Lack of harmonisation of greenhouse gases reporting standards and the methane emissions gap

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Abstract

Monitoring companies' contributions to climate dynamics and their exposure to transition risks requires accurate measurements of their non-carbon dioxide greenhouse gas emissions (non-CO_2 GHG). However, carbon accounting standards are not harmonised and allow for some discretion when converting emissions of different GHGs into CO_2 equivalent units, the currency in which carbon footprints are expressed. Focusing on methane, we build counterfactual harmonised standards using the latest IPCC Global Warming Potential (GWP) values over 100 years and estimate a cumulative gap in reported methane emissions of 170MtCO_2e ($\sim$ 6Tg a^{-1}) over a sample of 2864 companies. Changing the counterfactual from GWP_{100} to GWP_{20} , as recently codified in certain jurisdictions and initiatives, increases the cumulative gap to 3300MtCO_2e ($\sim$ 40Tg a^{-1}). The gap only covers direct emissions and hence understates the extent of potential under-reporting across value chains. Overall, our study underscores the importance of global harmonisation of CO_2-equivalence standards to coherently track corporate GHG emissions and their exposure to transition risks.

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Corporations play a crucial role in global decarbonisation efforts[1–3] but face substantial transition risks emerging from their business operations being exposed to changes in regulation, consumer preferences, technological innovation, and investors' pressure[4,5]. Their actions and transition plans are therefore systematically scrutinised by both policymakers and market participants, who have promoted greater transparency and accountability in reported GHG emissions and abatement plans[6–8]. By analysing the emissions disclosure of a large sample of publicly traded and privately owned companies across multiple countries and sectors, we show that such monitoring efforts are undermined by a degree of optionality embedded in most reporting protocols.

To produce GHG emission disclosures, companies follow accounting frameworks that are largely based on the GHG Protocol[9], which has become the de-facto standard for carbon accounting, as it has inspired most reporting frameworks, such as those set by the Global Reporting Initiative (GRI) and the International Financial Reporting Standards Foundation (IFRS). Under the Protocol, companies disclose their aggregate GHG emissions in CO_2-equivalent (CO_2e) terms across different scopes, whereas disclosure of individual GHGs, particularly those covered by the Kyoto Protocol, is recommended but not required.

In practice, the notion of CO_2-equivalence is pervasive, and market participants have grown accustomed to emission footprints and abatement targets reported in aggregate, CO_2e units[10]. Yet, different GHGs feature vastly different radiative efficiency and persistency profiles[11], with material implications for atmospheric oxidative capacity and ozone air quality. They therefore pose different challenges for climate risk mitigation[12], which have prompted calls for reporting and monitoring emissions in disaggregated and direct form[10,13,14]. Such changes would be of paramount importance to reliably monitor corporate contributions to global climate dynamics and national carbon budget calculations[15,16].

A particularly critical issue around disaggregated disclosure of individual GHGs is a lack of harmonisation of practices and guidelines, which allow for optionalities in reporting choices. For example, for companies disclosing individual, disaggregated, GHGs, the GHG protocol recommends reporting emissions in CO_2e terms based on the GWP computed over a 100-year horizon (GWP_{100}) sourced from the latest IPCC Assessment Report's (AR), but acknowledges the fact that corporates "may choose to use other IPCC Assessment Reports."[9]. Most corporations worldwide are not legally bound to follow the GHG protocol guidelines, and other choices and recommendations exist. Most countries and environmental agencies around the globe, such as, for example, the United States Environmental Protection Agency (EPA), as well as well-established reporting standards, such as the GRI, recommend the use of GWP_{100}, but not necessarily from the latest IPCC AR[17,18]. Indeed, some jurisdictions even recommend the use of older ARs[19], whereas the IFRS S2 Climate-related Disclosures requires the use of the latest GWP_{100}[20]. On the other hand, some jurisdictions (e.g., the US States of New York and Maryland) and initiatives (e.g., the Global Methane Pledge) have opted for the use of GWP based on a 20-year horizon (GWP_{20}) to pursue aggressive emission reduction plans, by putting greater emphasis on the abatement of short-lived gases such as methane[21,22].

The choice of appropriate metrics allowing comparability of different GHG emissions has received considerable attention in the scientific community. The IPCC suggests that GWP_{100} strikes a reasonable balance between the warming effects of climate forcers and their different lifetimes, but also acknowledges that the choice has no unique grounding[23]. Some authors[24] suggest that the time horizon can be tailored to pursue alignment with specific temperature goals (e.g., a 1.5°C warming and thereby a 24-year time horizon), whereas other authors link the time horizon to the discounting of climate damages with rates consistent with various economic studies[25]. Other authors[21] suggest that a 20-year time horizon should be used to pursue aggressive abatement of short-lived climate forcers to slow the rate of warming over the next few decades and "buy time". These views stand in contrast with those who emphasise the need to focus on long-lived climate forcers, as the warming they bring about is, for all practical purposes, irreversible[11].

In this article, we examine how companies navigate fragmented guidelines and recommendations on non-CO_2 reporting by analysing a large-scale dataset of corporate emissions across multiple countries and sectors. We study the implications of lack of harmonization by focusing on methane, which is the second most important contributor to historical warming after CO_2, with an effect that is comparable in scale (0.5° [0.3°-0.8°] versus 0.8° [0.5°-1.2°] for CO_2[26,27]) and is a critical driver of short-term warming dynamics[28,29], making it instrumental for meeting the 1.5°C target[30,31]. Moreover, methane's GWP varies significantly with the time horizon considered, due to its short lifetime[11,24]. Indeed, the GWP indicated over time by various assessment reports increased from 21x to 28x for the 100-year horizon and from 56x to 84x for the 20-year horizon (see table ST2 in the Supplementary Information). In other words, each ton of emitted methane could have contributed to a carbon footprint of between 21 and 84 CO_2e tons, depending on the assessment report and time horizon considered, a wedge ranging between 33% and 300%.

We quantify the implications of lack of harmonisation by comparing reported methane emissions with hypothetical, counterfactual emissions computed based on systematic applications of the latest available IPCC value for GWP_{100} and GWP_{20}. The approach allows us to compute a methane emission reporting gap - the gap between emissions reported and those expected under the harmonised standard - and to investigate how companies in different sectors tend to align or deviate from the counterfactuals. We then quantify the economic relevance of these results by using carbon prices. Overall, our results provide strong support for initiatives pursuing global harmonisation of non-CO_2 accounting, as well as direct reporting of differentiated GHG emissions in native unites of measure.

Results

Heterogeneity in emission metric selection

To document the behaviour of companies faced with fragmented reporting guidelines, we use data from CDP (formerly, the Carbon Disclosure Project) questionnaire between 2014 and 2023. CDP is a leading organisation for voluntary climate disclosures and a key benchmark for corporate emission data. Here, we collect data from self-reported Scope 1 emissions, by taking into account the breakdown between CO_2 and non-CO_2 gases along-side the GWP values used to report them in CO_2e units (see Methods for further details on the dataset). We focus on Scope 1 emissions because companies rarely report Scope 2 and Scope 3 emissions differentiated by individual GHGs. Moreover, Scope 3 emissions entail additional degrees of optionality as they can be estimated using different methodologies[9,32]. Finally, focusing on Scope 1 emissions reduces the risk of double counting.

Based on data made available to us by CDP, our full sample covers 14077 companies from 120 countries and across all economic sectors (see Figure S1 for a summary statistics of the dataset). We find that the number of companies responding to the climate change questionnaire has dramatically increased over time (from 1825 in 2014 to 10866 in 2023), but the number of those that have explicitly reported their methane emissions and made explicit the metric sourced from an IPCC AR is substantially lower (from 371 to 2072, Figure 1 panel **a**).

Overall, this subsample, which will be our main focus, includes 2864 companies responsible for approximatively 65% of the total Scope 1 emissions within the CDP universe, which includes ~ 8500 companies reporting non-zero Scope 1 values. Based on their reported information, the sample covers 11% and 2.5% of global GHG and methane emission (as available from the EDGAR inventory), respectively. In terms of economic relevance, the sample covers at least 40% of global revenue and market capitalisation. Most of the companies in our sample are from North America, China, Europe, Brazil and Japan. However, we also cover other geographies as shown in Figure S2 in the Supplementary Information.

The GWP used on average by this sub-sample of companies (dotted line in Figure 1 panel **a**) is systematically lower than what would be expected under the most recent IPCC guidance available in any given reporting year along the sampling period (AR5 from 2014 to 2021 and AR6 from 2022 to 2023). The differentiation in the most recent GWP values appearing in 2022 and 2023 is due to the fact that AR6 provides separate methane GWP values for fossil and non-fossil sources. Deviations of the average emission metric from the latest available values are mostly driven by heterogeneity in the choice of the reference AR used to source the relevant GWP (Figure 1 panel **b**). Interestingly, there are companies that for their 2023 reports still use GWP values published in the Second AR of 1995. On the other hand, most companies in our sample (82%-90%) rely on a 100-year time horizon for the GWP, consistently with the main recommendation of the GHG protocol (Figure 1 panel **c**).

Accounting optionality and its impact on methane emission monitoring

The deviation of the average GWP of the sample from the most recent values available in the reporting year (Figure 1 panel **a**) suggests that reported emissions are lower than they would be on aggregate under a hypothetical harmonised standard (e.g., the most recent GWP_{100}). The actual magnitude of the gap between reported and counterfactual emissions, however, depends on the methane specifically emitted by deviating companies. Here, we measure a methane conversion gap as the difference between methane emissions reported by each company and those that would be reported under a counterfactual, harmonised emission metric, which we denote by $\mathrm{GWP}_{\mathrm{IPCC,\,H}}$. The pair (IPCC,H) identifies the counterfactual chosen by including the benchmark IPCC report and time horizon H for the GWP metric (see The methane conversion gap). The conversion gap is then given by

$$\Delta^{\mathrm{H}}_{\mathrm{CH_4}}(t) = \mathcal{E}^{\mathrm{reported}}_{\mathrm{CH_4}}(t)\left(1 - \frac{\mathrm{GWP}_{\mathrm{IPCC,\,H}}(t)}{\mathrm{GWP}_{\mathrm{reported}}(t)}\right),$$

where we note that the counterfactual is time-varying, as it tracks the release of new guidance available in each reporting year t. A negative gap entails that emissions are under-reported relative to the counterfactual. In the following, we use the most recent GWP_{100} as a baseline counterfactual since this is consistent with GHG protocol's guidelines and the IPCC's default reporting choice aimed at balancing the contribution of short-lived and long-lived gases. We have $\mathrm{GWP}_{100} = 28$ and $\mathrm{GWP}_{100} = 28.4$ during the time intervals [2014,2021] and [2022,2023], respectively. However, we also consider the most recent GWP_{20} , as certain jurisdictions and initiatives have recently opted for such a metric and some authors believe it to more effectively enable alignment with the targets of the Paris Agreement[24]. We have $\mathrm{GWP}_{20} = 84$ and $\mathrm{GWP}_{20} = 81.1$ during the time intervals [2014,2021] and [2022,2023], respectively.

The conversion gap indicates that lack of harmonisation in reporting standards has resulted in a cumulative underestimation of methane emissions within our sample amounting to 170MtCO_2e for H$=100$. When considering the case of H$=20$, the extent of the cumulative underestimation rises to 3300MtCO_2e (Figure 2 panel **a** and **e**, see Methods). In relative terms, methane emissions would have been approximately 1.12 higher than reported under the GWP_{100} counterfactual, and 3.3 times higher if reporting had been instead harmonised to the 20-year time horizon (figure 2 inset **c** and **g**).

Notably, insets **b** and **f** in Figure 2 show that the impact of divergence from counterfactuals is not uniform within and across sectors, with companies in the Energy, Utilities, Material, and Consumer Staples sectors largely dominating the conversion gap. Importantly, while the average GWP of the sample converges towards the latest IPCC values throughout the observation period (Figure 1 panel **a**), sector-specific heterogeneity persists over time. In particular, sectors that are instrumental in enabling the low-carbon transition, such as Energy and Utilities, feature a significant gap even during the last few years of observation (Figure 2 panel **d, h**). For companies in those sectors, methane is a sizeable contributor to total Scope 1 emissions (up to an average of 10%, Figure S5 in the Supplementary Information). Hence, loose reporting guidance is particularly problematic since the choice of the GWP can distort aggregate GHG footprints, making them unreliable for assessing the effectiveness of climate policy and misleading for measuring the climate footprint of investors' portfolios.

Focusing again on GWP_{100} as our main baseline, we find systematic differences between companies that follow the guidelines and those that do not. Companies diverging from the guidelines in either the time horizon or the reference AR, are, on average, larger, more mature and hold a greater proportion of tangible assets in their books (i.e., property plants and equipment). Importantly, the probability of deviation from accounting standards is higher for companies that implement a lower number of carbon management activities as reported to the CDP climate change questionnaire, whereas it decreases with the time elapsed since the latest GWP_{100} release (see table ST1 and section B in the Supplementary Information).

Implications of longitudinal inconsistencies

Our analysis reveals important cross-sectional variability in the GWPs used by companies in our sample, but does not inform us as to whether companies are consistent with their own choices on a year-on-year (YoY) basis. To investigate the longitudinal consistency of each company's disclosure, we analyse the methane emission reporting choice over time.

Excluding companies switching towards the latest available counterfactual GWP, approximately 3% of the companies in our sample with at least two consecutive years of observations feature at least one switch from GWP_{100} to GWP_{20} or viceversa (Figure 3 panel **a** and **d**). This subsample represents 0.5% of the companies reporting non-zero Scope 1 emissions, but contributes to $\sim$ 1% of those emissions. Switching from GWP_{20} to GWP_{100} leads to YoY rate of change in emissions that is lower than what it would have been under a constant 100-year or 20-year counterfactual (see Intertemporal choices), making the change in metric equivalent to emission abatement from a reporting perspective. In our sample, this change leads to an average emission abatement of 200% relative to the counterfactual (red bars in Figure 3 panel **b** and **e**). Switching from GWP_{100} to GWP_{20} clearly has the opposite effect, but the overall impact on reported emissions is substantially smaller. Hence, time-variation in the choice of emission metrics leads to overall underestimation of changes in emissions reported by companies in our sample.

A substantially larger proportion of companies not switching towards the counterfactual and with at least two years of consecutive observations (26% under the GWP_{100} counterfactual and 42% under the GWP_{20} , representing 15-30% of CDP Scope 1 emissions) changed the reference AR at least once during the observation period. Most changes are associated with updates towards more recent ARs (Figure 3 panel **c** and **f**). However, we also observe switches in the opposite direction (from most recent, to older ARs), and more of these in recent years as opposed to the beginning of the sampling period. As for the impact on reported versus counterfactual emissions, updating towards a more recent AR implies an increase in YoY changes in reported emissions (relative to the counterfactual). In our sample, this difference is statistically significant but small (gray bars in Figure 3 panel **b** and **e**). The opposite is true for backward changes in ARs, but the net effect is indistinguishable from zero. Looking at the sectoral and geographical composition of the sample of companies that changed their GWP choice over time, we have not found any systematic bias.

Economic impact of optionality

Harmonisation of methane accounting standards is required to provide investors with accurate and comparable measurements of GHG emissions as well as aggregate emissions. As the methane conversion gap we estimate is negative (methane emissions are under-reported), the economic implications of a transition to harmonised standards cannot be overstated. As a proxy for this transition risk channel, we quantify the earnings at risk associated with the methane emission gap. We collect global carbon price data from active ETSs from the World Bank and estimate the economic impact of reporting optionality by taking the product of the yearly methane conversion gap and the price of carbon as of the year of reporting (see Economic impact and earnings at risk).

We were able to collect carbon price data for 1718 companies, as not every country in our sample has an active ETS during the observation period. The sub-sample is still relevant, as it covers $\sim 65\%$ of total Scope 1 emissions of the 2864 companies analysed in this study. However, several large methane emitters, particularly from the Consumer Staples sector (which includes agriculture activities) are not included. We find that the methane conversion gap of the sub-sample is associated with a cumulative economic loss of approximately

$1.6bn ($40bn) under the GWP_{100} (GWP_{20}) counterfactual over the observation period (Figure 4 panel **a** (**d**)). Notably, the economic loss in our sample is strongly driven by companies in the Energy, Utilities, and Material sectors where company-level yearly losses can amount to as much as $1bn (Figure 4 panel **b** and **e**). Looking at the geographical heterogeneity of the economic impact, we find that North American, Western and Southern European companies are most exposed to economic losses (Figure S9).

We measure transition risk as the portion of earnings "consumed" by the carbon cost of methane emitted. We then take the difference between such a measure computed under the counterfactual and for reported emissions (see Economic impact and earnings at risk). The higher the difference, the greater the fraction of earnings that would be at risk should methane emission reporting follow harmonised standards.

Reported methane costs represent in general a small portion of earnings - approximately 0.2-0.4% in high emitting sectors and less than 0.1% in any other sector (dotted lines in the top x-axis in Figure 4 panel **f,g**). However, we observe substantial heterogeneity in the distribution of transition risk across sectors, with Energy and energy-intensive sectors facing considerably greater earnings at risk than any other sector. Indeed, we find that in high-emission sectors companies face transition risks that can be 1.4 times larger than currently reported under an harmonised GWP_{100}, and as much as four times larger than currently reported under a change of norm to a harmonised GWP_{20} counterfactual. Looking at geographical heterogeneity, we find that North American, Western and Northern European companies have a greater exposure to transition risks (Figure S10).

Discussion

Monitoring corporate contributions to global climate dynamics and resolving ambiguities in temperature target alignment require accurate measurements of non-CO_2 emissions from business operations. Loose guidelines and regulations around reporting requirements allow companies to choose whether and how to disclose their non-CO_2 emissions. This makes, in turn, corporate emission footprints and abatement plans challenging to monitor and compare. Using data from the CDP climate change questionnaire, the most comprehensive source of non-CO_2 emission reporting to date, and focusing on methane, we have documented the extent to which companies deviate from well-established baselines as well as the economic implications of reporting optionality under GWP_{100} and GWP_{20} counterfactual harmonised standards.

Our results show that only a small portion of companies in our sample ($\sim 20\%$) actively disclose methane emissions using the latest GWP_{100} (Figure 1 and Figure S4). While most companies(82%-90%) still use a 100-year horizon, sourcing it from older ARs induces deviations from the harmonised standard that have a substantial impact on the sample's total emissions (Figure 2). Indeed, under a harmonised GWP_{100} counterfactual, cumulative Scope 1 methane emissions in the sampling period would have been 170MtCO_2e higher than actually reported. This represents approximately 12% of total reported Scope 1 methane emissions. The total amount of methane emissions that are not accounted for in the CDP reporting programme under the GWP_{20} counterfactual is substantially larger, i.e., ~ 3300MtCO_2e (approximately 230% of total reported Scope 1 methane emissions). While the GWP_{20} metric is not mainstream in emission reporting guidelines, it is gaining traction in jurisdictions pursuing aggressive emission reduction plans by targeting short-lived gases[21,24]. Hence, it is important to understand the impact of under-reporting of historical corporate emissions relative to those initiatives.

To contextualise our findings, we note that the cumulative methane conversion gap we have estimated under our two counterfactuals ranges between 1.3x (GWP_{100}) and 10x (GWP_{20}) of the 2022 methane emissions of countries such as Australia, Canada, and Saudi Arabia. We recall that these values only refer to the Scope 1 methane emissions of a relatively small, albeit economically significant, sample. This suggests that lack of harmonisation around methane emission reporting might result in substantial underestimation of the private sector's climate footprint after extrapolation to the wider universe of companies and their indirect emissions.

The impact of reporting optionality on the monitoring of corporate non-CO_2 emissions is highly heterogeneous in our sample. Indeed, most of the methane conversion gap has historically been, and still is, driven by companies in the Energy sector, where mean (median) methane emissions add up to ~10% (~5%) of total emissions (Figure S5). Our findings therefore highlight the need for robustifying their emission estimates in order to effectively support emission reduction targets, which have already been documented to be misaligned with the targets of the Paris Agreement[8]. As we limit ourselves to analysing Scope 1 emissions, we cannot assess the full impact of the methane reporting gap on the total footprint of those companies, but extrapolation across all scopes can be expected to make the overall impact considerably more sizeable. Future research should address this dimension by including more granular data on Scope 3 emissions broken down into individual GHGs. This is a challenge at the moment, given the further latitude allowed by accounting standards in estimating indirect emissions[32].

Moving beyond cross sectional statistics, our study reveals interesting dynamics in GWP choices. Notably, between 40 and 700 companies (depending on the choice of GWP_{100}

or GWP_{20} as a counterfactual) change their emission metrics over time by opting for a shorter time horizon, even if for a small period of time. This may result in inflation of their emission, even if only temporarily. We cannot observe or infer the rationale for this choice, but several drivers might be at play. For example, companies may switch metrics in anticipation of changes in regulation or they may wish to inflate the offsetting potential of abating certain short-lived gases, as emission permits are traded and retired on a CO_2 equivalent basis. Companies may also simply rely on emission estimates outsourced to providers that have discretion in how to interpret reporting guidelines. The lack of sectoral and geographical bias in corporate choices suggests that these dynamics are mostly driven by internal factors as opposed to external influences. Hence, harmonization of emission reporting standards could represent an important disciplining device to ensure comparability of reported emissions and mitigate greenwashing concerns.

In this study, we have not addressed the question of why companies might deviate from guidelines or choose a particular emission metric over other ones. We do not make any causality claims, neither in the cross-section nor in the temporal dimension. As discussed throughout the manuscript, there could be multiple reasons behind those choices, from regulatory requirements to country-level policy recommendations or strategic reporting behaviour, as well as simple lack of engagement. We also do not quantify the uncertainty around the estimates because companies do not share the raw data supporting their emission estimates. The uncertainty surrounding certain estimates is sometimes disclosed in sustainability reports but is typically limited to aggregate GHG emissions and provided in unstandardised format. This makes gauging the uncertainty of estimates at individual GHG level extremely challenging.

Optionality in the choice of emission metrics has important implications for investors assessing their portfolios' exposure to transition risks, as proxied, for example, by carbon price risk. Indeed, we have found that if companies were to follow harmonised standards, the cost of offsetting their methane emissions would represent a sizeable portion of their earnings. The effect of a change in reporting norm is particularly evident in the Energy and energy-intensive sectors, in which, under the GWP_{20} counterfactual, earnings at risk can be as high as four times those implied by reported methane emissions. These estimates are based on ETS carbon prices applied also to companies that are currently not subject to them. We note that companies participating to ETS are subject to tighter regulations in their emission computation, i.e., emission reporting regulations are harmonised within each ETS. Hence, given the fast growth of compliance markets worldwide, the economic costs of transition risks associated with the implementation of harmonised standards cannot be overstated.

Overall, our results contribute to the emerging literature on carbon accounting standards for non-CO_2 gases. As pointed out by some authors[33], recent efforts have aimed at improving the coherence and consistency of accounting within and across different scopes[32,34,35], but have taken the unit of account for granted. In this work, we have focused on methane to demonstrate the need for consistent reporting of non-CO_2 emissions broken down by individual GHGs measured in native units of emission. Reliable monitoring of corporate emissions and associated abatement plans can only be implemented by moving beyond reporting standards relying on loose or heterogeneous notions of CO_2-equivalence. Indeed, without global harmonisation of GWP standards, CO_2-equivalence may be misleading when comparing different corporate emissions and may be vulnerable to manipulation, due to the heterogeneity in emission abatement costs faced by different sectors. More prosaically, use of an inconsistent unit of measure seriously undermines accounting exercises that are so crucial in structuring and monitoring alignment with climate goals. The global harmonisation of direct reporting of disaggregated GHG emissions would also allow us to account for the different impacts of short-lived and long-lived climate forcers on global temperature[13], therefore enabling the accurate tracking of corporate contributions to global climate dynamics, particularly in sectors that are instrumental for the transition to a low-carbon economy.

We recommend that institutions and initiatives such as CDP explicitly require companies to disclose non-CO_2 emissions in differentiated format and report them either in native units of measure or under a harmonised GWP (e.g., the most recent GWP_{100} released by the IPCC) or following a double reporting standard[36,37] (i.e., reporting using both GWP_{100} and GWP_{20}) . We also recommend that all organisations that track corporate emissions and their alignment with global climate targets, such as the Science Based Target initiative, require companies to disclose individual GHG emissions and set targets either using a full mix of GHG under harmonised standards or by individual group of climate forcers, as for example recently proposed by some authors[10]. This is to ensure a level-playing field and avoid that companies take advantage of reporting optionality to boost their climate performance. This is also essential to assess the contribution of the corporate sector GHG mix to global temperature rises[13,14,29].

Finally, as mandatory reporting requirements emerge throughout the globe through, for example, the implementation of new ETSs and the addition of new GHGs to existing ETSs, it is vital that new regulations are developed and implemented by ensuring harmonisation of reporting standards across jurisdictions and geographies.

Methods

Data

We collected data from the CDP Climate Change questionnaires from 2014 to 2023 as available from our academic license. From each questionnaire, we extract companies' identifiers (company name, account number, ISIN and Ticker symbols) and metadata, i.e., country, sector, industry, and answers' submission date. Then, we filter out observations that refer to emission data from previous fiscal years (e.g., from the 2015 questionnaire, we only retain companies that report data on the fiscal year ending in either 2014 or 2015). Finally, for those companies reporting the breakdown of Scope 1 emissions across individual GHGs, we extract the gas name, emission value (in tCO_2e), and the GWP choice.

We focus on Scope 1 because Scope 2 and 3 emissions are rarely disaggregated by individual GHGs. However, even for Scope 1 emissions, not every CDP respondent discloses emissions breakdowns and only a subset of those that disclose them explicitly report methane emissions and the GWP value used for the conversion. We group all companies that report methane emissions but do not explicitly disclose an IPCC emission metric in a separate category denoted as "Other"; see, for example, Figure 1 panels **b,c**. Some of these companies refer to country guidelines (that might still be based on the most recent GWPs), others use internal factors, and others do not report this information in English (see table ST3 for examples of GWP choices within the "Other" category).

It is important to note that several companies in the "Other" category might still have disclosed methane emissions using an IPCC value, even if they have not explicitely chosen that value from those provided by CDP in a drop-down list. As these values cannot be validated without considerable risk of misclassification, we remove them from the main analysis. The only exceptions are companies that select the "Other, please specify" option and then indicate an IPCC value following the same structure adopted by the CDP default options (e.g., "IPCC Fifth Assessment Report (AR5 – 100 year)"). In our analyses we match the text after the "Other, please specify" string and include these companies. We also drop companies disclosing emissions using a 50-year time horizon, which is not a standard metric from the IPCC but an option provided by the CDP questionnaire. As shown in figure S1, these filters have a marginal impact on sample sizes across the years. Finally, some companies report methane emissions together with the emissions of other gases (e.g., "Other, please specify: CH4, N2O and HFC", "Other, please specify: CH4 (methane), N2O (nitrous oxide)"). We do not include these companies in our sample.

In terms of industry classification, we note that the raw data report it following inconsistent standards across the years. We therefore manually map industries and primary activities into the Global Industry Classification Standard (table ST4). Similarly, we map countries into geographical regions following the United Nations' SDG framework. Following the S&P geography classification scheme, we further aggregate data into three macro-regions (Europe, North America, Asia-Pacific) with one additional global region representing the rest of the world (table ST5). Aggregation is essential to guarantee enough yearly data for the sample statistics. To calculate the economic relevance of our sample we used data for approximately 53000 companies from Compustat. Global market capitalisation data are from the World Bank. Exact values of market share cannot be calculated because some of the companies in the sample are privately owned and other were lost in the matching process. Overall, the economic statistics are calculated over a sample of 1751 companies.

The methane conversion gap

For every company in the fully disclosing subset we calculate the counterfactual emission values under the most recent GWP_{100} and GWP_{20} from the IPCC report available at the time of disclosure, i.e., AR5 from 2014-2021 and AR6 in 2022 and 2023. The counterfactual emissions for company c in year t are calculated as $\mathcal{E}^{\mathrm{H,counter}}_{\mathrm{CH}_4,c}(t) = \mathcal{E}^{\mathrm{reported}}_{\mathrm{CH}_4,c} \frac{\mathrm{GWP}_{\mathrm{IPCC,H}}(t)}{\mathrm{GWP}^{\mathrm{reported}}_{c}(t)}$, where H is either 20 or 100. The associated methane conversion gap is then given by $\Delta^{\mathrm{H}}_{\mathrm{CH}_4,c}(t) = \mathcal{E}^{\mathrm{reported}}_{\mathrm{CH}_4,c}(t) - \mathcal{E}^{\mathrm{H,counter}}_{\mathrm{CH}_4,c}(t)$. The GWP values used in the calculations are reported in table ST2 in the Supplementary Information. The cumulative conversion gap shown in Figure 2 panel **a** is simply the cumulative sum along previous years and across companies' yearly conversion gaps. In other words, for each year T between 2014 and 2023, we have:

$$\Delta^{\mathrm{H}}_{\mathrm{CH}_4,\mathrm{cum}}(T) = \sum_{t\leq T} \sum_{c} \Delta^{\mathrm{H}}_{\mathrm{CH}_4,c}(t) \tag{1}$$

Intertemporal choices

The implications of intertemporal choices are estimated as follows. For every company that changes emission metric from the previous year and does not re-aligns itself with the counterfactual we calculate two quantities: (1) the percentage change in reported emissions between year $t-1$ and year t ($\mathcal{E}^{\mathrm{reported}}_{\mathrm{CH}_4}(t)/\mathcal{E}^{\mathrm{reported}}_{\mathrm{CH}_4}(t-1) - 1$) and (2) the percentage change in emission that would have occurred had the company followed the counterfactual in both $t-1$ and t ($\mathcal{E}^{\mathrm{counterfactual}}_{\mathrm{CH}_4}(t)/\mathcal{E}^{\mathrm{counterfactual}}_{\mathrm{CH}_4}(t-1)-1$) . The first term is a function of both emission reduction capabilities and change in emission calculation methodologies. The second term is simply a function of emission reduction capabilities except for changes occurring upon publication of AR6, when the GWP value of the counterfactual changes as well. We then take the difference between the two and the median over all companies, c, and time periods, t, ($\langle\cdot\rangle_{t,c}$, we use the median because the statistics is calculated over a relative small sample with a skewed distribution). That is:

$$r = 100 \times \left\langle \frac{\mathcal{E}^{\text{counterfactual}}_{c,\text{CH}_4}(t)}{\mathcal{E}^{\text{counterfactual}}_{c,\text{CH}_4}(t-1)} - \frac{\mathcal{E}^{\text{reported}}_{c,\text{CH}_4}(t)}{\mathcal{E}^{\text{reported}}_{c,\text{CH}_4}(t-1)} \right\rangle_{t,c}, \tag{2}$$

where t and c range over the set of all time periods and of all companies whose emission metric or AR source deviate from the previous year choice, respectively. The set excludes observations that switch to the most recent counterfactual. The statistics r is calculated independently for any change of time horizon and assessment report and it is shown in the bar plots in Figure 3 panel **b** and **e**. Positive values of r imply rates of change in emissions that are lower than what they would have been had the company consistently adopted the relevant counterfactual.

Economic impact and earnings at risk

Carbon price data are from the World Bank and are available at https://carbonpricingdashboard.worldbank.org/. We include any country with an active Emission Trading Scheme (ETS) during the observation period. For countries with both national and regional ETSs we use the price of carbon from the national market. For countries with only regional (or state) ETSs, such as the US, for example, where only a few states have active carbon pricing mechanisms, we use the average carbon price as national carbon price. For countries in the European union we use carbon prices from the EU ETS. The economic impact of the methane conversion gap for company c in year t is calculated as the product of the conversion gap and the price of carbon:

$$\mathcal{C}^{\text{H}}_{\text{CH}_4,c}(t) = \Delta^{\text{H}}_{\text{CH}_4,c}(t) \times \text{Carbon Price}(t) \tag{3}$$

From the above, we can compute useful metrics, such as the Earnings at Risk (EAR):

$$\mathrm{EAR}_c(t) = -\frac{\mathcal{C}^{\mathrm{H}}_{\mathrm{CH}_4,c}(t)}{\mathrm{EBITDA}_c(t)}, \tag{4}$$

where EBITDA are Earnings Before Interests, Taxes, Depreciation and Amortisation as reported in COMPUSTAT. EBITDA and carbon prices are measured in US$ and US$/t$CO_2$e, respectively. The transition risk analysis covers 1098 out of the 1718 companies in countries with available carbon prices because only for these companies we were able to match accounting data.

Data Availability. CDP data are covered by a license and therefore we cannot share them.

Code Availability. The Python code to extract CDP data from each questionnaire, and to generate the figures will be available on Harvard Dataverse upon publication of the paper.

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Authors contribution. SC and EB designed the study. SC collected the data and performed the analysis. SC and EB wrote the manuscript.

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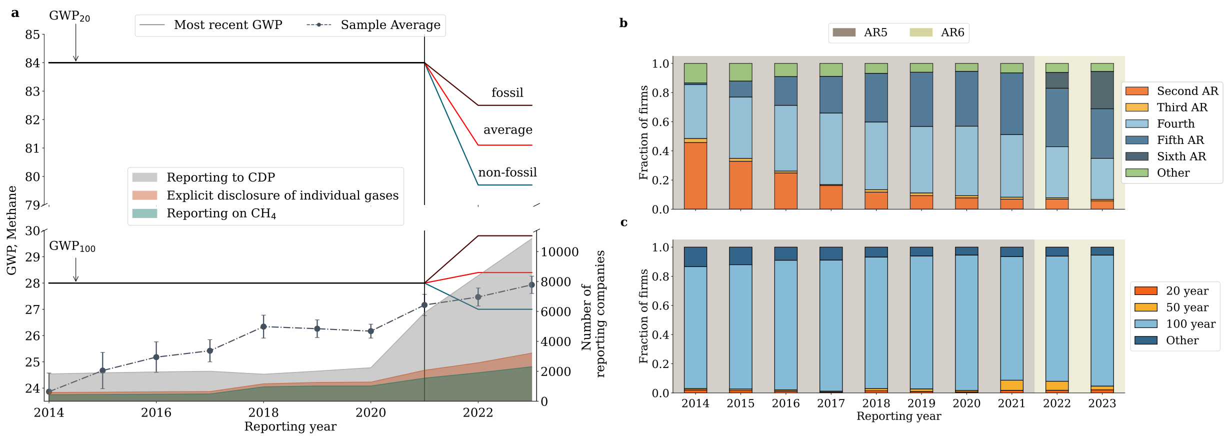

Fig. 1 | Emission metrics. Panel **a** shows the yearly number of companies in our sample (gray, bottom right y-axis), the number of companies that report differentiated Scope 1 emissions by individual GHGs (orange, bottom right y-axis) and the number of companies reporting methane emissions (green, bottom right y-axis). The dash-dotted line (left y-axis) shows the average GWP values used by companies to convert methane emissions into CO_2e units; the error bars show the standard errors, N = 9375. The solid lines show the GWP_{100} and GWP_{20} from the latest Assessment Report (AR), including the fossil and non-fossil GWP values from AR6. The solid vertical lines denote the transition year from AR5 to AR6. Panel **b** and **c** show yearly distribution of GWPs in the sample by Assessment Report (top) and GWP time horizon (bottom). The proportions are computed based on the 3248 companies reporting methane emissions (N = 10578).

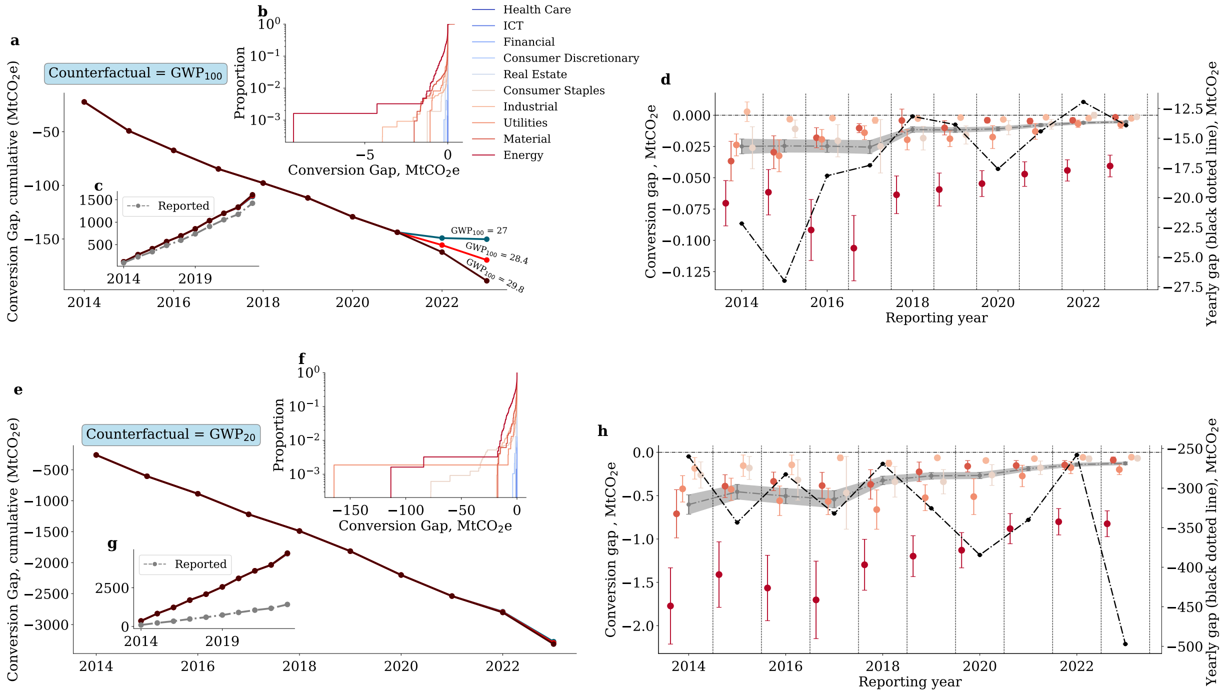

Fig. 2 | The methane conversion gap. Panel **a** (**e**) shows the cumulative value of the methane conversion gap over time, i.e., the sum of the yearly differences between reported methane emissions and emissions computed under the most recent GWP_{100} (GWP_{20}). The trifurcation of the solid lines from year 2021 shows the gap under the fossil and non-fossil GWPs from AR6, as well as their average. Panel **b** (**f**) shows the cumulative distribution of the methane conversion gap across companies under the most recent GWP_{100} (GWP_{20}). Panel **c** (**g**) shows the cumulative value of methane emissions as reported and as expected under the most recent GWP_{100} (GWP_{20}) (N = 9375). Panel **d** (**h**) left y-axis shows the average methane conversion gap across key sectors under the 100-year (20-year) counterfactual. The error bars are standard errors of the mean (N = 8713); low methane emission sectors and the bottom 1% of the gap distribution are excluded from the visualisation and the estimation of the averages. The gray dot-dashed line shows the sample averages across time, whereas the gray shading shows the standard errors. The black dotted line in the right y-axis shows the total gap over the sample, including all sectors, by year.

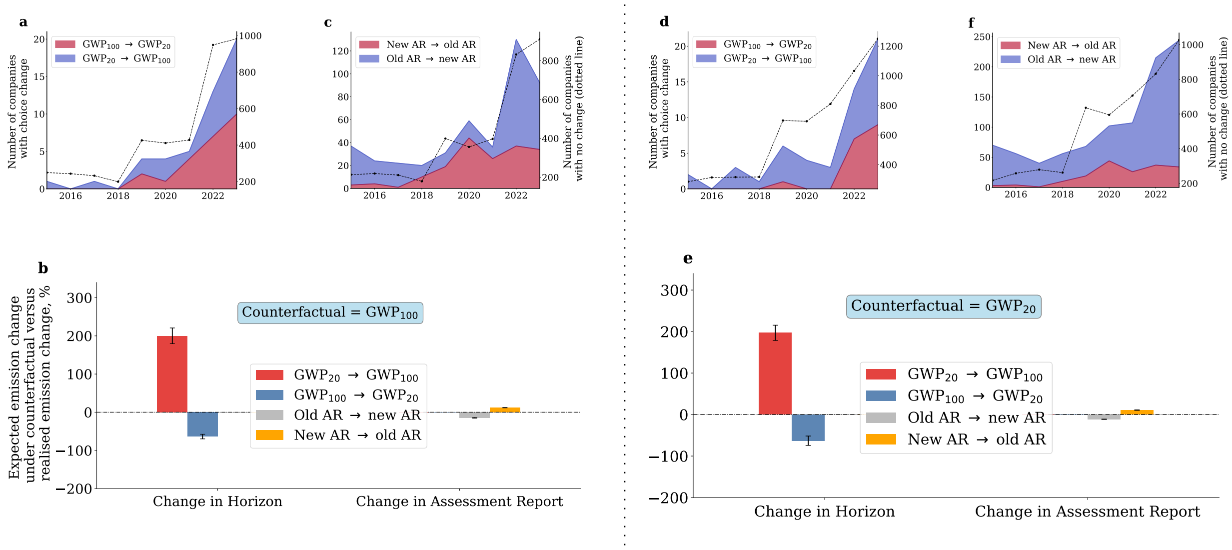

Fig. 3 | Intertemporal choice. Panel **a** and **d** (**c** and **f**) show the number of companies adopting a different emission metric (left y-axis) compared to the previous year's choice of Assessment Report, excluding companies adopting the counterfactual (the most recent GWP_{100} and GWP_{20} in panel **a,c** and **d,f**, respectively). The dark dotted lines show the number of companies that do not change metrics (right y-axes). Panel **b** (**e**) shows the implication of companies' choices on year-on-year changes in emissions under the GWP_{100} (GWP_{20}) counterfactual, as in Eq. (2). From the leftmost red bar in panel **b** to the rightmost yellow bar in panel **e**, the sample includes N=48,48,504,344,74,34,1316,344 observations which only represent companies that have changed metrics over consecutive years and exclude those that have switched towards the counterfactual GWP. Positive values imply realised rates of change in emissions that are lower than what they would have been had the company consistently adopted the counterfactual GWP. Error bars represent standard errors of the median.

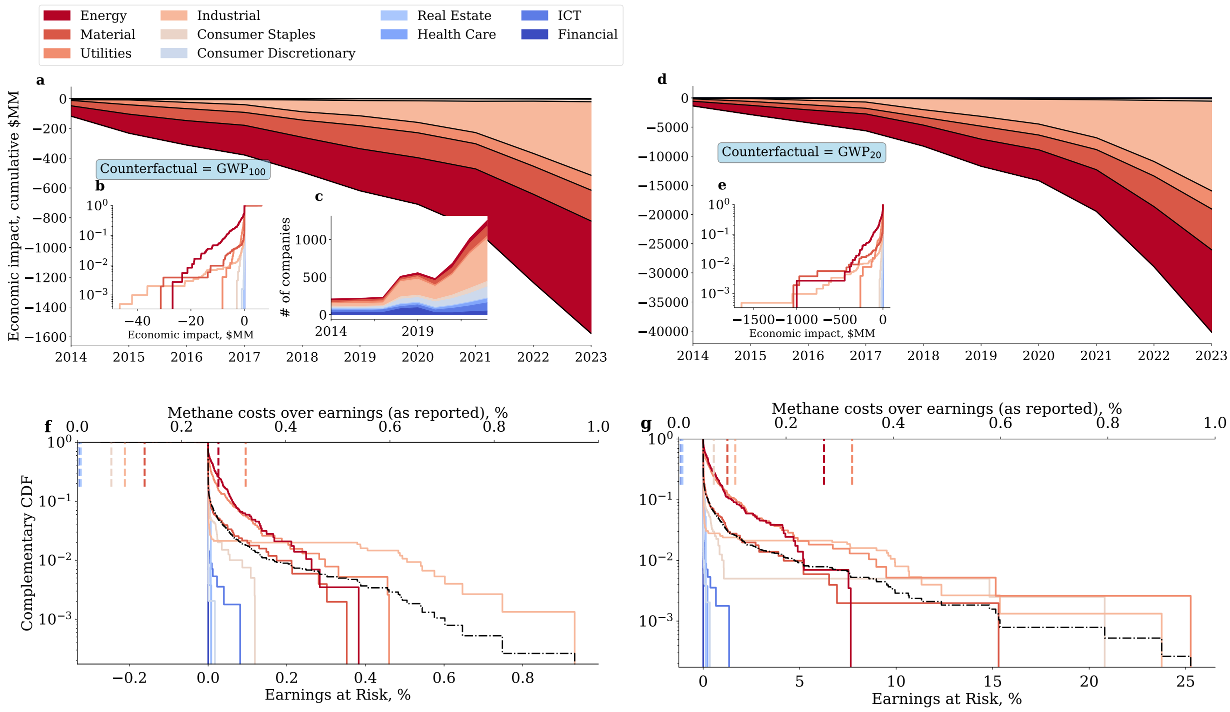

Fig. 4 | Economic implications of the methane conversion gap. Panel **a** and **d** show the cumulative sum of the yearly total difference between cost of methane under reported and counterfactual emissions by sector (N=5380). Panel **b** and **e** show the cumulative distribution function of the economic impact across companies and years under the GWP_{100} and GWP_{20} counterfactuals, respectively. Panel **c** shows the number of companies in the sample by year and sector (the number of companies is the same in panel **a** and **d**). Panel **f** and **g** show the complementary cumulative distribution function (1-CDF) of earnings at risk under the GWP_{100} and GWP_{20} counterfactuals, respectively (N=4265). We express EAR in percentage points and therefore multiply Eq. (4) by 100. The black line show the complementary cumulative distribution function across all sectors. The dotted vertical lines at the top of the figures denote the average cost of methane (as reported) as a fraction of EBITDA.

Supplementary Information: Lack of harmonisation of greenhouse gases reporting standards and the methane emissions gap

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A Firm and country level data

To identify differences between firms that follow the GHG protocol guidelines (i.e., that use the most recent GWP_{100} published by the IPCC in their disclosure) and firms that do not, we collect data on firms' fundamentals from COMPUSTAT and Refinitiv. Specifically we define Size as the log of sales (SALE, in USD) adjusted for inflation (sourced from the Federal Reserve Bank of St Louis Database) ; Tangibility is property plant and equipment (PPENT, in USD) divided by book assets (AT, in USD), Profitability is Earnings Before Interests, Tax, Depreciation and Amortization (EBITDA in USD) over lagged book asset. Market leverage is long-term plus short-term debt (F.DebtTot) divided by market value of assets: total assets (F.TotAssets) – book equity (F.ShHoldEqCom) + market equity (F.MktCap), market to book is the market value of assets divided bay Total Book Asset. Finally, we collect information on the number of carbon management activities from the CDP Climate Change questionnaire. These include, for example, activities that aim to increase efficiency of production processes, fleets fuel efficiency, new product design, among others.

To merge CDP data to COMPUSTAT and Refinitiv we first merge on ISIN numbers. Then, we merge the left over companies using companies names. Firms that could not be matched by ISIN numbers and company names, were matched based on standardised company names obtained after removing punctuation, capitalisations, and common suffixes such as *corp*, *llc*, and *inc*. Out

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of the 2864 companies that report methane emissions and an IPCC GWP metric, we could merge 1642 with their financial information.

We also collect country-level policy data from the Policy Instruments for the Environment Database (PINE), a dataset from the OECD that track countries' environmental policies. Finally, we collect global energy price data from the World Bank.

B Probit model

We estimate the systematic differences between the characteristics of companies that follow the GHG protocol guidelines in their methane disclosure and those that do not with a Probit model where the dependent variable is zero if in year t firms c uses the most recent GWP_{100} in the disclosure, and one otherwise (the dependent variable measures the probability of deviation from the standard). All the firm-level independent variables, that include firms' Size, ratio of property plants and Equipment over total book assets (Tangibility), Profitability, Market-to-Book and Leverage are measured on a three years rolling basis up to the fiscal year in which the reported emission occurred. For robustness we also repeat the estimation with the fundamentals measured on a yearly basis and by running multiple regressions to estimate the effect of each set of variables independently.

In the regressions, we also control for current (Scope 1) emissions per unit of sales (i.e., Scope 1 emission from CDP over sales in USD), the number of environmental policies active in the country in the year of the emission, the country GDP and the World Bank Energy Price Index. The objective of introducing country-level controls (either through fixed effects or policy variables) is to control for systematic deviation from IPCC GWPs due to factors exogeneous to the firms.

Because disclosure to CDP is a voluntary process our sample is subject to self-selection bias. To correct for this bias we estimate the model with the Heckman correction[38]. Specifically, we run a two-stage model. The first model is a Probit where the dependent variable is a binary indicator that takes the value of one if company c discloses emission to the CDP questionnaire in year t and zero otherwise. The independent variables include Profitability, Size, Tangibility, year-fixed effects. We also control for the proportion of companies in any single country and sector that disclose emission to CDP. These two factors are necessary for correct identification using the Heckman correction because they influence the selection equation but not the outcome[39]. We call the control set of the Probit model $\tilde{\mathbf{X}}$ to distinguish it from the control set of the main regressions. From the fitted Probit model, we estimate the inverse Mills ratio, $\mathcal{M}$, which is defined as: $\mathcal{M} = \frac{f(x)}{F(x)}$ where $f(x), F(x)$ are the (normal) probability density function and the cumulative distribution, respectively. Then we use the inverse Mills ratio from the Probit as an additional covariate in the main Probit. Notice that whilst the Heckman correction was originally derived using an OLS estimator in the second stage model, the statistical properties of the correction are preserved under a Probit[40].

$$\mathbb{P}[\text{Disclosure}_t|\tilde{\mathbf{X}}_t] = \Phi(\tilde{\mathbf{X}}_t^T\tilde{\boldsymbol{\beta}}) \tag{5}$$

$$\text{A) } \mathbb{P}[\text{Deviation from latest GWP}_{100,t}|\{\mathbf{X}_{c,\langle t_3\rangle}, \mathcal{L}_{g,t}, \mathcal{P}_t, \mathcal{S}, \mathcal{M}_{c,t}, \mathcal{D}_t, \mathcal{A}_{c,t}\}] = \Phi(c+ \tag{6}$$

$$+\alpha\mathbf{X}_{c,\langle t_3\rangle} + \beta\mathcal{L}_{g,t} + \gamma\mathcal{P}_t + \delta\mathcal{M}_{c,t} + \omega\mathcal{S} + \eta\mathcal{D}_t + \zeta\mathcal{A}_{c,t})$$

$$\text{B) } \mathbb{P}[\text{Deviation from latest GWP}_{100,t}|\{\mathbf{X}_{c,\langle t_3\rangle}, \mathcal{S}, \mathcal{R}, \mathcal{Y}, \mathcal{M}_{c,t}, \mathcal{D}_t, \mathcal{A}_{c,t}\}] = \Phi(c + \alpha\mathbf{X}_{c,\langle t_3\rangle}+ \tag{7}$$

$$+\beta\mathcal{R} + \gamma\mathcal{Y} + \delta\mathcal{M}_{c,t} + \omega\mathcal{S} + \eta\mathcal{D}_t + \zeta\mathcal{A}_{c,t})$$

$$\text{C) } \mathbb{P}[\text{Deviation from latest GWP}_{100,t}|\{\mathbf{X}_{c,t}, \mathcal{R}, \mathcal{C}, \mathcal{Y}, \mathcal{M}_{c,t}, \mathcal{D}_t, \mathcal{A}_{c,t}\}] = \Phi(c + \alpha\mathbf{X}_{c,t} + \beta\mathcal{R}+ \tag{8}$$

$$+\gamma\mathcal{Y} + \delta\mathcal{M}_{c,t} + \omega\mathcal{S} + \eta\mathcal{D}_t + \zeta\mathcal{A}_{c,t})$$

Where $\mathbf{X}_{c\langle t_3\rangle}$ are company-level data measured as rolling averages over the previous three fiscal years (the subscript c denotes company level variables); $\mathcal{L}_{g,t}$ are country-level data (i.e., environmental policies, GDP); $\mathcal{P}_t$ is the Energy Price Index, a global-level variable; $\mathcal{S}$ are sector fixed effects; $\mathcal{M}_{c,t}$ is the inverse Mills Ratio estimated from the Probit in Eq. (5); $\mathcal{D}_t$ is the distance, in years, from the release of the latest GWP_{100} ; $\mathcal{A}_{c,t}$ is the number of carbon management activities implemented and reported in year t. We then repeat the estimation using regional and year fixed-effect $(\mathcal{R}, \mathcal{Y})$ as opposed to country and global level data (Eq. (7)).

As a further robustness test, in the last regression (Eq. (8)) we measure financial fundamentals in the same year of the disclosure instead of including them in the model as historical averages. When using yearly data, there is a clear directionality in the relationship between the control variables. For example, in any given year revenue drives earnings which are used to measure Profitability. Hence including them both in the regression leads to unfair comparison of coefficients as one variable blocks the path of the other[41–43]. To fairly compare the coefficients we need to estimate multiple regression specifications each for each variable that plays a comparable role in the underlying data generating process. Specifically, we first estimate the effect of Size, controlling for self-selectivity, previous year book asset, year,country and sector fixed effects, as none of the other variables drive revenue on a contemporaneous basis. Then we add Profitability, Tangibility, and Market-to-Book (which are driven by, but do not drive, revenue and book value of assets) to the model, and finally we add Leverage, Current Emissions and the number of carbon management activities reported to CDP.

The results of the three regressions are shown in table ST1. The table shows that companies that are more likely to deviate from the GWP_{100} standard are larger, have predominantly tangible assets and have a low predicted growth (i.e., low "Market-to-Book" ratio). Interestingly, deviations are also more likely for companies that implement a lower number of carbon management activities as reported to the CDP climate change questionnaire, and, as expected, become less likely as new standards become established ("Time from new standard", i.e., the distance, in years, from the release of the latest GWP_{100}).

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	Main regression	With fixed-effects	Yearly measurements
Size	0.06***	0.05***	0.04***
Profitability	-0.0	-0.0	-0.0
Tangibility	0.03***	0.03***	0.02***
Market-to-Book	-0.03***	-0.03***	-0.02**
Leverage	-0.01	-0.02*	-0.02**
# Env. Policies	-0.01		
Current emissions	-0.01*	-0.01*	-0.01
GDP	0.02**		
Time from new standard	-0.08***		
Energy Price Index	0.14***		
Carbon management activities	-0.01**	-0.01**	-0.01**

Table ST1: | **Systematic differences between companies that follow standard carbon accounting guidelines and companies that do not.** The table shows the marginal effects from the Probit model for the main regression (Eq. (6), N=4518), the fixed-effects regression (Eq. (7), N=4518), and the regression that uses yearly measures of fundamentals (as opposed to their three-year averages, Eq. (8), N=4593). The dependent variable is zero if in year t firms c adopts the most recent GWP_{100}, and one otherwise. Hence, positive coefficients denote higher probabilities of deviating from the GHG protocol guidelines. *,**,*** denote statistical significance at 10%,5%, and 1%, respectively.

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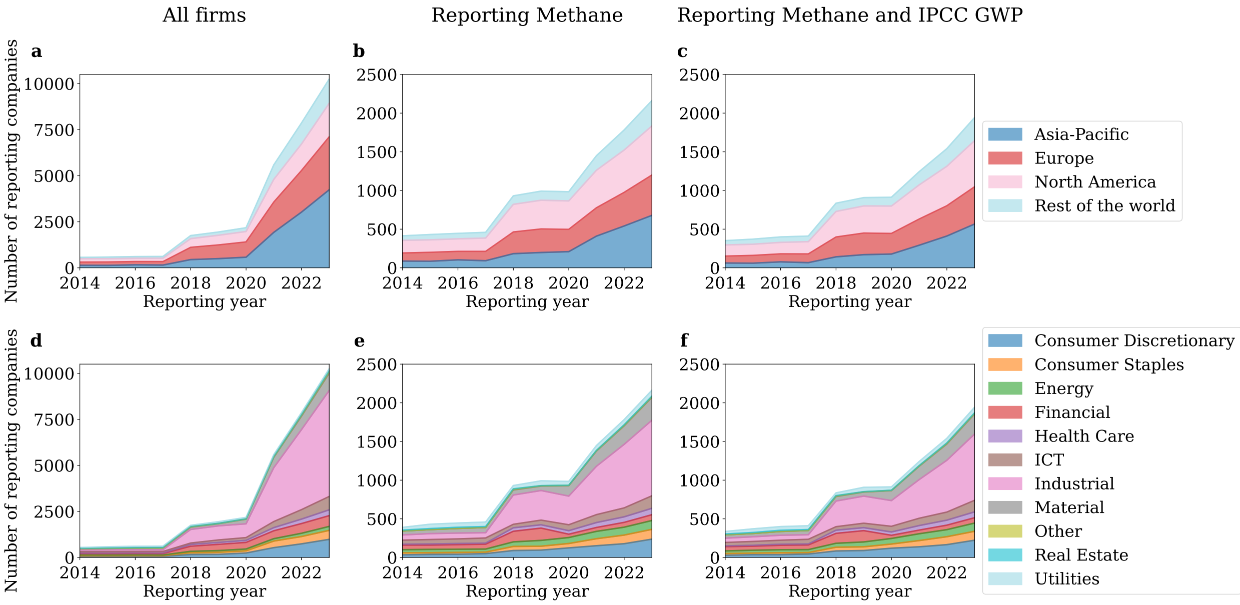

Fig. S1 | Number of companies in the sample by year, geography, and sector. The figure shows the number of firms by geography (panel **a,b,c**) and sector (panel **d,e,f**) that reports to CDP (panel **a,d**), that also reports methane emissions (panel **b,e**) and that also explicitly reports an IPCC GWP value (panel **c,f**). Details on sectors and geography can be found in tables ST4 and ST5, respectively.

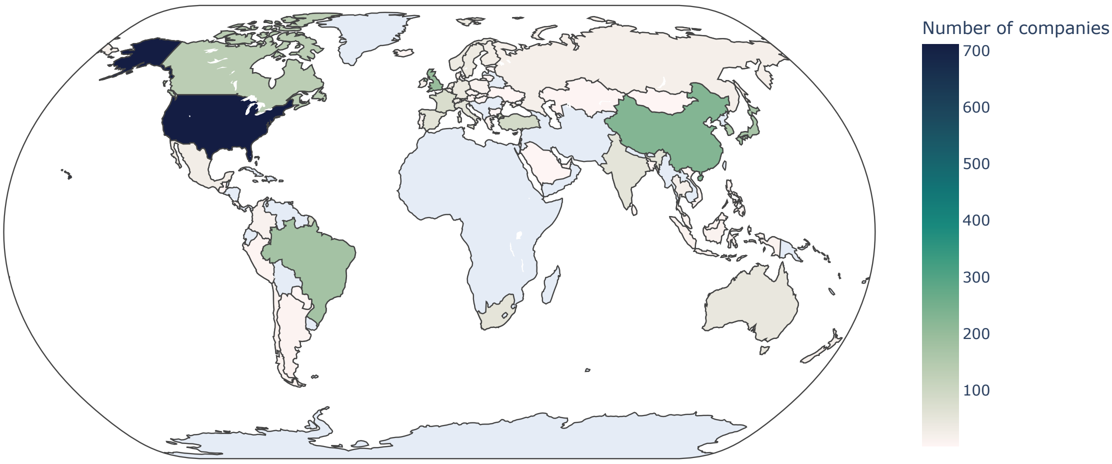

Fig. S2 | Geographical distribution of companies in the sample. The figure shows the distribution of the number of companies in the subsample with available data on methane emissions and GWP factors. Gray countries are missing from the sample.

Report	20-year	100-year
SAR	56.0	21.0
TAR	62.0	23.0
AR4	72.0	25.0
AR5	84.0	28.0
AR6	[79.7, 81.1, 82.5]	[27., 28.4, 29.8]

Table ST2: | **Global Warming Potential values.** The table shows the GWP values used in the main text to convert CH_4 emissions in CO_2e units. SAR, AR4 and AR5 are sourced from the GHG protocol at https://ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf. TAR is sourced from Table 1 in https://unfccc.int/resource/docs/tp/tp0403.pdf. The left and right extremes in AR6 denote non-fossil and fossil methane, respectively, as from table 7.15 in (IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.).The central value in the AR6 GWP are the mean values used for the analyses in the main text.

GWP source	Reporting ear
Other: The Climate Registry: General Reporting Protocol Version 2.0	2014
Other: All emission factors sourced from EPA's Emission Factors Hub, April 2014 (http://www.epa.gov/climateleadership/inventory/ghg-emissions.html)	2015
Other, please specify: Defra, Fuels Conversion Factors 2014	2020
Other: GHG indicator	2015
Other, please specify: GHG Protocol (Emissions factors from cross-sector tools) [March 2017]	2023
Other, please specify: Calculated CO2 emissions using MMBtu x fuel specific CO2 emission factors from 40 CFR Part 98 Subpart C Table C-1 (revised Nov 2013)	2022
Other, please specify: e-CFR as of August 15 2018	2023
Other, please specify: As per National Government regulation	2023
Other: EPA Mandatory Reporting of Greenhouse Gases-Final Rule, 40 CFR Part 98, Table A-1	2014
Other, please specify: DEFRA_Conversion factors_2020	2021
Other: Base Carbone ADEME, January 2014	2014
Other, please specify: WRI, WBCSD, NCASI wood Products worksheet	2019
Other, please specify: Scope 1: Natural gas shrinkage (Leakage +Theft of Gas+ Own use of gas) reported as tCO2e, but since natural gas is predominantly methane, any emissions are equivalent. Reporting in accordance with Ofgem Guidance: OFGEM GD-2RIGs.	2023
Other: GHG Protocol Tool 2011	2015
Other, please specify: Other, please specify:	2019

Table ST3: **Examples of GWP sources excluded from the analysis** The table provides a few examples of GWP sources that we have excluded from the analysis because we could not systematically map them into IPCC values.

hotels restaurants and leisure and tourism services	Consumer Discretionary
automobiles and components	Consumer Discretionary
consumer durables household and personal products	Consumer Discretionary
homebuilding	Consumer Discretionary
hospitality	Consumer Discretionary
apparel	Consumer Discretionary
retail	Consumer Discretionary
Education services	Consumer Discretionary
Dealers, wholesalers & distributors	Consumer Discretionary
Travel services	Consumer Discretionary
Consumer goods wholesale & rental	Consumer Discretionary
retailing	Consumer Discretionary
Animal products wholesale	Consumer Discretionary
specialized consumer services	Consumer Discretionary
textiles apparel footwear and luxury goods	Consumer Discretionary
tires	Consumer Discretionary
Consumer services	Consumer Discretionary
food and beverage processing	Consumer Staples
food and staples retailing	Consumer Staples
food beverage and agriculture	Consumer Staples
Agricultural products wholesale	Consumer Staples
Food & beverage wholesale	Consumer Staples
fossil fuels	Energy
oil and gas	Energy
Energy services & equipment	Energy
Insurance	Financial
Other financial	Financial
REIT	Financial
Asset managers	Financial
banks diverse financials insurance	Financial
banks diverse financials and insurance	Financial
Banks	Financial
healthcare providers and services and healthcare technology	Health Care
health care providers and services and healthcare technology	Health Care
pharmaceuticals biotechnology and life sciences	Health Care
healthcare equipment and supplies	Health Care
biotech health care and pharma	Health Care
Pharma & health care supplies wholesale & distribution	Health Care
Health care services	Health Care
software and services	ICT
IT services	ICT
media	ICT
technology hardware and equipment	ICT
Media	ICT
telecommunication services	ICT
Print publishing	ICT
Servers & data centers	ICT
semiconductors and semiconductors equipment	ICT
Web-based services	ICT
Telecommunications services	ICT

Software	ICT
Technology hardware wholesale & distribution	ICT
construction and engineering	Industrial
Engineering services	Industrial
professional services	Industrial
Commercial services	Industrial
aerospace and defense	Industrial
Transportation equipment wholesale & dealing	Industrial
manufacturing	Industrial
infrastructure	Industrial
Industrial machinery distribution	Industrial
Industrial services	Industrial
Transportation support services	Industrial
Other professional services	Industrial
building products	Industrial
trading companies and distributors and commercial services and supplies	Industrial
electrical equipment and machinery	Industrial
Printing services	Industrial
Vehicles & machinery rental & leasing	Industrial
transportation	Industrial
Chemicals wholesale & distribution	Material
materials	Material
forest and paper products - forestry timber pulp and paper rubber	Material
Mining & metals support services	Material
mining	Material
Biofuel supply	Material
Wood & paper products wholesale	Material
Construction & building materials dealing & distribution	Material
containers and packaging	Material
chemicals	Material
construction materials	Material
mineral extraction	Material
Marketing	Other
international bodies	Other
corporate tags	Other
real estate	Real Estate
Real estate services	Real Estate
services	Services
power generation	Utilities
gas utilities	Utilities
electric utilities and independent power producers and energy traders (including fossil alternative and nuclear energy)	Utilities
water utilities	Utilities

Table ST4: **Sector mapping** The table shows the mapping from sector and primary activities reported to the CDP Climate Change Questionnaire and the Global Industry Classification Standard

Country_adj	Geography
Afghanistan	Asia-Pacific
Hong Kong	Asia-Pacific
Japan	Asia-Pacific
Viet Nam	Asia-Pacific
Korea (the Republic of)	Asia-Pacific
Malaysia	Asia-Pacific
Fiji	Asia-Pacific
Marshall Islands (the)	Asia-Pacific
Mongolia	Asia-Pacific
New Zealand	Asia-Pacific
Norfolk Island	Asia-Pacific
Indonesia	Asia-Pacific
Philippines (the)	Asia-Pacific
China	Asia-Pacific
Cambodia	Asia-Pacific
Pakistan	Asia-Pacific
India	Asia-Pacific
Bangladesh	Asia-Pacific
Sri Lanka	Asia-Pacific
Australia	Asia-Pacific
Tuvalu	Asia-Pacific
Singapore	Asia-Pacific
Thailand	Asia-Pacific
Italy	Europe
Ukraine	Europe
Jersey	Europe
Luxembourg	Europe
Isle of Man	Europe
United Kingdom of Great Britain and Northern Ireland (the)	Europe
Latvia	Europe
Ireland	Europe
Liechtenstein	Europe
Lithuania	Europe
San Marino	Europe
Serbia	Europe
Sweden	Europe
Monaco	Europe
Netherlands (the)	Europe
Spain	Europe
Norway	Europe
Slovenia	Europe
Slovakia	Europe
Poland	Europe
Portugal	Europe
Romania	Europe
Russian Federation (the)	Europe
Switzerland	Europe
Malta	Europe
Åland Islands	Europe

Finland	Europe
Hungary	Europe
Belgium	Europe
Belarus	Europe
Estonia	Europe
Croatia	Europe
Guernsey	Europe
Iceland	Europe
Bulgaria	Europe
Czechia	Europe
France	Europe
Greece	Europe
Germany	Europe
Denmark	Europe
Austria	Europe
Canada	North America
Greenland	North America
United States of America (the)	North America
Bermuda	North America
Bolivia (Plurinational State of)	Rest of the world
Saudi Arabia	Rest of the world
Cayman Islands (the)	Rest of the world
Brazil	Rest of the world
Qatar	Rest of the world
Puerto Rico	Rest of the world
Cameroon	Rest of the world
Iraq	Rest of the world
Chile	Rest of the world
Bahrain	Rest of the world
Azerbaijan	Rest of the world
Trinidad and Tobago	Rest of the world
Tunisia	Rest of the world
Turkey	Rest of the world
Argentina	Rest of the world
Angola	Rest of the world
United Arab Emirates (the)	Rest of the world
Algeria	Rest of the world
Uruguay	Rest of the world
Venezuela (Bolivarian Republic of)	Rest of the world
South Africa	Rest of the world
Colombia	Rest of the world
Oman	Rest of the world
Peru	Rest of the world
Honduras	Rest of the world
Israel	Rest of the world
Guyana	Rest of the world
Jamaica	Rest of the world
Guatemala	Rest of the world
Jordan	Rest of the world
Kazakhstan	Rest of the world
Kuwait	Rest of the world
Ghana	Rest of the world
Lebanon	Rest of the world

Libya	Rest of the world
Georgia	Rest of the world
Costa Rica	Rest of the world
Madagascar	Rest of the world
Mauritania	Rest of the world
Mauritius	Rest of the world
Mexico	Rest of the world
El Salvador	Rest of the world
Egypt	Rest of the world
Morocco	Rest of the world
Mozambique	Rest of the world
Ecuador	Rest of the world
Nigeria	Rest of the world
Cyprus	Rest of the world
Panama	Rest of the world
Paraguay	Rest of the world
Equatorial Guinea	Rest of the world
Kenya	Rest of the world

Table ST5: **Geographical mapping** The table shows the mapping from country to macro geographical regions

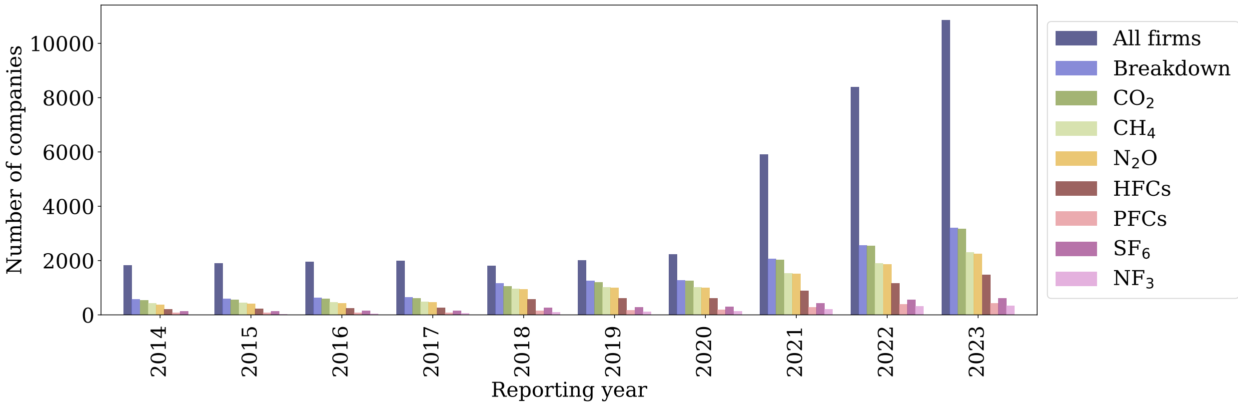

Fig. S3 | Breakdown of the non-CO_2 disclosure The figure shows the number of companies in the CDP dataset alongside the number of companies that breakdown Scope 1 emissions into individual GHG and the count of companies disclosing information in each gas.

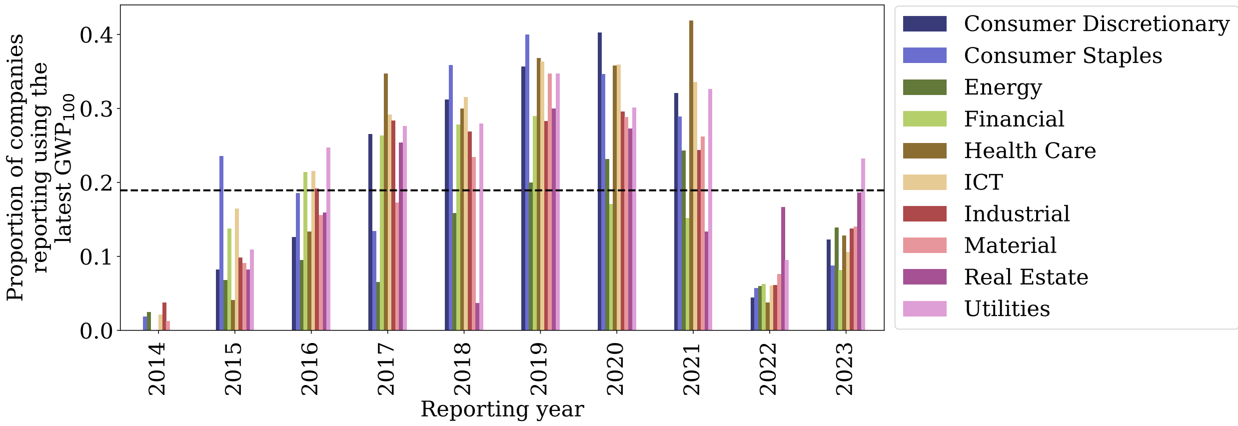

Fig. S4 | Proportion of companies reporting using the latest GWP_{100} The figure shows the proportion of companies, by sector, that report non-CO_2 emissions using the latest GWP_{100} as recommended by most reporting guidelines. The dotted horizontal line shows the sample mean.

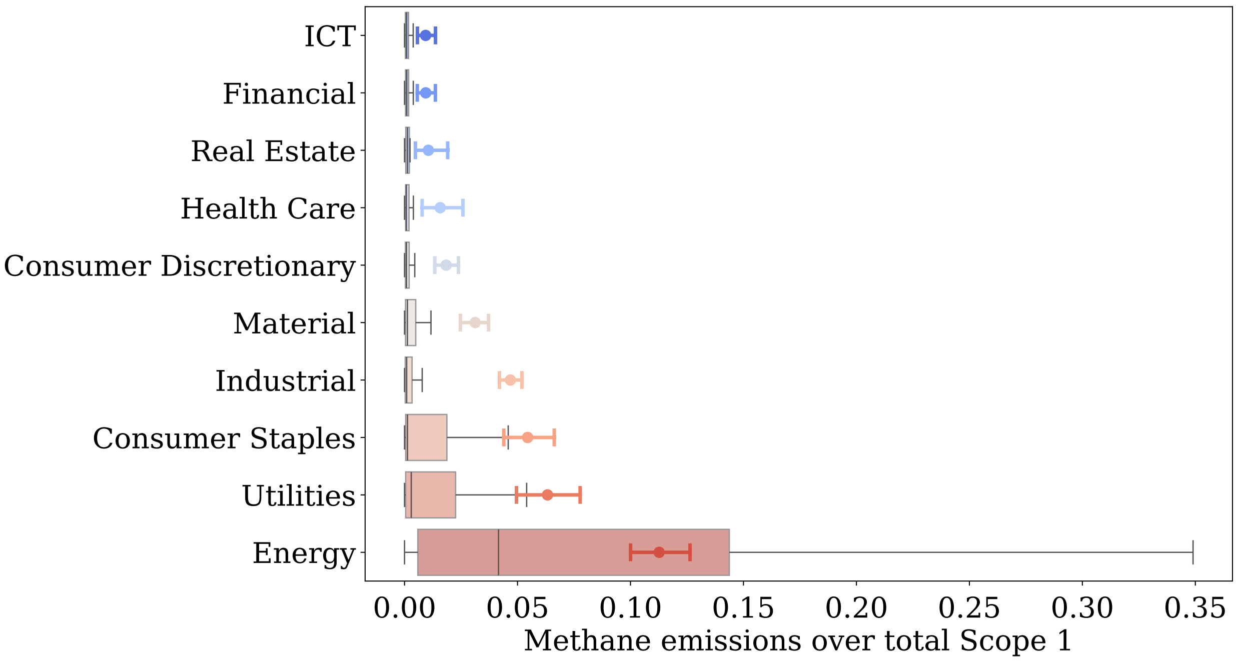

Fig. S5 | Methane intensity by sector. The figure shows the distribution of the ratio of methane emissions over total Scope 1 emissions by sector. Scope 1 emissions are those reported by the companies to CDP before breakdown into individual GHGs. As expected, the Energy and Consumer Staples (which includes Agriculture, see ST4) sectors are the most methane intensive sectors. The lines within the box plots are median lines, the full circles are the means of the distributions, and the edges of the boxes are the quartile range: the 25th and 75th percentile (N = 9703).

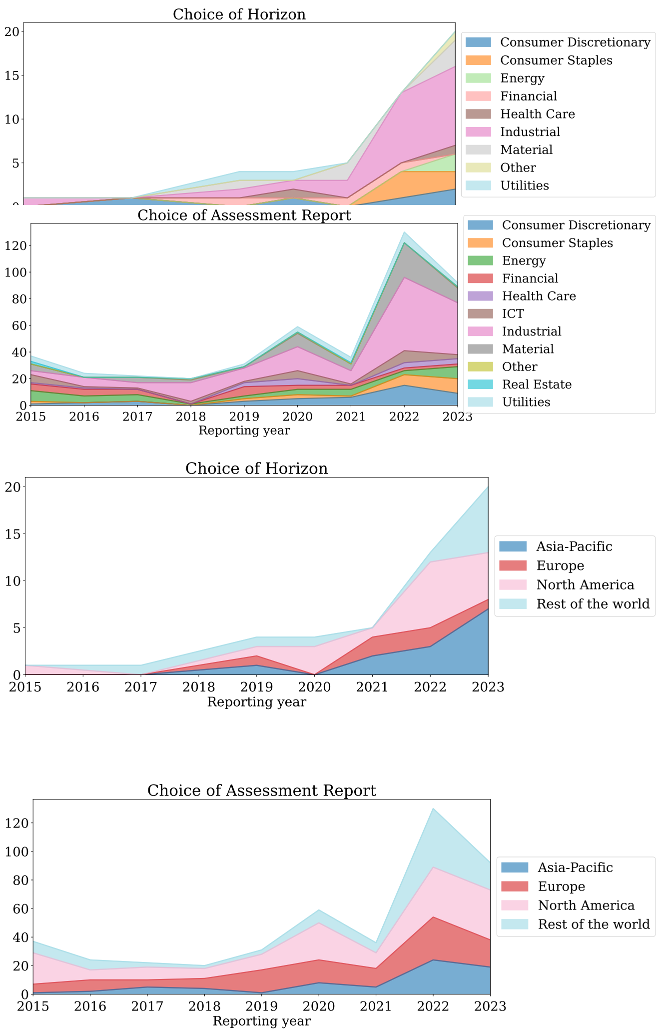

Fig. S6 | Sectoral and geographical decomposition of choice behaviour under the GWP_{100} counterfactual The figure shows the sectorial and geographical decomposition of the number of companies that change emission metric or AR source in any given year. Overall, we do not observe a substantial sector or geography bias in the sample.

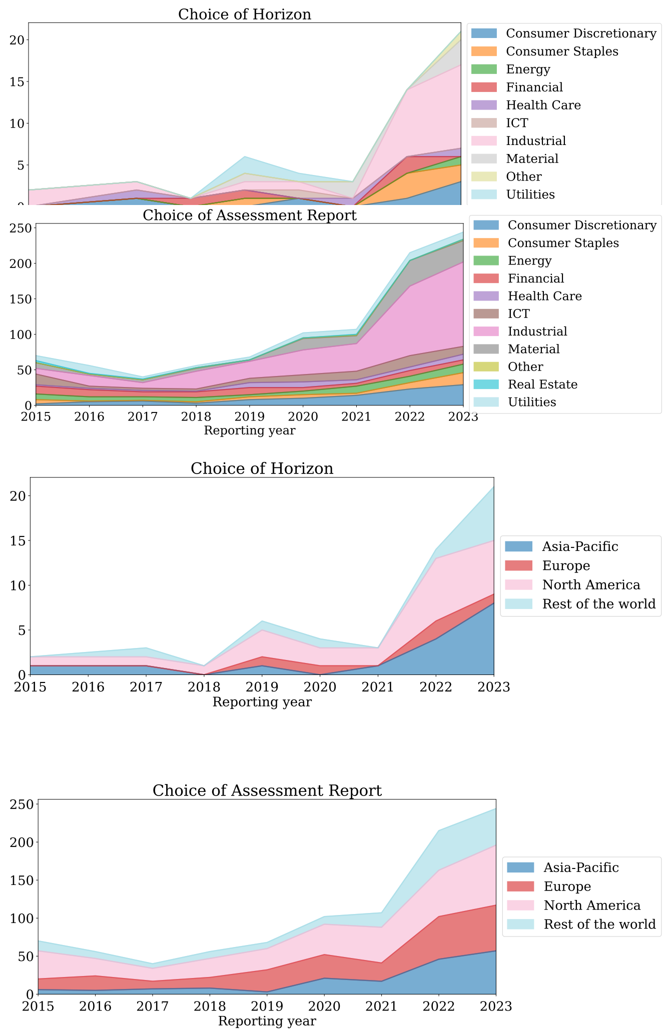

Fig. S7 | Sectoral and geographical decomposition of choice behaviour under the GWP_{20} counterfactual The figure shows the sectorial and geographical decomposition of the number of companies that change emission metric or AR source in any given year. The numbers are different from those reported in figure S6 because far fewer companies in the sample switch to the most recent GWP_{20} . Overall, we do not observe a substantial sector or geography bias in the sample.

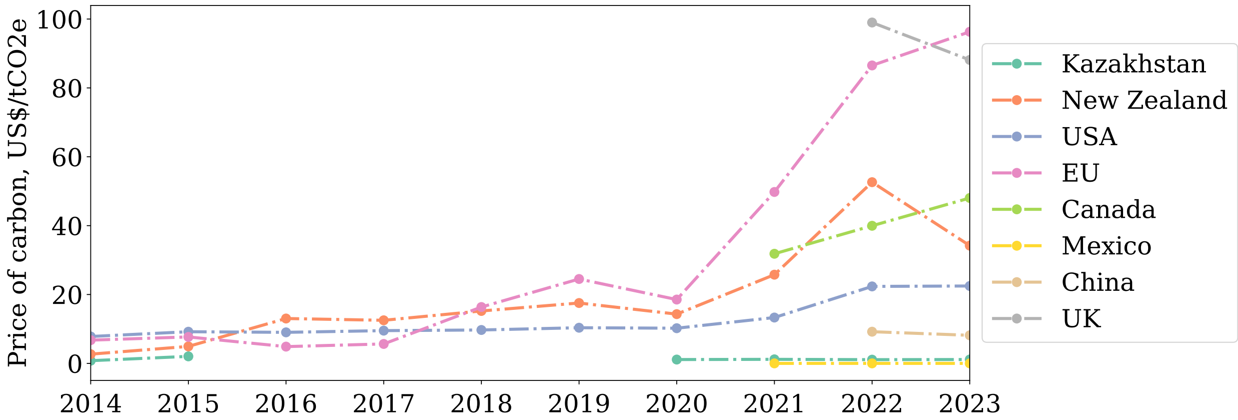

Fig. S8 | Carbon price. The figure shows the price of carbon used in the economic cost analyses in the main text. Data are from the world bank available at https://carbonpricingdashboard.worldbank.org/. For countries with both national and regional ETSs we use the price of carbon from the national market. For countries with only regional (or state) ETSs, such as the US, for example, where only a few states have active carbon pricing mechanisms, we use the average carbon price as national carbon price. For countries in the European union we use carbon prices from the EU ETS.

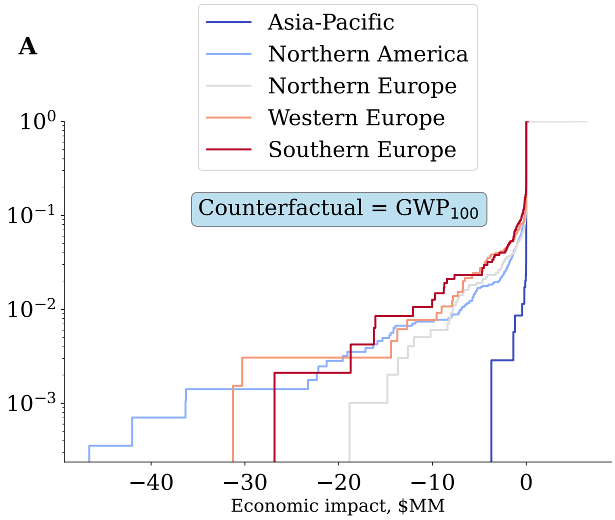

Fig. S9 | Geographical distribution of economic impacts. The figure show the distribution of economic impact by macro region. Note that the we have grouped together companies in Central and Eastern Asia with companies in Australia and New Zealand to balance the size of each group.

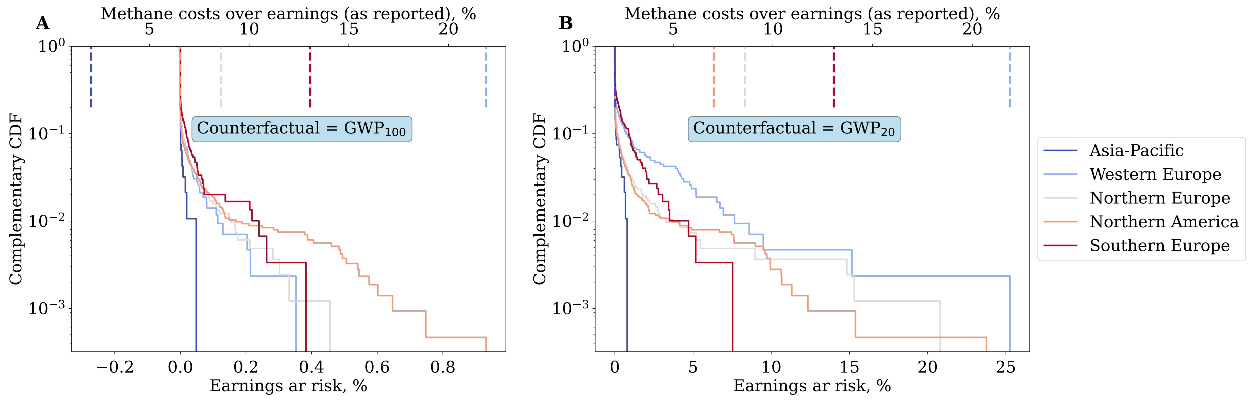

Fig. S10 | Geographical distribution of transition risks. The figure show the distribution of transition risks by macro region. Note that the we have grouped together companies in Central and Eastern Asia with companies in Australia and New Zealand to balance the size of each group.