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Renewable energy certificates threaten the integrity of corporate science-based targets

Anders Bjørn[1,3,4*], Shannon M Lloyd[1,4], Matthew Brander[2] and H. Damon Matthews[3,4]

[1]Department of Management, John Molson School of Business, Concordia University, 1450 Guy St., Montréal, Quebec H3H 0A1, Canada
[2]Centre for Business, Climate Change and Sustainability, University of Edinburgh Business School, UK
[3]Department of Geography, Planning and Environment, Concordia University, 1455 de Maisonneuve Blvd. W., Montréal, Quebec H3G 1MB, Canada
[4]Loyola Sustainability Research Centre, Concordia University, 1455 de Maisonneuve Blvd. W., Montréal, Quebec H3G 1MB, Canada
*Contact: anders.bjoern@concordia.ca

Abstract:
Companies are increasingly setting science-based targets (SBTs) to support the achievement of the Paris Agreement's mitigation goal, and a common approach to reduce reported emissions associated with purchased electricity (scope 2 emissions) is to buy renewable energy certificates (RECs). Previous analyses suggest that corporate REC purchases are unlikely to lead to additional renewable energy production. Here we show that the widespread use of RECs by companies with SBTs has led to an inflated estimate of the effectiveness of mitigation efforts. When removing the emission reductions claimed through RECs, companies' combined 2015-2019 scope 2 emission trajectories are no longer aligned with the 1.5°C goal, and only barely with the 2°C goal. If this trend continues, 42% of committed scope 2 emission reductions will not result in real-world mitigation. Our findings suggest a need to revise accounting guidelines to require companies to report only real emission reductions as progress towards meeting their SBTs.

There is an increasing focus on the role of the private sector in meeting global climate goals[1–3]. To this end, science-based targets (SBTs) are intended to align voluntary company-level emission reduction targets with the global temperature goal of the Paris Agreement[4–6]. To date, SBTs have been set by more than 1,000 companies, including many multinationals[7,8]. When reporting scope 2 emissions, i.e., emissions associated with the generation of purchased energy (primarily electricity, but also including steam, heat and cooling), the Science Based Targets initiative (SBTi) allows companies to use renewable energy certificates (RECs) to claim the use of renewably-generated electricity. Companies can then report zero emissions for each unit of electricity consumption covered by purchased RECs[9], regardless of the actual emissions produced by the electricity grid at their location. However, RECs do not reflect the physical electricity flow supplied to the companies purchasing them[10], and there is evidence that RECs are unlikely to lead to additional renewable energy generation[11–18]. Consequently, company-level emission reductions reported through RECs are unlikely to reflect real reductions of global emissions, which has the potential to compromise the alignment of SBTs with the Paris temperature goal[19,20]. In recognition of this issue, several emission accounting standards[21,22] restrict or do not endorse the use of RECs, but RECs are nevertheless permitted by the Greenhouse Gas Protocol[9] that forms the basis of SBTi's requirements.

Here, we combine information about SBTi-certified company emission reduction targets with data on REC purchases to assess the effect of RECs on the alignment of reported scope 2 emission trajectories with the Paris temperature goal. We use the climate change disclosures of 115 companies, which represents the subset of companies with SBTs that have also disclosed data which can be used to assess the contribution of RECs to their reported (2015-2019) and potential future emission reductions. Importantly, it was necessary that all companies in our sample reported their past emissions using both market-based and location-based emission accounting methods (Box 1). We also distinguish here between RECs and power purchase agreements (PPAs), which represent a long-term commitment by a company to purchase power from a particular renewable energy project. Although empirical evidence is still needed, we have adopted here the common assumption that PPAs do lead to additional renewable energy production and real emission reductions, since the long-term power price de-risks new projects and allows access to project finance[14,15,17,18] (Box 1). In contrast, we assume that RECs and similar market-based instruments are non-additional, i.e., not leading to additional renewable generation capacity or real emissions reductions, and we use the term RECs to refer to all non-PPA instruments for that reason (see Methods for details of these market-based instruments and terminology). While existing literature suggest that RECs are non-additional because of their low and uncertain prices[11–18], some claim that RECs may still contribute to the generation of more renewable energy in the longer term by, in aggregation, signaling to the market that there is a demand for renewable energy[9,23]. Analyses to date do not find evidence to support the existence of such an indirect market effect, and we consequently do not consider this potential effect here. We acknowledge, however, the possibility that such longer-term indirect effects may become evident in future analyses.

BEGIN Box 1: Corporate scope 2 emissions accounting and the role of RECs and PPAs

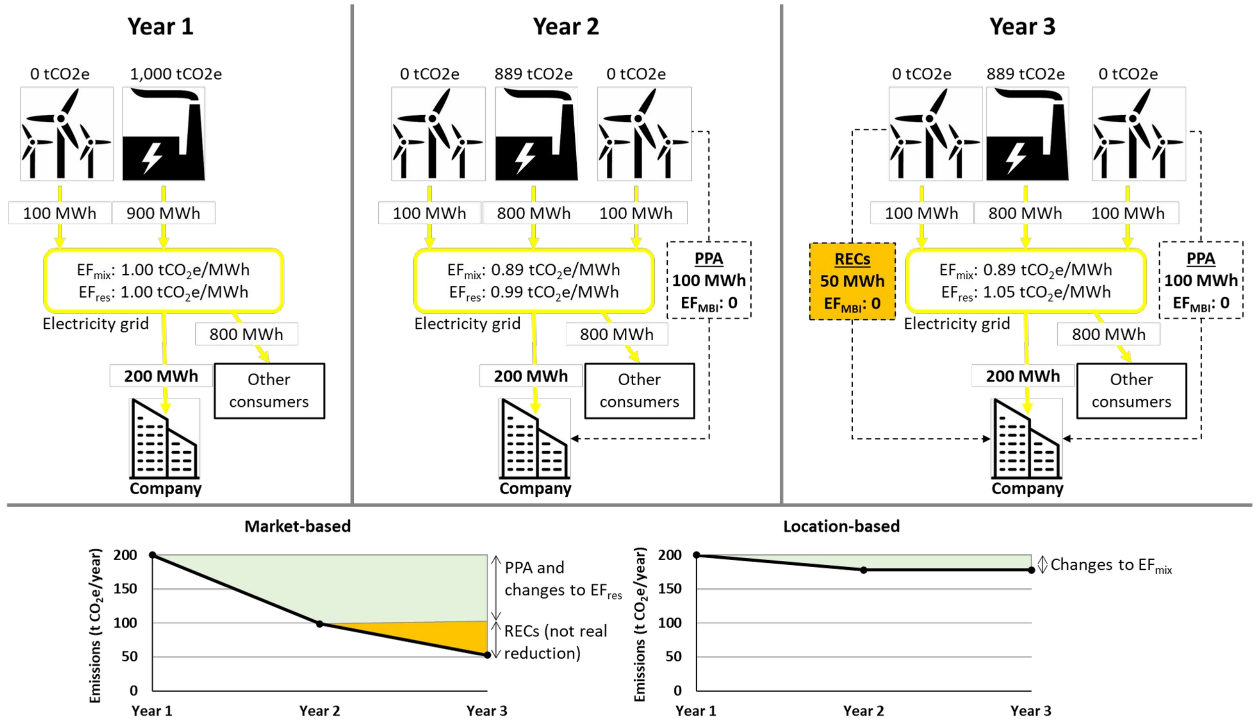
Under the Greenhouse Gas Protocol, companies are required to report their scope 2 emissions using both *market-based* and *location-based* accounting. Market-based accounting allows the use of market-based instruments, including RECs and PPAs, giving companies the right to claim that they are supplied by renewable electricity and to report the emissions from its production (usually zero), regardless of the actual electricity mix they consume[9]. At a given site and year, a company calculates market-based (MB) scope 2 (S2) emissions (E) by, first, multiplying the part of their electricity consumption covered by the market-based instrument (C_{MBI}) by the emission factor of the instrument (EF_{MBI}) and, second, multiplying any uncovered electricity consumption ($C - C_{MBI}$) by a "residual grid mix" emission factor (EF_{res}), representing the local grid without the electricity generation that has been claimed by RECs or PPAs:

$$E_{MB,S2} = C_{MBI} \cdot EF_{MBI} + (C - C_{MBI}) \cdot EF_{res}$$

Under location-based (LB) accounting, all companies on a grid multiply their electricity consumption (C) by the same average emission factor (EF_{mix}), regardless of whether they have purchased RECs or entered into PPAs:

$$E_{LB,S2} = C \cdot EF_{mix}$$

For companies with multiple sites and that consume other energy products from a grid (heat, steam or cooling) in addition to electricity, emissions (whether market-based or location-based) are calculated for each energy product and site, followed by aggregation. We use a simple example to illustrate the calculation of market-based and location-based emissions, considering the role of RECs and PPAs, for a company over three years:



In Year 1, the company has the same market-based and location-based emissions because it does not purchase any RECs or sign any PPAs and because the grid average and residual emission factors are the same (since no grid customers purchase RECs or enter into PPAs).

In Year 2, the company enters into a PPA that allows the project developer to secure a loan to build a new windfarm. The PPA achieves additionality because the project would not have happened in the absence of the PPA. Moreover, because total demand does not change, the coal power plant reduces its production. The PPA gives the company the right to apply an emission factor of zero to 100 MWh of its electricity consumption, and the residual grid factor (which slightly reduces due to the reduced generation from coal) is applied to its remaining electricity consumption. The PPA allows the company to report a substantial market-based emission reduction. The company's location-based emissions are also reduced due to the lower grid average emission factor from the reduced generation from coal. However, the reported emission reduction is less than with the market-based approach, since the emission benefit of the new windfarm is shared equally by all consumers on the grid.

In Year 3, the company's PPA is still active, and the company also purchases RECs from the windfarm that already operated in Year 1. The RECs are *non-additional* because they do not lead to the generation of additional renewable energy. The RECs (covering 50 MWh) allow the company to report a reduction in market-based emissions, compared to Year 2, even though total grid emissions did not change (889 t CO_2e). The reported reduction is therefore not real and the RECs effectively increase the market-based emissions of other energy consumers on the grid through an increase in the residual emission factor. By contrast, the company's location-based emissions are the same as in Year 2 because the grid average emission factor did not change. **END Box 1**

Effect of RECs on reported historical emission reductions

The sample of companies reported a combined 30.7% reduction in market-based scope 2 emissions between 2015 and 2019 (from 68.9 to 47.8 Mt CO_2e/year, see solid black line in Figure 1e). This corresponds to a substantially higher reduction than the annual 4.2 percentage points required by SBTi's linear 1.5°C global mitigation pathway (purple line, see Methods). However, most of this reported emission reduction is caused by companies' use of RECs (Figure 1d), which increased from covering 8.0% of purchased energy in 2015 to 27.0% in 2019. Based on the existing empirical evidence, we assume that this part of the reported reduction does not reflect actual reductions of emissions from the energy grid. Without the RECs contribution, market-based emissions would have reduced by only 9.9% between 2015 and 2019, with the resulting emission trajectory closely aligning with the required 2.5 percentage points annual emission reduction of SBTi's linear well-below 2°C pathway (compare the dashed black and turquoise lines in Figure 1e). This real emission reduction is driven by decarbonization of the residual electricity grid (representing the grid mix without the energy production that has been claimed by RECs or PPAs, see Box 1) (Figure 1b) and to a lesser extent by a net-increase in company use of PPAs (Figure 1c). In contrast, the increase in energy consumption had a net-positive contribution to the change in emissions (Figure 1a). Hence, the appearance that the combined historical scope 2 emission trajectory of companies with SBTs easily aligned with the 1.5°C goal is strongly misleading and a consequence of heavy reliance on RECs, which are not associated with real emission reductions.

Reported location-based emissions (black line in Figure 1h) reduced from 77.1 to 69.2 Mt CO_2e/year (10.3%) over the period, far less than the reported market-based emissions. This is because RECs and PPAs are not considered in location-based accounting (Box 1), which is also why location-based emissions were higher than market-based emissions in 2015. Instead, decarbonization of the electricity grid was the main contributor to the reported emission reduction (Figure 1g), with the increase in energy consumption again having a net-positive contribution (Figure 1f). The location-based emissions trajectory overall barely complied with the well-below 2°C goal (turquoise line) and is similar to the market-based trajectory adjusted to exclude RECs (dotted black line in Figure 1e).

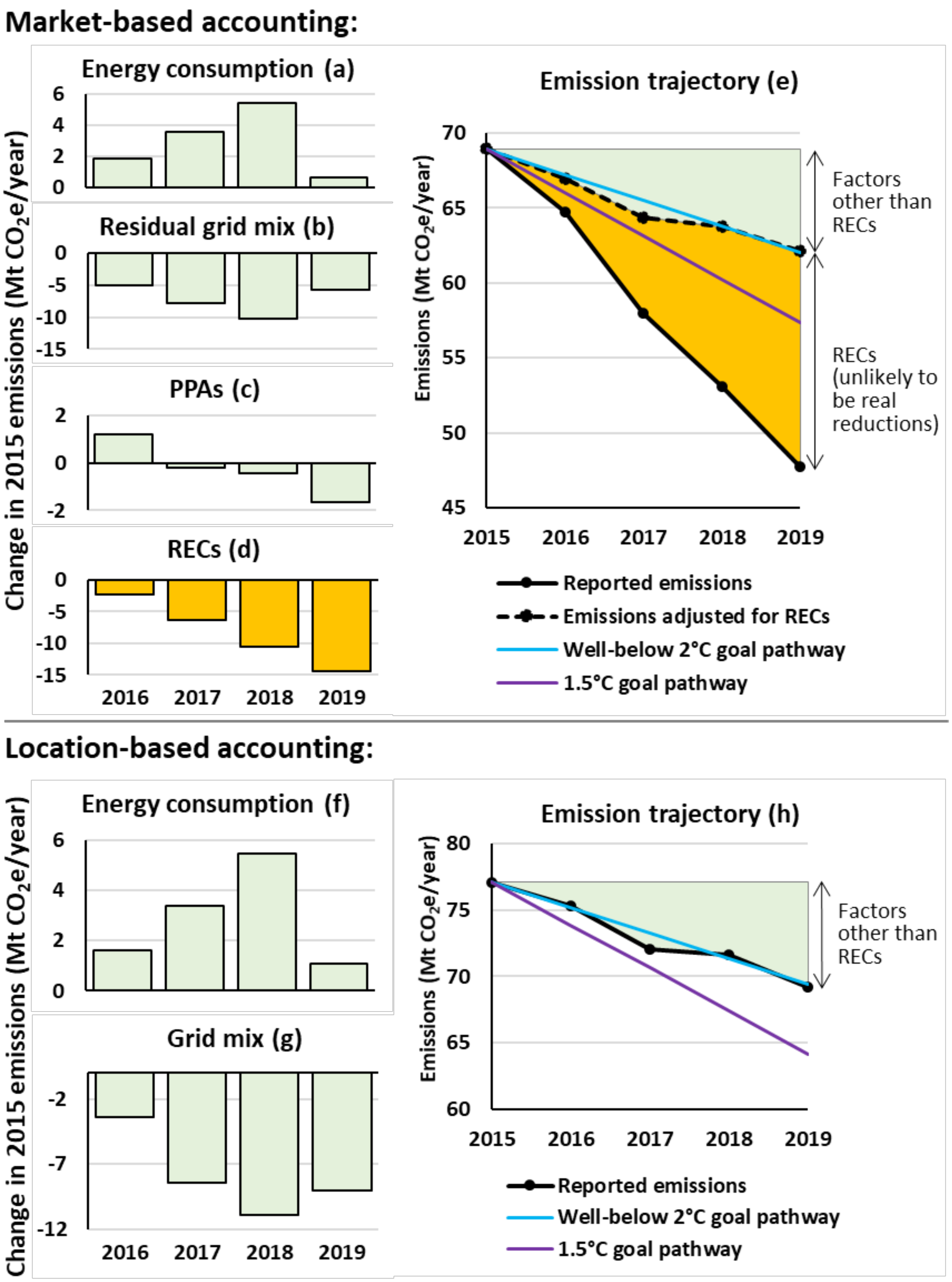


Figure 1: Combined scope 2 emissions of sample companies and the factors contributing to their reductions since 2015. The small charts (Figure 1a-d and 1f-g) show the contributions of individual factors to the market-based and location-based emission trajectories in the large charts (Figure 1e and 1h), with the contribution of RECs to reported market-based emission reductions highlighted in orange.
END Figure 1

Companies headquartered in Europe and North America (88% of the sample) reported larger combined market-based emission reductions in 2015-2019 than companies based in Asia (11% of the sample), but also relied more on RECs in their reporting. When removing the contribution from RECs, North American companies' combined market-based emission trajectory merely aligned with the well-below 2°C goal, while European companies in aggregate did not align with any Paris goal (see supplementary Figure S7). At the industry-level, only companies in Materials, Hospitality and Biotech, health care & pharma (together accounting for 21% of the sample companies) aligned with the 1.5°C goal in aggregate after adjusting the emission trajectories for RECs (see supplementary Figure S8).

RECs also had a substantial influence on the reported emission trajectories of individual companies. 89% of sample companies purchased RECs in the 2015-2019 period and the sample companies' median market-based emission reduction changed from 30.2% to 8.5% when removing the contribution from RECs. Likewise, the share of companies aligned with the 1.5°C goal, aligned with the well-below 2°C goal, and not aligned with either goal changes from 68%, 8%, and 24% to 36%, 12%, and 52% when excluding RECs (Figure 2). 40% of the companies whose reported market-based emissions aligned with the 1.5°C goal did not align with any Paris goal after adjusting for RECs (see grey flows between first and second column of Figure 2). Hence, market-based emission disclosures give the impression that three quarters of the companies were in alignment with one of the Paris goals. However, when removing contributions from RECs, only half of companies still demonstrated such alignment and of these, alignment with the less ambitious goal became more common. Much of the difference in the distribution of company alignment with the Paris goals between the market- and location-based accounting disappears after removing the contribution of RECs (Figure 2). However, a third of companies' temperature goal alignment is still different for adjusted market-based and location-based accounting, including 8% of companies whose increased use of PPAs over the period contributed to the fact that adjusted market-based emissions aligned with a more ambitious temperature goal than location-based emissions (supplementary spreadsheet).

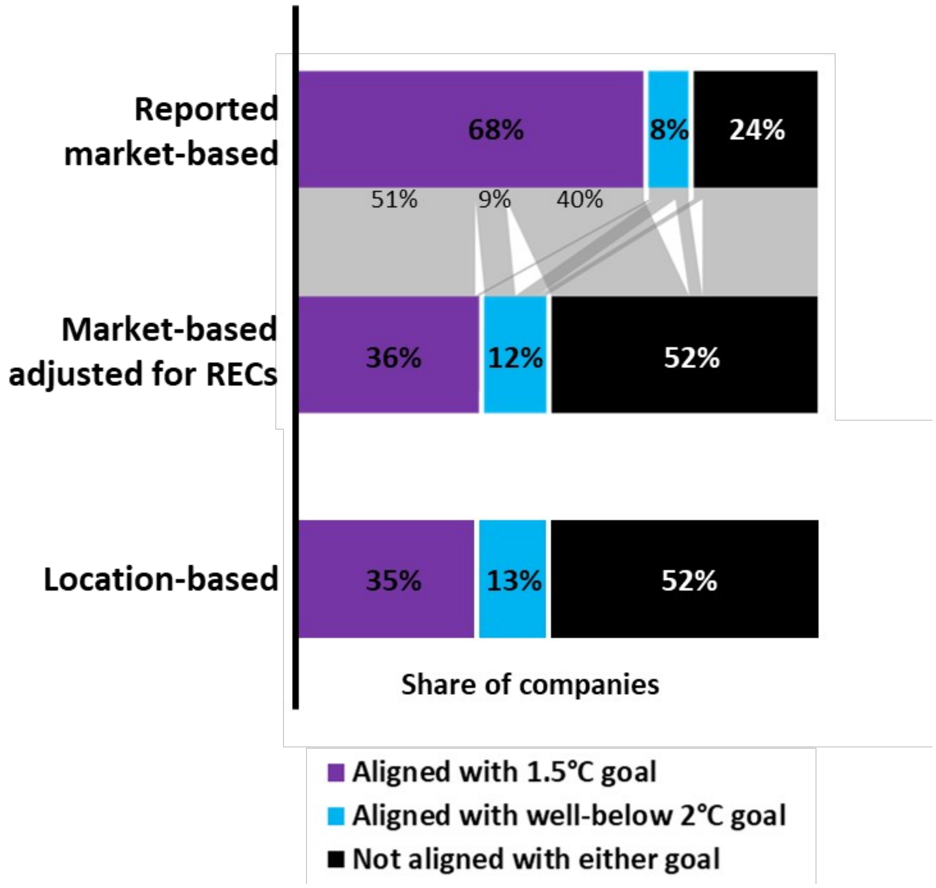


Figure 2: Share of sample companies whose 2015-2019 scope 2 emission trajectories aligned with temperature goals for three emission accounting approaches. The grey flows between the first and second column indicate the shares of companies for which the temperature goal alignment changed when removing RECs from their market-based emission trajectories. See supplementary spreadsheet for individual company results. **END Figure 2**

Scenario of future REC usage in pursuit of SBTs

We now turn from the sample companies' past reported emissions to their future commitments to reducing emissions through SBTs (Figure 3a). Few companies (6%) report scope 2 SBTs independent from other emission scopes. Most companies (82%) report scope 2 SBTs in combination with SBTs for scope 1 (covering direct emissions[24]) and the rest (12%) in combination with scope 1 and 3 SBTs (covering value chain emissions beyond scope 2[24]). Most companies (89%) state that their SBT refers to market-based accounting, while the SBTs of the remaining 11% refer to location-based accounting (in short, market-based and location-based SBTs). This indicates that most companies aim to use RECs and PPAs in pursuing their targets.

Companies with market-based SBTs tend to commit to more ambitious emission reductions (compare orange and blue boxes in Figure 3a). The trend is especially pronounced for SBTs covering scope 1 and 2 emissions, where the median annual reduction rate is 1.7 percentage points higher for market-based than location-based SBTs (4.2 vs. 2.5 percentage points). This may be because market-based accounting offers a relatively low-cost means of appearing to reduce emissions[14], and therefore companies using this approach are willing to set more ambitious reduction targets. 58% of market-based SBTs align with the 1.5°C goal (below purple line in Figure 3a) and 28% with the well-below 2°C goal (between turquoise and purple line). The corresponding shares for location-based SBTs are 8% and 54%. Some SBTs do not align with either temperature goal because SBTi until 2019 approved targets aligning with a less ambitious 2°C goal[8] and one target-setting method (the sectoral decarbonization approach[4,25]) allows companies with certain characteristics to reduce emissions at a lower rate than is required globally.

Next, we estimated the SBTs specifically for scope 2 (Figure 3b) from SBTs that cover scope 1 and 2 or scope 1, 2 and 3, assuming future scope 2 emission reduction will have the same relative contribution to total emission reductions as in the past (see Methods). These estimates illustrate the implications of a continuation of current trends, rather than an explicit prediction of future emissions pathways. The estimated market-based scope 2 SBTs are generally more ambitious than the reported market-based SBTs for overarching emissions scopes and are closer to the reported SBTs specifically for scope 2 (Figure 3a). Note, however, that 3% of these estimated market-based SBTs involve emission increases (above the 0% line in Figure 3), because the companies in question increased scope 2 emissions during the past reference period. 75% of the estimated market-based scope 2 SBTs comply with the 1.5°C goal and 12% comply with the well-below 2°C goal. In combination across companies, the estimated market-based scope 2 SBTs involve an annual emission reduction of 7.2 percentage points (weighted average by base year emissions, see Figure 3b) and would thereby appear to easily comply with the 1.5°C goal (purple line). By contrast, the estimated location-based scope 2 SBTs only barely comply with the well-below 2°C goal collectively (the weighted average reduction rate is 2.7 percentage points). However, the potential use of RECs may overstate the apparent Paris goal alignment of the market-based SBTs.

To investigate further, we estimated and removed the future contribution of REC from the estimated market-based scope 2 SBTs (Figure 3c), based on the contributions of RECs to past emissions reductions (see Methods). This exploratory scenario results in combined reduction rate across companies of 3.6 percentage points (see weighted average in Figure 3c), which is markedly lower than the 7.2 percentage point reduction rate for unadjusted market-based scope 2 SBTs (Figure 3b) and merely complies with the well-below 2°C goal. Moreover, while nearly all (77 of 102) companies pursuing market-based scope 2 SBTs appear to align with the 1.5°C goal (Figure 3b), far fewer (38 of 102) companies will in fact align with the 1.5°C goal if they continue their past pattern of REC usage (Figure 3c). In that scenario, companies will most commonly not align with either temperature goal (45 of 102), while a minority (19 of 102) will align with the less ambitious well-below 2°C goal. The 25th to 75th percentile range of estimated market-based emission reduction rates adjusted for RECs (Figure 3c) is similar to the corresponding range for estimated location-based SBTs (Figure 3b), which challenges the appearance that market-based SBTs tend to be more ambitious than location-based SBTs (Figure 3a and 3b). Taken together, the implication of this future emission scenario is that an estimated 42% of the committed cumulative scope 2 emission reductions (101 Mt CO_2e) from base year to target year will come from REC purchases and, hence, will not reflect actual reductions of global emissions (Figure 4).

At the regional level, European and North American companies generally targeted higher future emission reductions than Asian companies. However, these regional differences substantially reduce after adjusting the targets for estimated future RECs purchases (see supplementary Figure S9). Companies in half of the ten industries (together accounting for 45% of the sample companies) collectively align with the 1.5°C goal after adjusting the SBTs for RECs, while companies in two industries align with the well-below 2°C goal and companies in three industries do not align with either (see supplementary Figure S10).

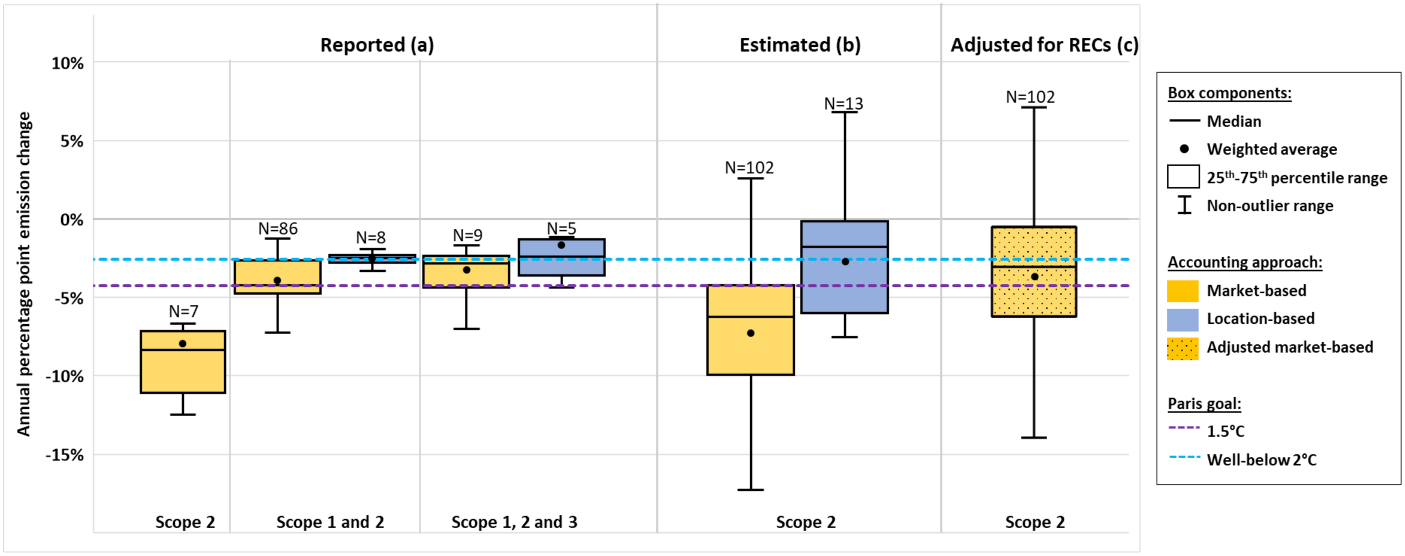


Figure 3: Annual future emission reductions based on the SBTs of the sample companies. All SBTs have been annualized by dividing their targeted percentage emission reduction by the timespan (target year minus base year). Figure 3a reflects SBTs as reported by companies, covering different emissions scopes and emission accounting approaches. Figure 3b reflects scope 2 SBTs estimated based on companies' reported SBTs (Figure 3a) and past scope 2 to total emission reductions. Figure 3c reflects market-based scope 2 SBTs adjusted by removing the estimated contribution from RECs based on past REC-related to total scope 2 emission reductions. The number of targets covered is indicated above each box. The non-outlier ranges (whiskers) are defined as 1.5 times the 25th-75th percentile range. Outliers are not displayed. See supplementary spreadsheet for individual company estimates. **END Figure 3**

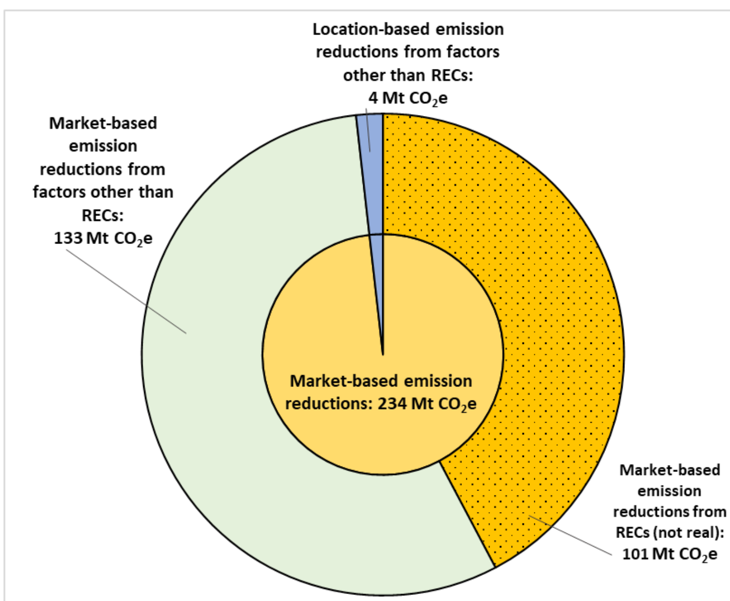


Figure 4: Estimated cumulative scope 2 emission reduction from base year to target year based on the sample companies' SBTs and the estimated role of RECs in achieving these reductions. The inner circle represents the estimated emission reduction commitments by companies whose SBTs refer to market-

based and location-based accounting. The outer ring represents the estimated contributions of RECS and other factors (see Figure 1) to these reduction commitments. The median base year and target year of the SBTs are 2017 and 2030, respectively. **END Figure 4**

Implications and outlook

In this study, we assessed the use of RECs by companies with SBTs and the implications for their Paris alignment claims. The widespread use of RECs raises doubt on companies' apparent historic Paris-aligned emission reductions, since it allows companies to report emission reductions that are not real. Moreover, a continuation of recent trends would mean that nearly half of future scope 2 emission reductions reported by companies with SBTs would not be real. Overall, our results confirm earlier suppositions[19,20], and suggest that corporate use of RECs in the pursuit of SBTs is the norm, rather than the exception. This is consistent with recent findings for a smaller sample of companies with net-zero targets[18]. SBTs are required to cover both scope 1 and 2 emissions[6] and for many industries scope 2 emissions are the larger of the two (see supplementary Figure S11-S13 for a contribution analysis of our company sample). Consequently, companies' use of RECs threatens to undermine the integrity of SBTs as a whole. Together with recent findings of widespread accounting and reporting issues for scope 3 emissions[26,27], our findings should inform future work scrutinizing SBTs and companies' progress against them[5,8,28].

While our sample only covers 115 (14%) of the 813 companies with SBTs at the time (due to data availability and the exclusion of energy generators, utilities and companies with intensity targets), it is fairly representative in terms of regions and industries (see supplementary Figure S5 and S6). We encountered several difficulties in interpreting companies' disclosure of RECs and PPAs and our main results (Figure 1-4) are based on conservative interpretations (see supplementary section 1 for details). A set of parallel results (supplementary Figure S1-S4) show that reported emission reductions could be even more inflated by the RECs than is the case for our main results. We also conservatively evaluated the Paris alignment of corporate scope 2 emission trajectories using the same global mitigation pathways used in SBTi's target progress assessment[8] (4.2 and 2.5 percentage points annual reduction for the 1.5°C and well-below 2°C goals, respectively). However, Paris-aligned mitigation scenarios commonly involve substantially higher reductions in direct emissions for the power sector than for the rest of the economy (for example, 7.2 and 3.7 percentage points annual reduction between 2020 and 2030 for the 1.5°C and well-below 2°C goals, respectively, in the mitigation scenario underlying SBTi's sectoral decarbonization approach[25,29]). This would translate to a requirement for companies to reduce scope 2 emissions at a higher rate than the global mitigation pathways.

Our findings have implications for SBTi's current approach of allowing companies to choose between market-based and location-based accounting when setting SBTs and reporting target progress[6]. In addition to the problem that market-based accounting allows reporting emission reductions that are not real, there is a risk of double-counting the emission benefits of renewable energy generation if one company claims the use of specific renewable energy generation using market-based accounting while other companies count that same renewable energy using the grid average emission factor in their location-based accounting. There are at least two alternatives that would make it more likely that all reported scope 2 emission reductions are real and renewable energy generation is only counted once (see Table 1). First, SBTi could require all companies to use only location-based accounting. A potential drawback with this option is that it would disincentivize companies from using PPAs or other market-based instruments that can lead to additional off-site renewable energy generation. In the second alternative, all companies could be required to use a restrictive version of market-based accounting, involving mandatory demonstration of the additionality of market-based instruments (whether PPAs or RECs), that is, evidence that the renewable energy generation would likely not have occurred without the instrument[30,31]. The Net Zero Carbon Buildings Framework of the UK Green Buildings Council includes such a requirement[22,32]. However, experience from carbon offsetting markets shows that demonstration of additionality is complicated and often contested[33] and more research and method development may therefore be needed for this option to be viable. Also, some stakeholders might reject the use of market-based instruments altogether, whether additional or not, since this way of claiming to be supplied by renewable energy does not reflect how renewable energy supply relies on a broader system of grid-balancing, back-up capacity, and transmission services, which are often supported by tax payers or other energy consumers[10].

Table 1: The current emission accounting requirement of SBTi and two (not exhaustive) alternatives that could potentially prevent double counting and the reporting of emission reductions that are not real.

Accounting requirements	**Issues with reporting emission reductions that are not real?**	**Issues with double counting?**	**Other potential issues (not exhaustive)**
Companies choose between location-based and market-based accounting with no mandatory demonstration of additionality (current requirement of SBTi)	Yes: companies may use non-additional RECs.	Yes. A unit of generated renewable energy can count towards the market-based emission reduction of one company and the location-based emission reductions of other companies.	Resources may be diverted from interventions linked to actual emission reductions (such as energy efficiency improvements) to RECs.
All companies use location-based accounting	No.	No.	May disincentivize additional renewable energy generation, and the associated real emission reductions, through PPAs and other market-based instruments.
All companies use market-based accounting with mandatory demonstration of additionality	No.	No.	Demonstration of additionality is complicated and uncertain. Use of market-based instruments for claiming

			renewable energy supply may be seen as misleading, since they do not reflect the dependence of the user on the wider electricity generation and transmission system.

Our study highlights issues with the use of RECs in the context of SBTs. However, the Greenhouse Gas Protocol scope 2 guidance argues that the use of non-additional market-based instruments is not a problem as the main goal is to allocate total grid emissions to individual consumers[9]. From that perspective, individual companies can legitimately use RECs to report emissions reductions that do not reflect a global emission reduction, since the market-based emissions of all energy users on the grid sum to total grid emissions. Based on our analysis, we encourage the Greenhouse Gas Protocol to reconsider its stance on additionality for two reasons. First, since many corporate energy users do not report emissions (nor do residential households), a company's purchase of non-additional RECs effectively increases the market-based emissions of other actors that do not report emissions (through an increase in the residual emission factor, see Box 1). This means that total reported market-based emissions will always overstate the actual grid-total emissions reduction because of incomplete reporting. Second, since companies increasingly disclose emissions in the context of targets informed by the need to reduce global emissions (SBTs[5] and net-zero targets[34,35]), it is clearly misleading to stakeholders if companies can meet these targets without reducing global emissions. This would also be the case in a situation with complete reporting. We acknowledge that this second issue raises a related and broader limitation with the use of standard corporate emissions accounting (whether market-based or location-based), in that changes in emissions outside the scope 1, 2, and 3 accounting boundary are not shown. Therefore, apparent reductions within the boundary may not reflect total reductions in global emissions. For example, a company's use of bioenergy may cause emissions outside its value chain through indirect land use change[36]. Accordingly, SBTi should consider options for complementing standard scope 1, 2, and 3 accounts with consequential emission accounting methods[36] to ensure that actions taken to achieve STBs do not unintentionally increase emissions outside the accounting boundary.

In conclusion, our study shows that the common voluntary corporate practice of using RECs that are unlikely to drive additional renewable energy production casts serious doubt on the veracity of reported corporate emission trajectories and their apparent alignment with the most ambitious Paris Agreement temperature goal. More broadly, there is a need to critically consider the extent to which voluntary corporate actions can be relied on for achieving a Paris-aligned transition[5].

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Methods

Terminology for market-based instruments and their potential effects on global emissions

There is no formally agreed terminology for the market-based instruments that companies can use to obtain renewable energy attributes (i.e., rights to claim usage of renewable energy) under the market-based accounting approach. A large number of instruments with similar characteristics exist and the same instrument may go by different names in different regions[9]. For example, the Bloomberg database[37] defines RECs broadly as the "amount of bundled and unbundled energy attributes purchased in the form of tradable certificates from an official registry, in thousands of MWh. This field includes voluntary certificates such as Guarantees of Origin sold within the Renewable Energy Certificate System and European Energy Certificate System as well as Renewable Energy Certificates commonly used in the United States." SBTi identifies RECs and PPAs as the two available market-based instruments for meeting renewable electricity targets within its net-zero standard[38], although other contractual arrangements exist, such as supplier-specific emission factors, and green power products or tariffs. It should also be noted that PPAs themselves often include the RECs associated with the power that is purchased (though it is also possible to structure a PPA for the power only, without the associated RECs). For simplicity in the terminology used we use the term REC for all contractual arrangements for renewable energy attributes other than PPAs.

We use the term additionality in relation to the effect of RECs and other market-based instruments on the generation of renewable energy. The additionality term originated in the carbon offsetting literature[31,33]. In the context of using market-based instruments for renewable energy to report emission reductions, we here follow the definition of the term from the ISO 14064-2 standard[39]: "Additionality, as a concept, describes the relationship between cause and effect. For any cause and effect, the effect can be described as being additional if it would not have occurred in the absence of the cause.". In this study, the effect can both refer to the generation of renewable energy and the development of new capacity (e.g., windmill or solar panels) for renewable energy generation.

Company data

Our initial sample was composed of the 813 companies with approved SBTs as per the online SBTi database[7] on July 20th, 2021. The SBTs in the SBTi database generally contain the following data of relevance to this study: sector, emission metric (absolute or intensity-based), emission scope (1, 2, 3, or a combination), base year, target year and targeted percentage reduction in the emission metric. We first excluded 28 energy generators and utilities (3% of the initial sample) because of our focus on companies that purchase energy. We excluded another 101 companies (12% of the initial sample) that only have intensity-based SBTs covering scope 2 to avoid the additional uncertainty associated with converting intensity-targets to absolute emission targets. For companies with multiple SBTs covering different emissions scopes and target years, we selected a single SBT, prioritizing targets specifically for scope 2, when available (otherwise, we prioritized targets for scope 1 and 2 combined over targets for scope 1, 2 and 3 combined), followed by prioritization of the shortest target timespan (i.e., difference between base year and target year). In addition to the target data sourced from SBTi, we collected information about the scope 2 accounting approach that each SBT refer to (market-based or location-based) from company disclosures to CDP[40] (this information is not provided by SBTi, more details in supplementary section 2.4). Note, however, that only around half of companies with approved SBTs reported to CDP. Therefore, we were left with 338 of the 813 companies after removing energy generators and utilities (28), intensity targets (101) and companies that did not report to CDP (346).

For these 338 remaining companies, we analyzed their past emission for 2015-2019. The start year (2015) aligns with the publication of the Greenhouse Gas Protocol standard related to market-based accounting (see Box 1)[9], the introduction of a distinction between market-based and location-based scope 2 emissions in the CDP questionnaire[40] and the approval of the first SBTs by SBTi[7]. We ended the period in 2019 to avoid abnormalities caused by COVID-19 and because 2019 is the most recent year for which complete data was available for many companies. We used companies' 2015-2019 emissions disclosed to CDP and, in cases of missing or apparently erroneous data, complemented with emission data from the Bloomberg database[37]. We also used CDP data on companies' purchased energy (electricity, heat, steam and cooling) and purchased RECs and PPAs (details in supplementary section 1). We adjusted ambiguous or apparently erroneous datapoints (details in supplementary section 2). We excluded 223 companies (27% of the initial sample and 66% of the restricted sample of 338 companies) due to missing data or poor data quality, leaving 115 companies (14% of the initial sample) that are included in our analysis (details in supplementary section 2).

The resulting sample of 115 SBTs have been approved by SBTi between 2016 and 2021. We used SBTi's classification of headquarter regions and industries[7] to assess the representativeness of the final company sample (supplementary section 4) and to estimate combined results at the region level (supplementary Figure S5 and S6). For combined results at the industry level (supplementary Figure S8 and S10) and the industry-level assessment of scope 2 emissions relative to other emission scopes (supplementary Figure S11-S13), we used the industry classifications of CDP[40] because it involves a more manageable number of industries (10 versus the 49 of SBTi's classification system[7]).

Reference mitigation pathways for the Paris temperature goal

We used SBTi's linear 1.5°C and well-below 2°C global mitigation pathways[41], involving annual emission reductions of 4.2 and 2.5 percentage points, respectively. The SBTi developed these pathways from a subset of the pathways described in the Special Report on Global Warming of 1.5 °C of the Intergovernmental Panel on Climate Change[42]. SBTi determined this subset by applying criteria related to temperature limit probability, temporary overshoot of emission budget, year of peak emissions and near-term emission reduction rate, with the aim of isolating pathways conforming with principles of plausibility, responsibility, objectivity, and consistency[41]. The SBTi notes that linearization of emission pathways over long timespans can result in substantial deviations of the pathways' cumulative emissions and therefore recommends the use of the derived annual emission reduction requirements (4.2 and 2.5 percentage points) for the shorter time span of 2020-2035. However, the SBTi also advises companies to apply these annual emission reductions requirements to set SBTs for base years before 2020[6] and SBTi applied the requirement of the 1.5°C pathway (4.2 percentage points reduction per year) as a benchmark for the combined emission trajectory of companies with SBTs in the 2015-2019 period in its latest target progress report[8]. Following SBTi, we here apply the annual emission reduction rates of the two SBTi pathways (4.2 and 2.5 percentage points, respectively) as references to evaluate the Paris alignment of past corporate emission trajectories (2015-2019) and future targeted trajectories (median values 2017-2030) for the 115 companies.

Estimating the contribution of scope 2 to total emission changes for 2015-2019 (Figure 1 and 2)
Based on the equation for calculating market-based scope 2 emissions (Box 1), we used the following set of equations to calculate the contribution of changes in energy consumption, use of PPAs, use of RECs (collectively referred to as market-based instruments or MBI) and residual grid mix emission factor to reported changes in market-based scope 2 emissions for each year (i.e., 2016, 2017, 2018 and 2019, noted with t below) relative to 2015.

Contribution to reported emission changes (ΔE) from change in energy consumption (C) relative to 2015 (in ton CO_2e per year):

$$\Delta E_{MB,S2,\Delta C,t} = E_{MB,S2,2015} \cdot \frac{C_{2015} - C_t}{C_{2015} - C_{MBI,2015}} \quad \text{(Eq. 1)}$$

Contribution to reported emission changes (ΔE) from change in energy consumption covered by PPAs (C_{PPA}) relative to 2015 (in ton CO_2e per year):

$$\Delta E_{MB,S2,\Delta PPA,t} = E_{MB,S2,2015} \cdot \frac{C_{PPA,t} - C_{PPA,2015}}{C_{2015} - C_{MBI,2015}} \quad \text{(Eq. 2)}$$

Contribution to reported emission changes (ΔE) from change in energy consumption covered by RECs (C_{REC}) relative to 2015 (in ton CO_2e per year):

$$\Delta E_{MB,S2,\Delta REC,t} = E_{MB,S2,2015} \cdot \frac{C_{REC,t} - C_{REC,2015}}{C_{2015} - C_{MBI,2015}} \quad \text{(Eq. 3)}$$

Contribution to reported emission changes (ΔE) from change in the residual grid mix emission factor (EF_{res}) relative to 2015 (in ton CO_2e per year):

$$\Delta E_{MB,S2,\Delta EF_{res},t} = \left(E_{MB,S2,2015} - E_{MB,S2,t}\right) - \left(\Delta E_{MB,S2,\Delta C,t} + \Delta E_{MB,S2,\Delta PPA,t} + \Delta E_{MB,S2,\Delta REC}\right) \quad \text{(Eq. 4)}$$

Note that Eq. 1-4 is based on the approximation that EF_{MBI} is zero for all RECs and PPAs. This allows treating the RECs and PPAs as if they virtually eliminate the energy consumption they cover (as in denominators of Eq. 1-3). This approximation is needed because companies do not disclose the EF_{res} behind their reported emissions to CDP and because companies only reported EF_{MBI} values to CDP for part of the study's time period (2016, 2017 and 2018). We consider the approximation that EF_{MBI} is zero in all cases sound, since biomass and biogas incineration is the only type of renewable energy generation known to emit (small amounts of) GHGs during operation (in addition to emission of biogenic CO_2, which is considered climate neutral in corporate accounting[24]) and since this energy source accounted for a negligible share of the combined energy consumption claimed by RECs or PPAs (C_{MBI}) across the company sample (less than 1% in 2019). We note that some companies reported non-zero values of EF_{MBI} for other types of renewable energy generation, such as hydropower, wind and solar and we assume that this reflects a misunderstanding of the CDP questionnaire (e.g., reporting life-cycle emission factors instead of operational emission factors).

Next, we used the following equation to calculate adjusted historical market-based scope 2 emissions ($aE_{MB,S2}$, in ton CO_2e per year) with the contribution from RECs to reported emission changes (see Eq. 3) removed for each year following 2015 (t):

$$aE_{MB,S2,t} = E_{MB,S2,t} + \Delta E_{MB,S2,\Delta REC,t} \quad \text{(Eq. 5)}$$

For location-based accounting, we used a similar set of equations, based on the equation for calculating location-based scope 2 emissions (Box 1), to calculate the contribution of changes in energy consumption and the grid mix emission factor to reported changes in scope 2 emissions between 2015 and each following year (t):

Contribution to reported emission changes (ΔE) from change in energy consumption (C) relative to 2015 (in ton CO_2e per year):

$$\Delta E_{LB,S2,\Delta C,t} = E_{LB,S2,2015} \cdot \frac{C_{2015} - C_t}{C_{2015}} \quad \text{(Eq. 6)}$$

Contribution to reported emission changes (ΔE) from change in the average grid mix emission factor (EF_{mix}) relative to 2015 (in ton CO_2e per year): $E_{LB,S2,\Delta EF_{mix},t} = \left(E_{LB,S2,2015} - E_{LB,S2,t}\right) - \Delta E_{LB,S2,\Delta C,t}$
(Eq. 7)

Annualization of SBTs (Figure 3a)

To allow for comparison of the targeted emission reductions across SBTs with varying timespans, we annualized the reported SBTs, formulated as a percentage reduction between the company-specific base year (B) and target year (Y), following Wang et al[43]:

$$SBT' = \frac{SBT}{Y - B} \quad \text{(Eq. 8)}$$

The resulting annualized SBT (SBT') indicates an annual percentage point reduction of base year emissions and assumes a linear emission trajectory between base year and target year.

Estimation of SBTs specific for scope 2 (Figure 3b)

Most companies in our sample (94%) do not have SBTs specifically for scope 2. Instead, they have targets that combine scope 1 and 2 (82%) or scope 1, 2 and 3 emissions (12%). To derive SBTs specifically for scope 2 in these cases, we first calculated the past contribution of scope 2 emission changes ($S2C_{past}$, dimensionless) to the emission reductions for the emission scopes covered by a company's reported SBT:

$$S2C_{past} = \frac{E_{S2,b} - E_{S2,y}}{E_{SR,b} - E_{SR,y}}$$
(Eq. 9)

Here, E_{S2} is the reported historic scope 2 emissions and E_{SR} is the reported historic emissions for the scopes covered by the company's reported SBT, both referring to market-based accounting for companies with market-based SBTs and location-based accounting for companies with location-based SBTs. b and y are company-specific start- and end-years within the 2015-2019 period, selected to represent the longest consecutive decrease in E_{OS}. This approach (as opposed to a common start- and end-year) avoids past increases in E_{SR}, which is desirable, given that $S2C_{past}$ forms the basis for projecting a company's future scope 2 emissions in the context of a targeted emission decrease across the emission scopes covered by its reported SBT. On average across our sample, the b to y period spans 2.5 years. For one of the sample companies, E_{SR} increased consistently in the 2015-2019 period, meaning there was no company-specific basis for projecting scope 2 emissions, and we instead assigned $S2C_{past}$ the average value calculated for the other sample companies with reported SBTs covering the same emission scope (1-3, market-based), which was 13.4%.

Next, we assumed that $S2C_{past}$ applies to the full period between the specified base year (B) and future target year (Y) of the reported company SBT (note that these are not the same as the historic start- and end-years, b and y, in Eq. 9) and calculated the corresponding targeted annual reductions in scope 2 emissions for that period ($\Delta E_{S2}'$) (again, market-based or location-based, depending on the reported SBT):

$$\Delta E_{S2}' = E_{SR,B} \cdot SBT' \cdot S2C_{past} \qquad \text{(Eq. 10)}$$

Finally, we estimated the annualized SBT specifically for scope 2:

$$SBT_{S2}' = \frac{\Delta E_{S2}'}{E_{S2,B}} \qquad \text{(Eq. 11)}$$

Adjustment of past market-based scope 2 emissions to remove REC contribution (Figure 3c)

Given that many companies in our sample used RECs to report market-based emission reductions in the 2015-2019 period, it is likely that they will continue to use RECs as a contribution to meeting their scope 2-specific SBTs. To take this into account, we modified Eq. 9 to remove the contribution of RECs to past changes in scope 2 emissions, by drawing on Eq. 3 and Eq. 5 modified to cover the b-y period (same as for Eq. 9) instead of the 2015-t period:

$$aS2C_{past} = \frac{E_{MB,S2,b} - aE_{MB,S2,y}}{E_{MB,SR,b} - E_{MB,SR,y}} = \frac{E_{S2,mark,b} - \left(E_{MB,S2,y} + \Delta E_{MB,S2,\Delta REC,y}\right)}{E_{MB,SR,b} - E_{MB,SR,y}} = \frac{E_{S2,mark,b} - \left(E_{MB,S2,y} + E_{MB,S2,2015} \cdot \frac{C_{REC,y}}{C_b -} \right.}{E_{MB,SR,b} - E_{MB,SR,y}} \qquad \text{(Eq. 12)}$$

$aS2C_{past}$ can be interpreted as the contribution of a real change in scope 2 emissions (i.e., without the contribution of RECs) to a reported change in emissions for the scopes covered by the reported SBT. Following this, we calculated the adjusted scope 2-specific annualized SBTs ($aSBT_{S2}'$) by using Eq. 10 and Eq. 11 with $aS2C_{past}$ as input instead of $S2C_{past}$. For the sample company with a consistent increase in E_{SR} in the 2015-2019 period, we (similarly to above) assigned $aS2C_{past}$ the average value calculated for the other sample companies that have SBT covering the same emission scope (1-3, market-based), which was 11.9%.

Contribution of RECs to committed cumulative scope 2 emission reductions (Figure 4)

Based on the above estimations of SBT_{S2}' for market-based and location-based targets and $aSBT_{S2}'$ for market-based targets, we estimated the contribution of RECs to the cumulative emission reductions from the base year (B) to the target year (Y) for each SBT. First, we calculated the reductions in scope 2 emissions (market-based or location-based, depending on the reported SBT) between Y and B:

$$\Delta E_{S2} = E_{S2,B} \cdot SBT_{S2}' \cdot (Y - B) \quad \text{(Eq. 13)}$$

For 33 companies, Eq. 13 resulted in a ΔE_{S2} larger than $E_{S2,B}$, which would imply negative scope 2 emissions in Y. This is unlikely to occur (the median Y is 2030) and we therefore assumed that these companies will stop reducing scope 2 emissions when they reach a value of zero. We therefore corrected the value of ΔE_{S2} to $E_{S2,B}$ in these cases and corrected Y to the time of zero scope 2 emissions:

$$Y = B + \frac{1}{SBT_{S2}'} \quad \text{(Eq. 14)}$$

For each SBT, we then calculated the cumulative reduction of scope 2 emissions between B and Y:

$$cum\Delta E_{S2} = \Delta E_{S2} \cdot (Y - B) \cdot \frac{1}{2} \quad \text{(Eq. 15)}$$

For market-based SBTs, we further calculated the annual scope 2 emission reduction between B and Y adjusted to remove the REC contribution ($a\Delta E_{S2}$) by using $aSBT_{S2}'$ instead of SBT_{S2}' as input in Eq. 13. In cases where ΔE_{S2} is larger than $E_{S2,B}$, we downscaled $a\Delta E_{S2}$ based on the correction of ΔE_{S2} (described above):

$$a\Delta E_{S2} = E_{S2,B} \cdot \frac{aSBT_{S2}'}{SBT_{S2}'}$$

(Eq. 16)

We then calculated the adjusted cumulative emission reductions with the contribution of RECs removed ($a.cum\Delta E_{S2}$) by using $a\Delta E_{S2}$ instead of ΔE_{S2} as input in Eq. 15. We then estimated the cumulative contribution from RECs to emission reductions ($REC.cum\Delta E_{S2}$) as the difference between $cum\Delta E_{S2}$ and $a.cum\Delta E_{S2}$. Finally, we aggregated $REC.cum\Delta E_{S2}$ for all market-based SBTs and compared it to the aggregated $cum\Delta E_{S2}$ for all market-based SBTs and the aggregated $cum\Delta E_{S2}$ for all location-based SBTs. Note that five of the sample companies reduced their purchases of RECs between b and y (the start- and end-years in Eq. 9) to such an extent that a continuation would lead to a projected negative use of RECs in the target year (Y) or earlier, which would not be possible. For the estimation of $REC.cum\Delta E_{S2}$ of these five companies, we therefore corrected $aSBT_{S2}'$, assuming that the use of RECs would decrease linearly from B until reaching a value of zero in Y:

$$corrected.a\,SBT'_{S2} = SBT'_{S2} + \left(aSBT\text{¿¿}S2' - SBT'_{S2}\right) \cdot \frac{C_{REC,B}}{\left(C\text{¿¿}REC,b - C_{REC,y}\right) \cdot \frac{Y-B}{y-b}\text{¿}}\text{¿}$$

(Eq. 17)

Note that the SBT of one of the five companies has 2011 as base year (B), which is before the Greenhouse Gas Protocol began permitting the use of RECs through the market-based accounting approach[9]. To account for the reported use of RECs between b and y, we used b instead of B in Eq. 17 for this company. The corrections of $aSBT_{S2}$’ for these five companies had a modest influence on results, causing the aggregated $REC.cum\Delta E_{S2}$ (illustrated in Figure 4) to change from 97 Mt CO_2e to 101 Mt CO_2e.

Data availability statement

This study is based on preexisting datasets, primarily references[7,37,40]. The data behind all figures are available in the supplementary spreadsheet.

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Author contributions

AB conceived the study idea. AB developed the study design with contributions from MB, SL and HDM. MB synthesized the literature on market-based scope 2 emission accounting. AB performed the data analysis and produced the figures with contributions from SL. HDM assisted with framing the manuscript. AB drafted the manuscript with contributions from HDM, SL and MB. All authors contributed to manuscript editing and revisions.

Competing interests

The authors declare no competing interests.

Tables

Figure Legends/Captions (for main text figures)