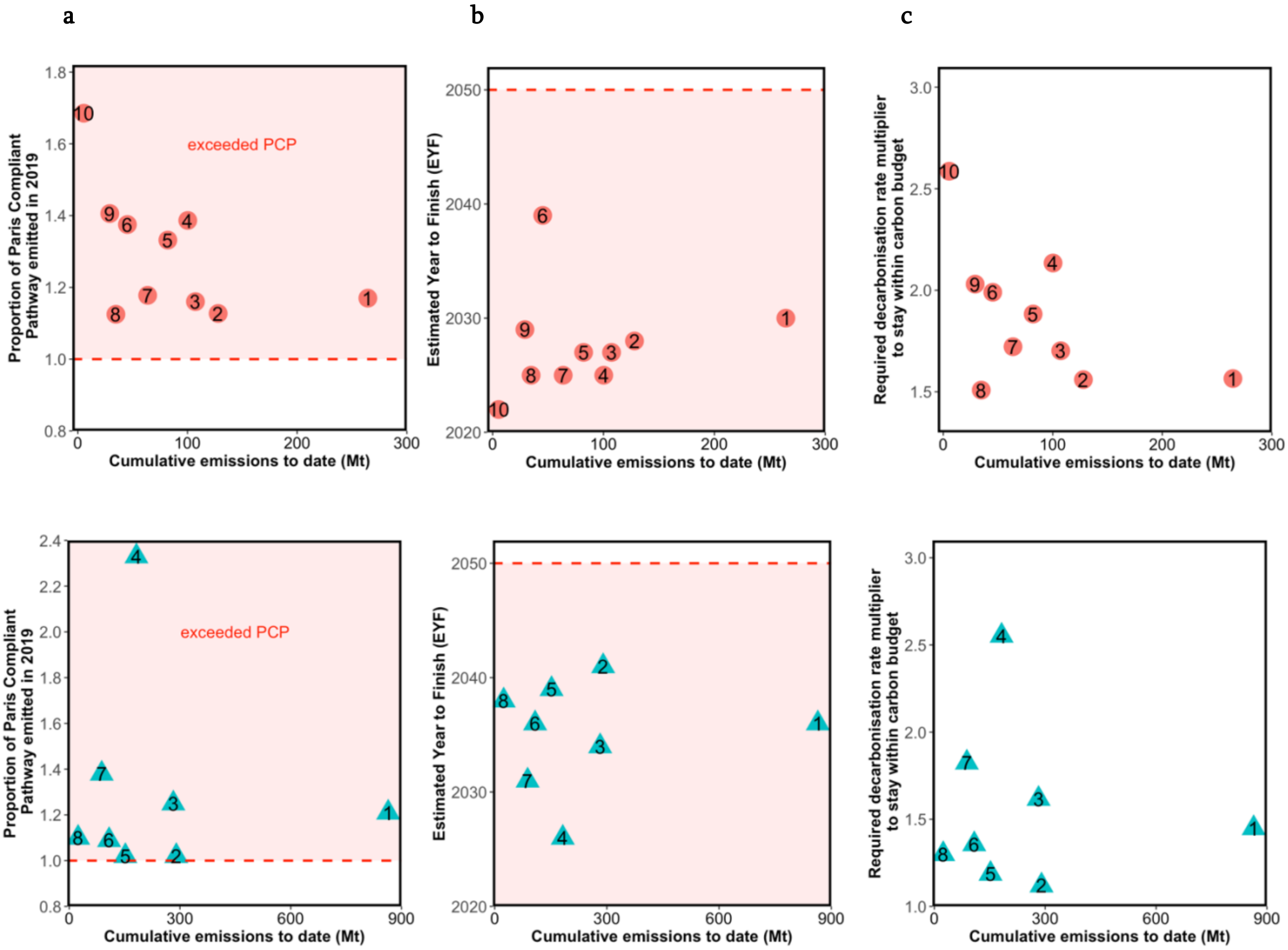


Figure 2 | Transition performance metrics for the ten largest producing energy generators in Australia (a-c), and eight cement producers from various countries (d-f) for metric 1, 2a and 3. Panel a, d shows Metric 1 - the proportion of the Paris-Compliant Pathway (PCP) (in absolute emissions, $PCP_{emissions}$) actually emitted in 2019 since the base year 2014, **Panel b, e** shows Metric 2A- the Estimated Year to Finish the carbon budget if carbon intensity is decarbonised according to the maximum action pathway (panel b) or Reference Emission Trajectory – geometric carbon intensity growth 2014-2019, **Panel c, f** shows Metric 3 - the multiplier on decarbonisation rates required (compared to if it had followed its PCP (in carbon intensity, $PCP_{intensity}$) since 2014) to be Paris-Compliant. Additional metrics are shown in Extended Data Figure 1. Panel a-c: 1 = AGL, 2 = Energy Australia, 3 = Origin Energy, 4 = Stanwell, 5= CS Energy, 6= Alinta Energy, 7= Delta, 8=Millmerran, 9=Callide and 10= Pelican Point. Panel d-f, 1=Holcim, 2= Cemex CPO, 3 = Utltratech cement, 4=Crh (lon), 5= SIAM cement, 6=Acc, 7=Shree Cement, 8=Ppc.

The PCP approach provides companies with a means of accurately ensuring their efforts are aligned with the goals of the Paris Agreement. Our three proposed metrics can thus be used by companies, investors, and other stakeholders to evaluate the company's *transition performance*. A company's transition performance is related to their exposure to *transition risk*

[29, 36, 37, 38] which manifests primarily as assets stranded due to a reduction in demand for their services, from technological change, or from regulatory, legal, and fiscal measures to reduce emissions [36, 40]. The more a company exceeds their PCP, the larger the company's misalignment with meeting the Paris goals, and the more likely they will be exposed to such transition risks. However, it should be noted that the concept of transition risk is much broader than stranded assets and can manifest as a loss of market share (market risk), as a disadvantage through ownership of inferior technologies (technology risk), exposure to litigation (legal risk), and erosion of investor or consumer confidence (reputation risk) [38]. As some of these risks involve historic emissions and actions (e.g. legal and reputation risk) they are not fully covered by the PCP metrics.

We used the SDA method to demonstrate the PCP approach. It should be noted that the SDA method itself also has some known limitations within its foundations [39], such as allowing companies with a higher initial intensity to have a greater share of the remaining global carbon budget (i.e., grandfathering). In addition, the IEA B2DS pathway used by the SDA relies on significant amounts of carbon capture and storage and negative emissions technologies which are currently not being deployed at anywhere near the rate required by this scenario [23, 41], which does not alter the total carbon budget but could have implications for the sectoral breakup of the budget. The B2DS pathway is also only consistent with the more conservative interpretation of the Paris Agreement with a 50% chance of keeping global warming below 1.75°C. Further, company data availability is a concern in calculating PCP's, especially for the SDA method as it requires production output in addition to emissions. We deliberately demonstrated PCPs with a data rich set of companies (Australian energy providers) and a data poor set (global cement companies) to demonstrate PCPs could still be adequately applied. Furthermore, the companies themselves can still make the necessary calculations to provide stakeholders interested in their Paris compliance, and our PCP approach provides directions to stakeholders on what data to request from companies.

Conclusions

Nobel Laureate Milton Friedman once famously wrote that the social responsibility of business was to increase its profits [42]. However, society is now putting much loftier demands on companies, and the many stakeholders now have much more influence on corporate behaviour including shareholders, most obviously through the exclusion or inclusion of companies' debt or equity in their portfolios [43-45]; regulators, central banks, and banks, through lending restrictions and disclosure requirements [46]; and customers, suppliers, employees, politicians, academics, and communities through purchasing decisions, employment preferences, publications, policies, and various forms of activism [47-51]. The failure to accurately monitor, verify and benchmark corporations' GHG emissions reductions obscures the perceived risks for these stakeholders [52] and limits their capacity to make decisions aligned with the Paris Agreement. If companies are able to claim compliance while exceeding carbon budgets, then Paris-compliance will not be achieved, and investors will have been misled.

We have presented here a strict science-based methodology for measuring companies' compliance with the goals of the Paris Agreement. We have specified the strict methodological conditions and operationalisation requirements for producing Paris-Compliant Pathways that are consistent with the goal of achieving a "well-below 2C" transition to net zero emissions. We have also provided three metrics for evaluating company's performance against their pathways and demonstrated how such metrics can be used to evaluate companies within different sectors. When applied to major corporations in both the Australian electric utility sector and the global cement sector our metrics showed alarmingly that all companies were clearly not on track to meeting the goals of the Paris Agreement, and that their decarbonisation efforts will need to be ramped up significantly to avoid increased exposure to transition risk.

Our proposed conditions and requirements for Paris-Compliance have thus been demonstrated to provide a consistent approach for calculating and comparing the company's Paris-Compliance and transition performance. Regulators, investors, customers and other stakeholders must also play their part in ensuring that the firms that correctly report and demonstrate Paris-Compliance are rewarded with profitability through their transition [12].

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Author Contributions

S.R., B.W. and C.G. designed the study; S.R. and L.W. collected, verified, processed and analysed the data; S.R. and M.I. wrote the paper; B.W. and C.G. edited the paper. All authors contributed to the methods and interpretation of the results.

Competing Interest

All authors declare no competing interests.

Data Availability

Source data are provided with this paper. The raw data underlying the figures in this manuscript and all new data associated with the paper can be accessed in the following data repository https://doi.org/10.48610/289d707.

Code Availability

Code used to generate the results is available upon request.

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[2] "This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances." Part 2 of Article 2 of Paris Agreement

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Methods

Paris-Compliant Pathway (PCP)

We use the Sectoral Decarbonisation Approach (SDA) initially published by Krabbe et al. (2015) [13] and updated by the Science-Based Targets initiative (2019) to determine a companies' Paris-Compliant Pathway (PCP). The SDA methodology sets carbon intensity targets based on a company's initial carbon intensity, the IEA B2DS' sectoral decarbonization pathway and their projected market share. The IEA B2DS' pathway is consistent with a 50% chance of limiting average future temperature increases to 1.75°C. The $PCP_{emissions}$ is a pathway of cumulative emissions that would be consistent with an IEA B2DS pathway provided all companies stay on or below their PCP.

The $PCP_{emissions}$ is calculated as follows:

Paris-Compliant Pathway ($PCP_{emissions}$) for a company in year y (base year 2014):

$$PCPemissions_y = \sum_{y=2014}^{t} PCPintensity_{y,SDA} * CA_y$$

Where the "base" $PCP_{intensity}$ in year y is calculated using the SDA methodology:

$$PCPintensity\ _{y,SDA} = dp_y m_y + SI_{2060}$$

Where

$$d = CI_b - SI_{2060},$$

$$p_y = \frac{(SI_y - SI_{2060})}{(SI_b - SI_{2060})},$$

$$m_y = \frac{(CA_b/SA_b)}{(CA_y/SA_y)}$$

$$CI_b = Carbon\ intensity\ in\ the\ base\ year\ (2014)\ set\ by\ IEA\ B2DS$$

$$SI_y = Sectoral\ Intensity\ in\ year\ y\ set\ by\ IEA\ B2DS$$

$$SI_b = Sectoral\ Intensity\ in\ base\ year\ (2014)\ set\ by\ IEA\ B2DS$$

$$SI_{2060} = Sectoral\ Intensity\ in\ 2060\ set\ by\ IEA\ B2DS$$

$$CA_b = Company\ Activity\ in\ base\ year\ (2014)$$

$$CA_y = Company\ Activity\ in\ year\ y$$

$$SA_b = Sectoral\ Activity\ in\ base\ year\ (2014)$$

$$CA_y = Sectoral\ Activity\ in\ year\ y$$

Sectoral activity (SA) is set by the IEAB2DS pathway, and we use the activity for the region the company produces (so we use IEA B2DS-consistent activity for the OECD for Australia).

We distinguish between a) a "base" $PCP_{intensity}$ calculated using actual market share (AM) where available, thus in 2019 the $PCP_{intensity}$ is based on actual market share 2014-2019, and b) a "base" $PCP_{intensity}$ calculated using projected market share (PM) for future years, assuming the company had followed their "base" $PCP_{intensity}$ to date.

Whilst a company can set targets for their PCP using their projected market share, the PCP can only be finalized once the activity, and thus market share, of a company is known (usually at the end of the year). Therefore, the PCP needs to be continuously revised when new market share data becomes available. We can therefore distinguish between two PCPs: actual and projected. For the actual PCP, m_y and CA_y is known, for the projected PCP, m_y and CA_y is projected, keeping market share constant according to sectoral activity projections (OECD or non-OECD). For the year 2020, this results in:

$$Actual\ PCPemissions_{2014-2019} = \sum_{y=2014}^{2019} PCPintensity_{y,SDA} * CA_y$$

$$Projected\ PCPemissions_{2020-2060} = Actual\ PCPemissions_{2014-2019} + \sum_{y=2020}^{2060} PCPintensity_{y,SDA} * CA_y$$

Metric 1. To measure performance to date, we compare their actual cumulative emissions to date, i.e. their actual "Emission Pathway", to the Actual PCP and calculate the percentage of PCP emitted to date. We calculate the actual EP as the company's actual carbon intensity multiplied by the company's actual activity.

$$Actual\ EP_{y,2014-2019} = \sum_{y=2014}^{2019} CI_y * CA_y$$

We can then calculate the Corporate Climate Performance to date:

$$Corporate\ Climate\ Performance\ to\ date = \frac{Actual\ EP_{y,2014-2019}}{Actual\ PCP_{emissions,y,2014-2019}}$$

If > 1, the company has emitted more than their $PCP_{emissions}$ (not consistent with Paris goals)

If ≤ 1, the company has emitted the same or less than their PCPemissions (consistent with Paris goals)

It is important to note that we use $PCP_{emissions}$ and not $PCP_{intensity}$ here. The $PCP_{intensity}$ simply captures what the intensity should be in a certain year, but gives us no indication on whether a company has exceeded its $PCP_{intensity}$ to date, and by how many tons of emissions. This is captured by $PCP_{emissions}$.

Metric 2. To understand the implications of a company's performance to date and their projected emissions, we use three sub-indicators (metric 2a, 2b and 2c). We project emissions forward for the electric utility companies using a "maximum action pathway". In this pathway, the company produces until closure date and replaces plant solely with net-zero carbon (e.g. renewables, nuclear or gas + CCS). We understand that this trajectory cannot easily be used for other sectors, where plant/asset data and intensity are not available. Also, ideally real company projections are used to estimate these trajectories. If this is not available, we suggest projecting forward using other estimation methods proposed in Rekker et al.(2018), such as recent emission growth or reduction rates. For the cement companies in Figure 2 (Fig 2d, e, f) we have projected forward using the 2014-2019 Carbon Intensity geometric growth/reduction rate.

Metric 2a. The first sub-metric follows Rekker et al. (2018) [20] by using the "Estimated Year to Finish", which is the year the company is estimated to have emitted their full Company Carbon Budget. We define the company's carbon budget as the total amount of carbon the company can emit to operate consistently with the chosen climate pathway (e.g. IEA B2DS) in the respective timeframe (e.g. 2014-2060 for IEA B2DS). Under the IEA B2DS however, and the power sector specifically, there is a temporary overshoot allowed. The Sector Intensity for power goes negative from about 2050 to 2060. Therefore, we define the carbon budget of a company at the year that the $PCP_{emissions}$ is at its highest level:

$$Company\ Carbon\ Budget = max\ (PCP_y)$$

This is subject to the company generating negative emissions after the year t that satisfies $max\ (PCP_{y,t})$ *such that it reaches* $PCP_{y,2060}$ *in the year 2060.*

This is slightly different to the approach of the SBTi, who uses 2050 as the year of convergence for all the sectors. Note that the company carbon budget is not fixed, it depends highly on the projected company activity (captured under *Projected* $PCP_{emissions}$*)*. It should be updated and refined on a yearly basis. Assuming the company has not yet exceeded its carbon budget in 2019, the remaining carbon budget in year "EYF" can be calculated by subtracting the emissions to date from the Carbon Budget:

$$Remaining\ Carbon\ Budget_y = Company\ Carbon\ Budget - Actual\ EP_y$$

The firm is estimated to finish its remaining carbon budget in the year "EYF" that satisfies:

$$Actual\ EP_{EYF} = \ Company\ Carbon\ Budget$$

The EYF is based on a lenient Company Carbon Budget (the company will have to generate negative emissions after), thus the EYF is also a lenient measure.

Metric 2b. This metric measures the production levels (CA_y) that are estimated to be still in place when the company reaches its EYF (metric 2a). This is a measure of how much energy generation capacity will need to be retired at the EYF if the company is to continue with its projected outputs but stay within its carbon budget. Metric 2b is observed from the difference in the reference emission trajectory in the EYF and the year prior.

Metric 2c. This metric evaluates how many times the company's carbon budget will be exceeded if the company continues along their maximum action pathway when their $PCP_{intensity}$ should reach zero, which is around 2050 (but depends on the individual company). It is calculated as the cumulative emissions in the year the $PCP_{intensity}$ should reach zero, divided by the company's carbon budget.

Metric 3. To stay within the carbon budget consistent with the IEA B2DS' pathway, companies that have emitted more than their fair share (i.e. their total $PCP_{emissions}$), will have to compensate for this in the future. This is closely aligned with transition risk– the companies that have decarbonized the least to date are the most vulnerable to a transition to a world that meets the Paris goals.

To understand the pathway a company should follow to re-align its emissions, we calculate a "re-alignment factor". This factor captures how much faster the company must decarbonize in order to maintain its projected outputs and stay within its carbon budget, compared to when it had followed the $PCP_{emissions}$ from the start.

To calculate this re-alignment factor, we first calculate the speed of decarbonisation required if the company had followed its $PCP_{emissions}$ since 2014. We derive this 'speed' by calculating the "base" $PCP_{intensity}$ for the firm, and then inferring the required (annual) decarbonisation rates to adhere to this pathway. As the IEA B2DS uses 5-year intervals, we construct our decarbonisation rates such that it ensures the pathway is built on the known data points (while interpolating the pathway between these years using geometric growth rates).

As such, the required decarbonisation rate is constant between the (IEA-specified) time intervals, but not across the whole period. We use the time-intervals (beginning year and ending year) for the geometric growth rates in accordance with the IEA B2DS' timeline. For example, the IEA B2DS reports forecasts for the years 2014, 2025, 2030, 2035, and every 5 years after that until 2060.

As such, the decarbonisation rate (where t is between 2014 and 2025) is calculated as follows:

$$d_t = \left[\left(\frac{CI_{2025}}{CI_{2014}}\right)^{1/(2025-2014)} - 1\right]$$

where d_t is the decarbonisation required at time t (given the firm is aligned to date).

With the acquired decarbonisation rates, we can computationally solve the following equation simultaneously to compute the (constant) z value. If the firm is aligned to date, the z score is 1.

$$(1) \quad CI_{t+1} = CI_t \times (1 + z \times d_t)$$

$$(2) \quad \sum_{n=2020}^{2050} CI_t \times CA_t = Remaining\ Carbon\ Budget$$

Data

To select our sample, we sourced the activity data for all Australian electric utility companies on a disaggregated level (generator-by-generator activity from NEM dispatch data provided by the AEMO) and aggregated the data to a firm-level. We used the NEMReview6 software [53] and sorted each generator by owner, then calculated the total activity for each firm by summing the generators' activity for a given time interval. We did this for the years 2014 - 2019. For robustness, we cross-checked the activity values generated from this method with the activity data for AGL and Origin, which are the only two public companies and have activity data available through the Bloomberg database (code "Total Power Generated") [54]. Our activity values were found to be consistent with the Bloomberg metrics.

We ranked the firms by their activity in 2014 and selected the 10 largest producing firms for our sample. However, due to the nature of some of the corporate entities, certain firms had to be excluded. Two firms, Hazelwood Power and Flinders Power, were excluded from the analysis as their (sole) plants, Hazelwood Power Station and Flinders Power Station, respectively, were decommissioned by the time of analysis. Two other firms, Hydro-Electric Corporation and Snowy Hydro Limited, were excluded from the analysis as these firms were renewable energy generators. Due to the hydro power resulting in much lower carbon intensities [55], their inclusion would have complicated the method to construct a Carbon Budget, and result in these firms having a negative carbon budget (i.e. the method expects these firms to withdraw emissions from the atmosphere that are not related to their own production). For that reason, we have included a minor operationalisation that companies whose emissions make up less than 0.1% of emissions for their national sector do not need to be assessed for Paris Compliance.

To source company-specific emission data, we first considered the National Greenhouse and Energy Reporting (NGER) database published by the Clean Energy Regulator (CER). Since 2007, Australian corporations have been required by law to report their greenhouse gas emissions to CER each year. Although this may seem the most logical (and most accurate) dataset for company-specific emissions, this data source was not fit for our analysis for the following reasons: i) The data is reported in financial years, whereas the SDA method is constructed using calendar years. As the NGER data is published as an aggregate, there was/is no possibility of transforming the data from financial years to calendar years, ii) In the earlier reporting years, certain firms chose to publish emissions by holding company (e.g. Loy Yang, Tarong) rather than consolidating it under the 'final' owner (e.g. AGL). To avoid this complexity, we use the same method as we used for the activity data, and thus sourced disaggregated emissions data by generator (using the NEMReview 6 software) and aggregate it to a company level. The same robustness check was conducted using AGL and Origins emission data in Bloomberg (code "GHG_SCOPE_1") and were found to be consistent with our calculations. As a final confirmation of the accurateness of our data, we compared the emission intensity produced from the disaggregated method's results (Emission Intensity = $\frac{Emissions}{Activity}$) against the corresponding Bloomberg value (using the code 'GHG_SCOPE_1_INTENS_PER_PWR_GEN'). Again, these values were in line with one another, further confirming the accuracy of our dataset.

We retrieved the IEA B2DS sectoral data from the International Energy Agency, Energy Technology Perspectives 2017 - www.iea.org/etp2017.

To source the data from cement companies, we used the Thomson Reuters Datastream service [56]. We retrieved emission data (scope 1) and carbon intensities (scope 1 per tonne of cement), from which we derived cement production in tonnes of cement.

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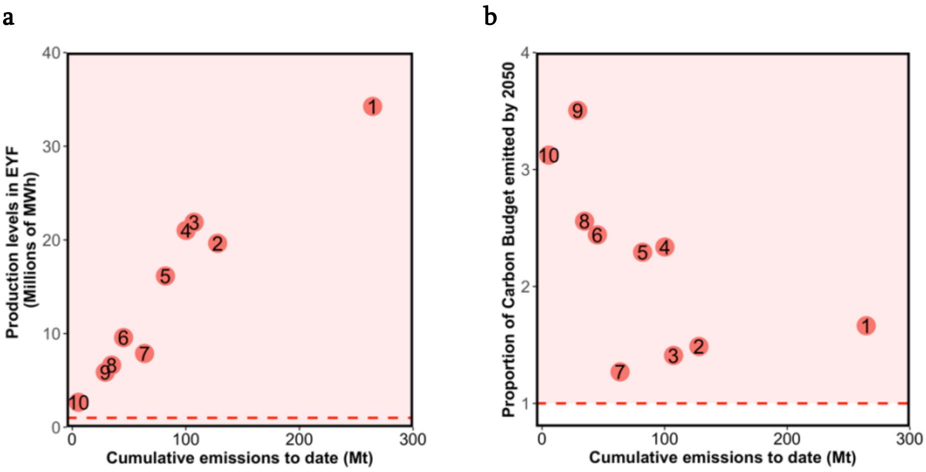

Extended Data Fig 1 | Transition performance metrics for the ten largest producing energy generators in Australia, for metric 2b and 2c under a "maximum action case". Panel a) shows the projected production capacity in the EYF that produces a greater than zero emission intensity (metric 2b), **b)** proportion of the company carbon budget emitted in the year the company's $PCP_{intensity}$ must become net-zero (around 2050 for the electric utilities sector) (metric 2c).