Climate and TEP Resource Portfolios – Emissions Reduction and Cumulative Carbon Budgets

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Project Overview

This report is a technical summary of Phase 2 of the TEP/UA Greenhouse Gas Emissions Reductions Targets project. We completed Phase 1 and published that report in Fall 2019 (Knudson et al., 2019). The Phase 1 report includes two elements. First, it provides an overview of the state of the climate and the implications for the U.S. Southwest. Second, it offers a preliminary review of utility practices for setting greenhouse gas emissions reductions targets. Phase 2 further explores emissions reductions guidelines for companies, the logic behind science-based targets for emissions reduction, and sector-specific practices consistent with targeted limits to warming. We expanded the analysis to include the role of discrete carbon budgets that set limits on carbon emissions based on specific warming targets (e.g., 1.5 C, 2 C, etc.). We evaluated TEP Integrated Resource Plan portfolio scenarios provided by TEP and informed by input from TEP's Stakeholder Advisory Council. Our evaluation focused on 1) emissions reductions targets associated with current scientific guidance regarding general and sector-specific emissions reductions required to keep global warming under various targets, and 2) a calculation of the relationship between discrete carbon emissions budgets developed by TEP and specific warming targets (1.5 C, 2 C, etc.). For an overview of the TEP IRP process and the role of the Stakeholder Advisory Council, please refer to https://www.tep.com/resource-planning/.

Background & Context of GHG Reduction Efforts

This project is informed by the framing of the Paris Climate Agreement – which is broadly focused on the emissions reductions and changing practices required to limit warming to well below 2 C above pre-industrial levels, with a target of 1.5 C. While the current state of the U.S. commitment within that agreement is in flux, the initial U.S. Nationally Determined Contribution (or US NDC) was framed as the intention to "*achieve an economy-wide target of reducing its greenhouse gas emissions by 26%-28% below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%.".* This initial target was to be followed by "deep, economy-wide" transformations to achieve 80% reductions under 2005 emissions by 2050.

The Science Based Targets Initiative (SBTI) expands on this framework with a goal of "institutionalizing" the use of science-based targets (SBTs) for emissions reduction across countries and sectors. By standardizing the process, their goal is to help companies and organizations set practical but sufficiently ambitious targets. SBTs are helpful for setting overall goals, and the sectoral guidance is useful across sectors. Still, one limitation of this approach is that it applies uniform goals across all companies instead of addressing different companies and their unique circumstances. These include current investments in generating resources or geographic variability in the feasibility and availability of renewable resources (hydropower, wind, solar, etc.). The SBTI is the result of a collaboration between the Climate Disclosure Project (CDP), the United Nations Global Compact, the World Resources Institute (WRI) and the World Wide Fund for Nature (WWF). According to their protocol, a greenhouse gas reduction target is "science-based" if it would lead to the decarbonization necessary to meet the Paris Agreement's goals, namely, to limit warming to 1.5 C or well below 2°C compared to pre-industrial levels (SBTI 2015, SBTI 2019).

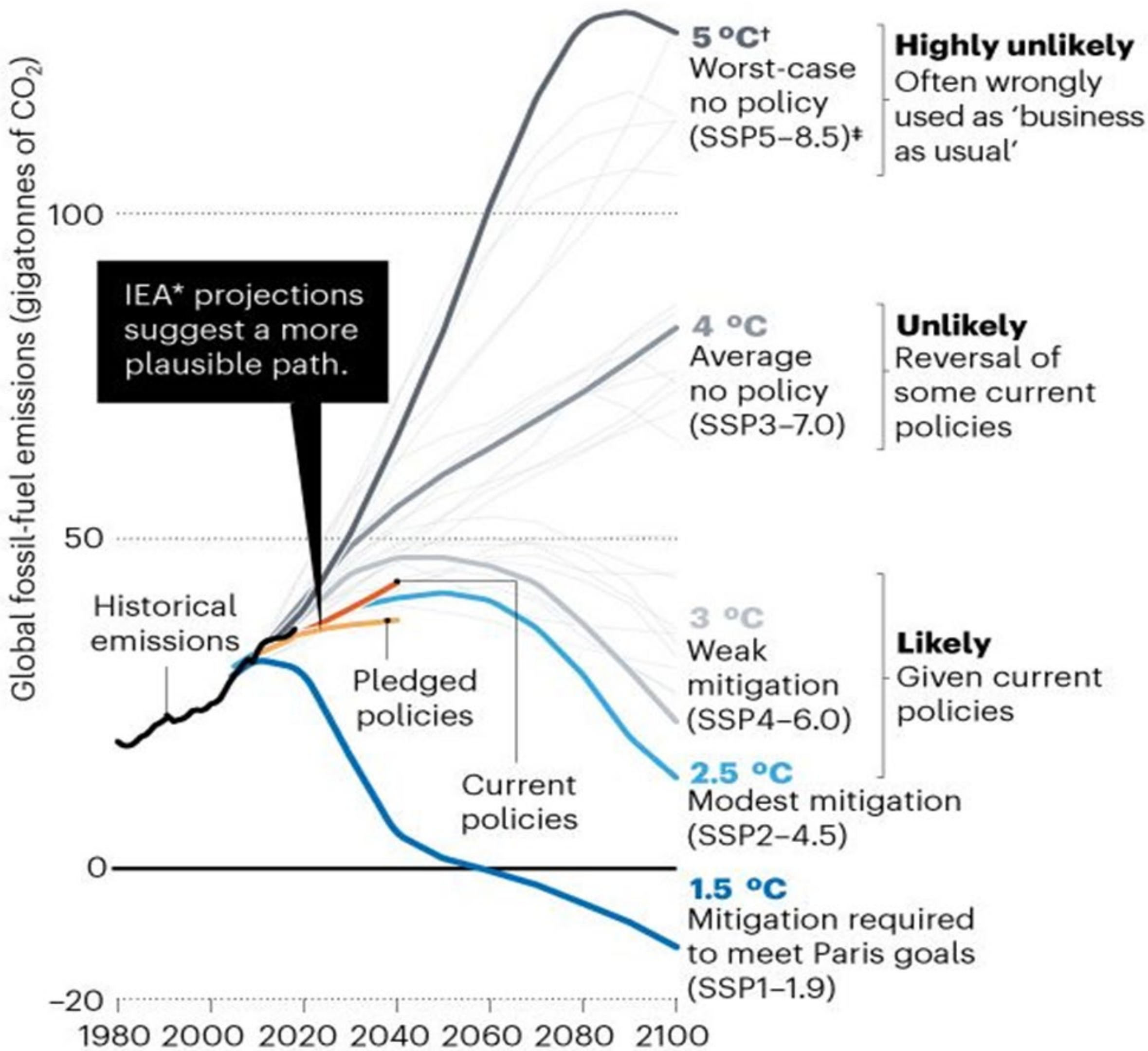

Figure 1 – Historical Emissions and Projected Emissions Trajectories

Reductions targets and commitments are showing promise in the effort to limit global warming. A recent report by the International Energy Agency (IEA) - summarized by Hausfather and Peters in Nature (2020) – highlights progress in limiting warming based on actual emissions reductions (current policies) as well as country and sector commitments to future reductions (pledged policies). Figure 1 shows that after the historical emissions leading up to the present in 2020, the pledged policies are consistent with 3 C warming, and they describe this as the current "likely" scenario. This is an improvement on the worst-case scenarios for warming (4C or 5C by 2100), which they describe as less likely than if these reductions had not been implemented or pledged. The IEA also highlights that reductions to a 2 C warming limit require more aggressive and ambitious action, while the 1.5 C target would require negative emissions (carbon sequestration, carbon capture, and storage) given the amount of historical warming that has already taken place (for more information on negative emissions see Minx et al., 2018; Fuss et al., 2018, and Nemet et al. 2018).

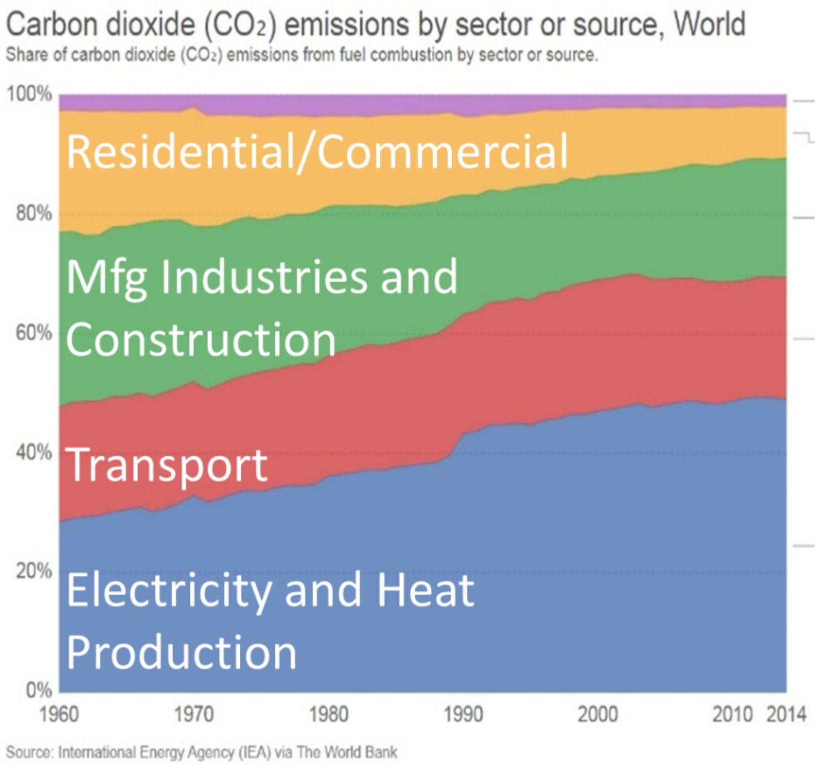

Figure 2 - Global CO2 by Sector

Global contributors to carbon dioxide emissions by sector or source as a percent of the global share over the last fifty years (Figure 2) demonstrate that the proportion of residential-commercial emissions has declined and the proportion of manufacturing-industries-construction and transportation has remained relatively constant. The proportion of emissions linked to electricity and heat production has increased over this same period. This sector also has considerable potential to make significant reductions that will make substantive impacts in terms of reducing global emissions. Their capacity to make these substantive reductions is enhanced by ongoing technological developments in renewable energy and other low-carbon sources of energy. Their need to make these changes is necessitated by an increasingly electrified future (electric vehicles, homes/appliances, etc.) extending the trend shown in Figure 2 (see Ritchie and Roser 2017 for details), and likely to lead to increased emissions if this power is not derived from low carbon sources.

The SBTI recognizes the differences across sectors. Their sectoral decarbonization approach (or SDA) is based on the recognition that different sectors make different contributions to global carbon emissions, and that the pathways to reductions consistent with limits to 1.5 C or well below 2 C warming will vary based on these differences between sectors. This approach advocates for a concerted effort across sectors to set sector-specific reductions targets that are consistent with limiting warming to 1.5 C or well below 2 C. Figure 3 shows the carbon budget for different sectors going out to 2050 and demonstrates the reductions necessary to achieve decarbonization consistent with limiting warming to 1.5 C or well below 2 C. Note the dramatic reduction in percent share of emissions for the power generation sector compared to other sectors. This reduction occurs despite the aforementioned increase in demand associated with demographic growth and increasing electrification (of transportation in particular).

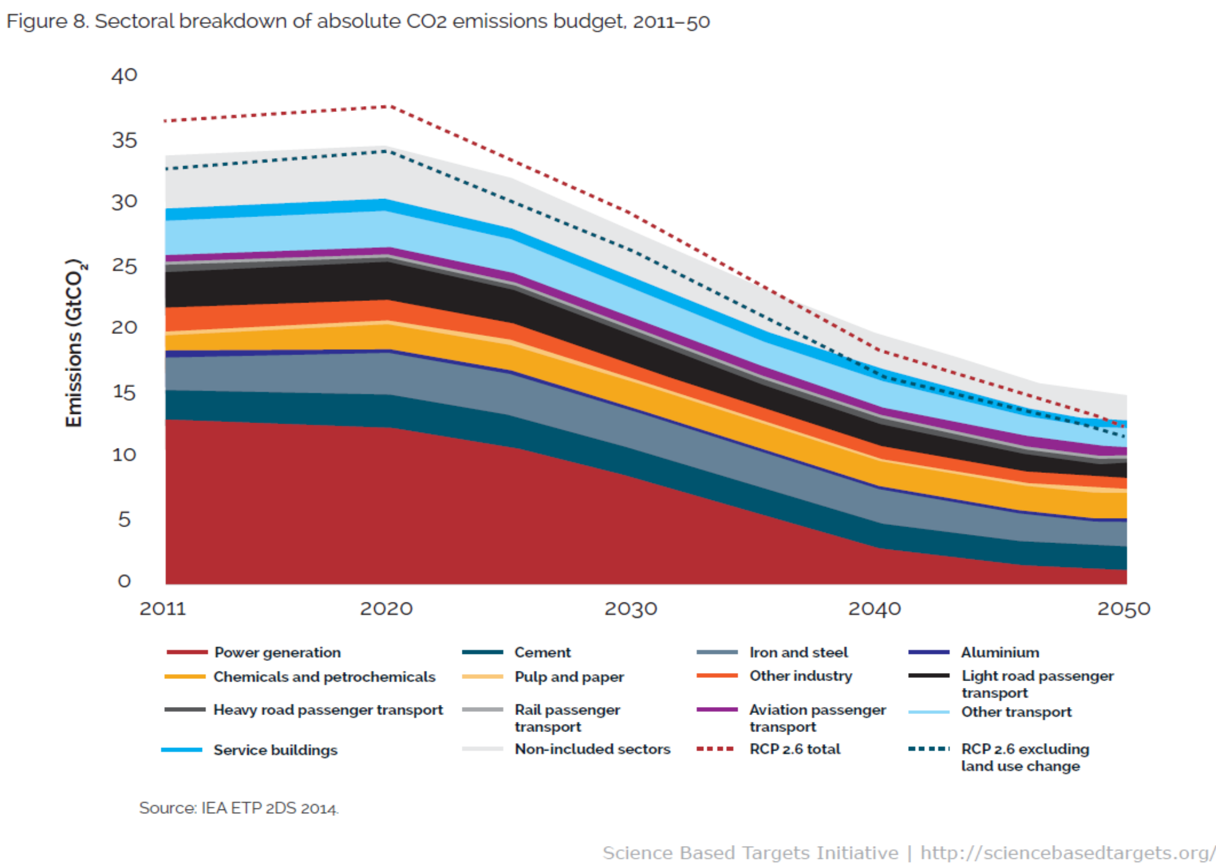

Figure 3 - Sectoral Carbon/Emissions Budgets, 2011-2050

The sectoral decarbonization approach (SDA) for U.S. electricity generation expands on the baseline of an 80% reduction of 2005 levels by 2050. For the electricity generation sector, the updated SBTI SDA documentation suggests an approximately 90% reduction of 2005 levels by 2050 is consistent with the well below 2 C warming targets (SBTI SDA 2015). The emissions reduction framework – typically expressed as a percent reduction from a baseline year (typically 2005) by a target year (often 2050) helps set the overall reductions targets. Still, it does not specify when or how these targeted reductions would occur, nor does it account for all of the uncertainties associated with these reductions and their associated limits to warming (see EPRI 2018).

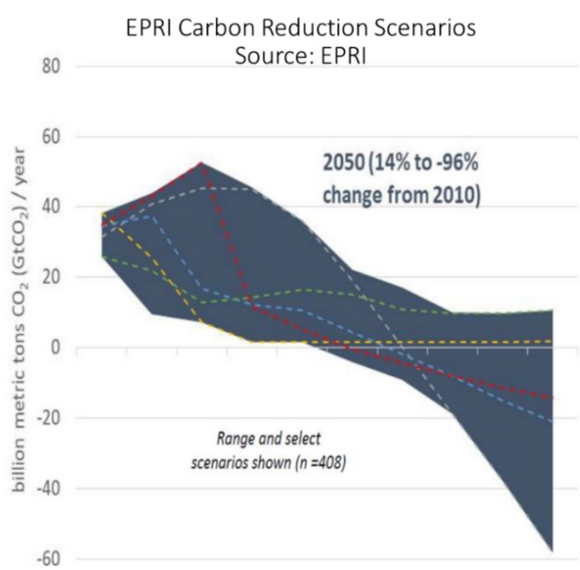

Figure 4 - Range for over 400 global emissions pathways consistent with limiting warming to 2C (EPRI Rose and Scott 2018).

The Electric Power Research Institute (EPRI) addressed emissions reductions scenarios in their 2018 report (Rose and Scott, 2018), and revisited the 1.5 C targets in their 2020 follow up report (Rose and Scott, 2020). In the 2018 report, they presented a cluster of hypothetical scenarios for emissions pathways (Figure 4), meant to demonstrate numerous possible pathways to temperature targets, based on timing, fuel source, load growth, etc. They highlighted the numerous pathways that could conceivably hit a temperature target and offered some guidance on what utility emissions reductions targets should emphasize. In the 2020 report, they provided a critique of global scenarios as benchmarks, given embedded assumptions and missing uncertainties, along with the variable contexts of different companies and the multiple pathways to hit warming targets identified in the 2018 report.

As part of our phase 1 report and review of utility-based emissions reduction strategies, (Knudson et al., 2019), we reviewed the 2018 EPRI report. We identified four key insights for creating emissions reductions targets, summarized as 1) a focus on the specific context of the company, 2) an emphasis on the scientific understanding of climate goals and the companies' relationship to those climate goals, 3) the variability of what would constitute a cost-effective target across companies, and 4) the need to develop "flexible" strategies that made sense given the companies' history and future. These insights are in line with the initial conclusions from our phase 1 report, which identifies that different utilities have different starting points for their emissions reduction based on historical emissions and baselines, current practices, and opportunities for their transition to a low-to-zero carbon future portfolio. They also have different futures and uncertainties regarding their pathway to hitting these temperature targets, each with risks and opportunities. These insights also reflect on an issue discussed below – namely the importance of timing, and how different emissions reductions pathways can hit similar percent reduction targets but vary considerably under other metrics.

Emissions Reductions Targets – Percent reduction of baseline year emissions with a future target

The typically used metric for emissions reductions is a percent decrease by a target year, using a baseline year, and occasionally with an interim target year and percent reduction. These emissions reductions are linked to different warming scenarios within the SBTI and SDA frameworks. Phase 1 of our report identified 2005 as the most common baseline year within the electrical utility sector, while the most common reduction by 2050 was 80-percent. This corresponds to initial sectoral guidance that identified an 80% reduction of 2005 emissions by 2050 was likely needed to reach the 'well below 2 C' warming limits. Revised estimates for the sectoral decarbonization approach have shifted, and the power generation sector is now estimated to need to reduce their 2050 emissions by approximately 91% compared to the 2005 baseline (to achieve the well below 2C target).

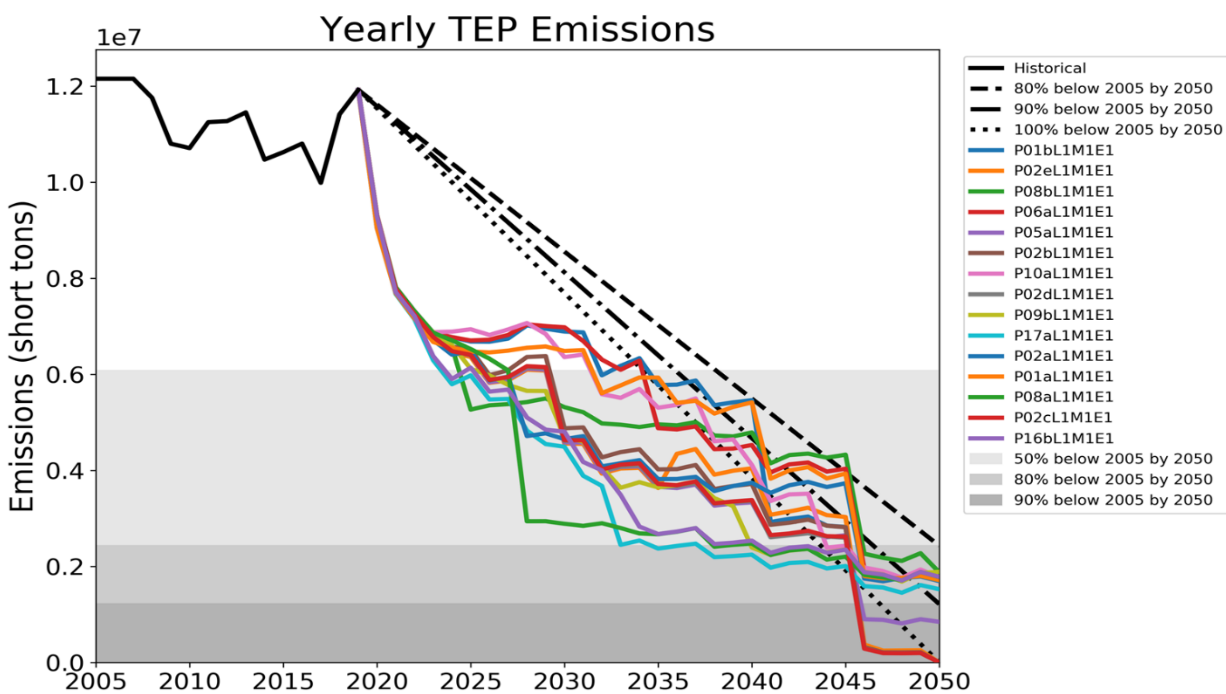

Figure 5 - TEP Emissions - Historical and Forecast (from IRP Portfolio Scenarios)

The portfolio scenarios from TEP can be analyzed using the percent-emissions-reduction framework. This framework demonstrates the extent to which various portfolio scenarios eventually settle on similar percent reduction targets, despite varied paths to these reduction percentages. The solid black line in Figure 5 is annual emissions by TEP from 2005-2018. The multi-colored lines are the annual emissions of various portfolios from 2020-2050. The dashed black line shows the linear reduction of annual emissions required to reach the 80-percent reduction of 2005 levels, given the current (as of 2018) level of annual emissions (and the other two dash-dot and dotted lines correspond to 90- and 100-percent reductions). The background shading shows the percent reduction targets frequently discussed in the emissions reduction literature (50%, 80%, and 90% in light, medium, and dark grey, respectively). This demonstrates the point highlighted in the EPRI report – namely that multiple portfolio scenarios can ultimately hit the same or very similar percent reduction targets, despite taking relatively different pathways to get there.

Carbon Budgets

We used a cumulative carbon budget framework that allows us to estimate the relationship between the global carbon budget and TEP's modeled portfolios. This framework sets TEP's carbon budgets for different global warming targets (1.5C, 2.0C, 2.5C) based on TEP's share of the U.S. electric utility sector, the electric utility sector's share of the U.S. national emissions, and the U.S. national emissions share of global emissions. We also calculated the expected amount of warming for each portfolio if all other countries, sectors, and utilities were to scale their cumulative carbon emissions proportionally to TEP's emissions. We analyzed the portfolios independent of their composition (% renewables, cost, coal retirement, etc.) and solely based on whether they were expected to hit the different warming targets and the expected warming for each portfolio.

We adapted the transient climate response to cumulative carbon emissions (TCRE) framework presented by Rogelj et al. (2019). This expands on work by Matthews et al. (2009) and the 5th National Climate Assessment Report (2018). Rogelj et al. (2019) describe the framework for analyzing the transient climate response to cumulative carbon emissions (TCRE) in detail. This framework establishes a limit on remaining CO2 emissions that would keep global warming under various targets (1.5 C, 2 C, etc.). Essentially, this sets a carbon emissions budget and allows for planning based on these discrete carbon emissions targets. The following equation describes the calculation of this carbon budget (B_{lim}).

$$B_{lim} = \frac{T_{lim} - T_{hist} - T_{nonCO2} - T_{ZEC}}{TCRE} - E_{sfb}$$

- **B_{lim}**: cumulative carbon emissions budget
- **T_{lim}**: global warming target level (e.g., 1.5C, 2C, etc.)
- **T_{hist}**: historical warming since pre-industrial period (currently ~1.0C)
- **T_{nonC02}**: warming from non-CO2 forcing (~0.0-0.2 C)
- **T_{zec}**: Zero Emissions commitment
- **TCRE**: transient climate response to cumulative carbon emissions
- **E_{sfb}**: additional earth system feedback

We can simplify this equation with T_{rem} – the remaining warming

$$T_{rem} = T_{lim} - T_{hist} - T_{nonCO2} - T_{ZEC}$$

The cumulative carbon emissions budget limit (B_{lim}) is the remaining carbon budget allowed under different warming targets based on the TCRE.

$$B_{lim} = \frac{T_{rem}}{TCRE} - E_{sfb}$$

In practice, this sets a starting point for the carbon emissions budget based on historical warming since the pre-industrial period (approximately 1.0 C). This also sets a target for remaining carbon emissions (the remaining carbon budget) given the specified warming target.

An emissions budget for TEP (BTEP) can be constructed from the global emissions budget, the national and sectoral share of cumulative CO2 emissions for the different warming targets, and TEP's fraction of the national sectoral share. The TEP emissions budget is described in the following equation:

$$B_{TEP} = B_{lim} F_{US} F_{USElec} F_{TEP}$$

- $\mathbf{B_{lim}}$: Global carbon budget based on the specified warming target
- $\mathbf{F_{US}}$: U.S. fraction of global emissions
- $\mathbf{F_{USElec}}$: the U.S. Electricity Sector's fraction of U.S. Emissions
- $\mathbf{F_{TEP}}$: TEP's fraction of the U.S. Utility Sector

F_{US} is estimated at 8.5%. This is the average of the allocated U.S. fraction of global emissions (2020-2050) under the staged scenario for 2 C of warming (Climate Action Tracker 2020).

F_{USElec} is estimated at 25%. The baseline is historical emissions data from the EIA (2020)[1]. The 25% estimate is an approximation of the fraction of carbon emissions (2020-2050) consistent with a well below 2 C target (SBTI 2015, IEA 2014).

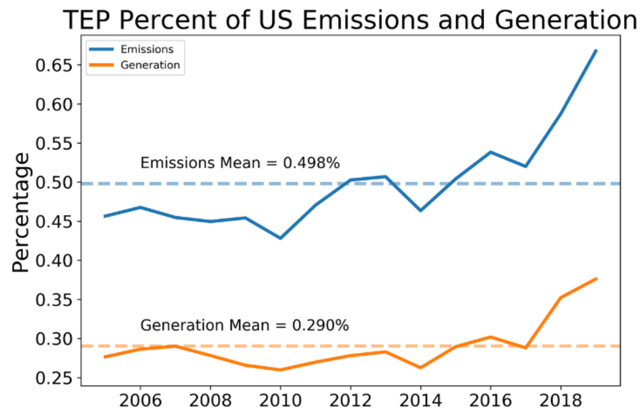

Figure 6 - TEP Percent of US Emissions and Generation

F_{TEP} is estimated two ways: 1) based on TEP's share of utility sector emissions over the past ten years (0.498%), and 2) based on TEP's share of utility sector generation over the past ten years (0.290%). Using the emissions share results in a larger carbon budget than the generation share, but both are reasonable estimates of TEP's percentage of the U.S. utility fraction.

Key Takeaway: The carbon budget calculation sets a quantitative limit on carbon emissions based on TEP's contribution to established warming targets. It scales TEP's cumulative emissions by its fraction of the U.S. utility sector, the U.S. utility sector's fraction of the U.S. total emissions, and the U.S. share of global emissions. In practice, this asks the question: "how much global warming would occur if TEP emitted this much carbon through 2050 – given its share of the U.S. utility sector, the U.S. utility sector share of total U.S. emissions, and the U.S. share of global emissions – and all other utilities, sectors, and countries followed their similarly prescribed cumulative carbon budgets?"

It is important to note that our approach only quantifies uncertainty in the TCRE calculation, as this was the only term in the equation with a robust and quantifiable estimate for uncertainty. This approach estimates the cumulative fraction for F_{US} and F_{USElec} as a single term (via methods described above), but does not account for uncertainty in these estimates. This is an area where these calculations can be improved as these terms are better defined and understood. This is particularly true for F_{USElec}, as TEP and other utilities will likely be confronted with numerous factors that may shift these fractions, including emergent or maturing technologies, shifts in energy markets, and the role of federal policies.

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[1] The EIA reference case in their Annual Energy Outlook reflects a relatively flat share of emissions for the U.S. Electrical Utility Sector (EIA 2020). This reference case reflects an approximation of recent practices, and they update these trajectories each year. Recent literature suggests more aggressive 2050 decarbonization targets are required for this sector to remain consistent with the well below 2 C warming target (see IEA 2020).

Cumulative Emissions: The dashed black line in Figure 7 shows the cumulative emissions that would result if TEP enacted a linear 80%, 90%, and 100% reduction of 2005 emissions by 2050 (these are the same dashed, dash-dotted, and dotted black line as shown in Fig. 5, above). The solid black horizontal line is the 2.0 C budget best estimate based on the TCRE calculation above. The grey bands characterize the uncertainty of this calculation based only on uncertainty in TCRE.

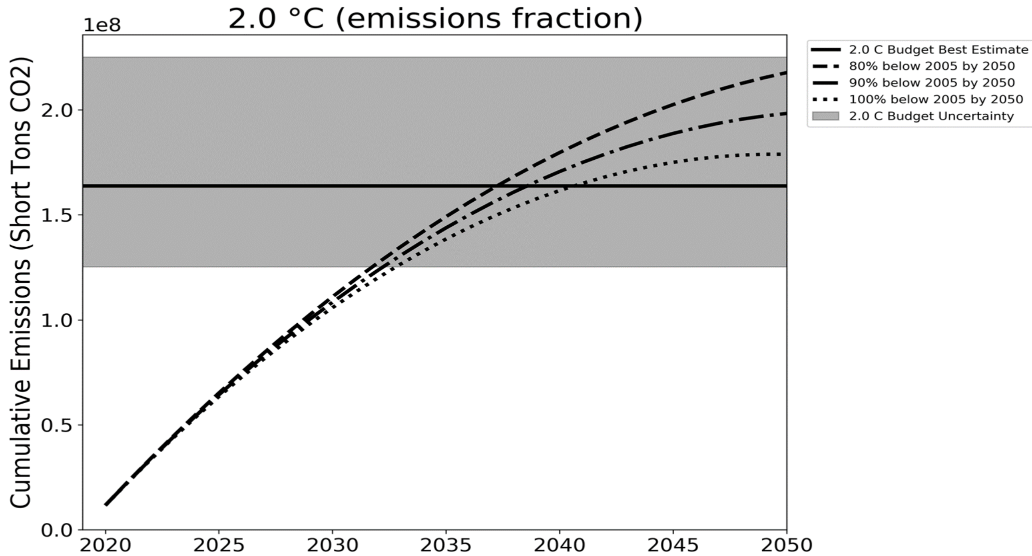

Figure 7 - Cumulative Emissions - 80% reduction of 2005 Emissions by 2050

Figure 8 includes the same data as Figure 7 but adds cumulative emissions for the TEP IRP portfolios. This demonstrates the range of cumulative carbon emissions associated with each portfolio, and where they fall in comparison to the cumulative emissions of the 80%, 90%, and 100% linear reduction targets(2020-2050), as well as the 2.0 C budget best estimate and uncertainty.

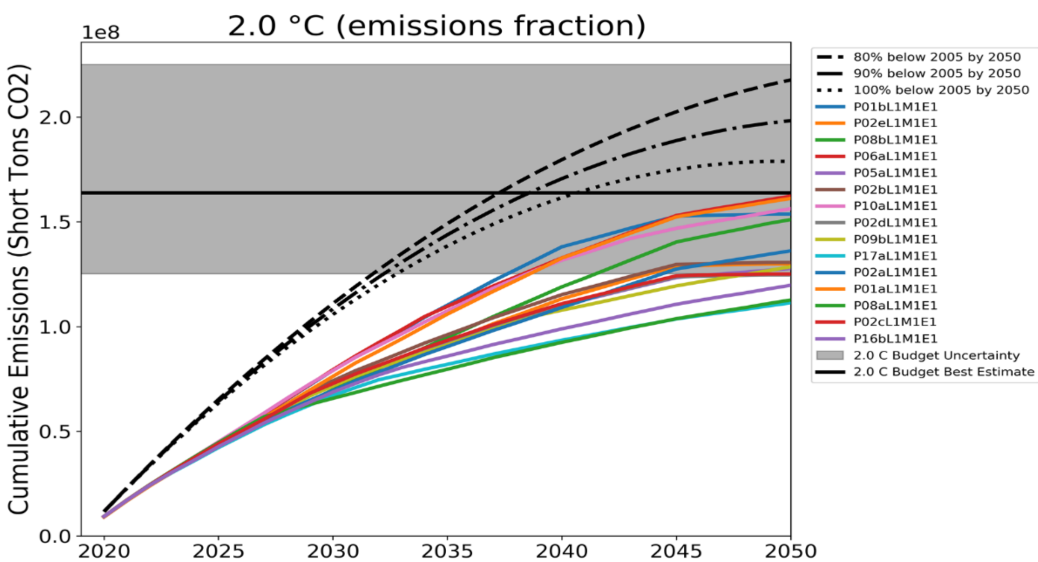

Figure 8 - Cumulative Emissions - 80% reduction by 2050 & TEP IRP Portfolios

Figure 9 is the same data as Figure. 8 but adds the 1.5 C and 2.5 C budget best estimates and uncertainty bands. This figure is based on the emissions-based estimate of TEP's fraction of the U.S. Utility Sector (0.498%), which results in a larger carbon budget for TEP (to hit the various warming targets).

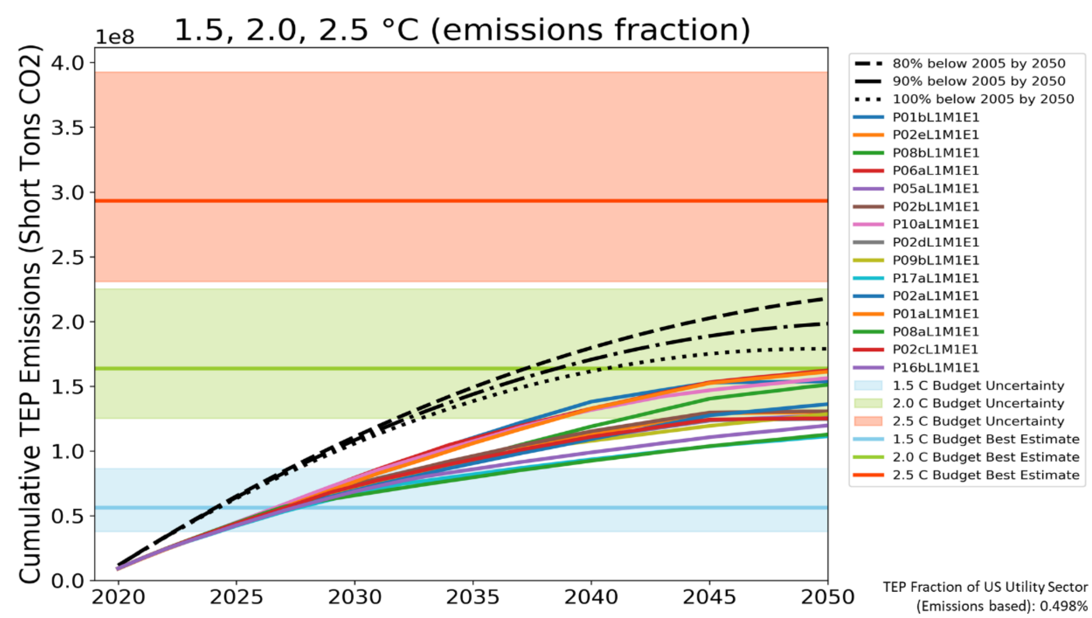

Figure 9 - Cumulative Emissions - 1.5, 2.0, 2.5 C Warming Targets (Emissions Based Calculation)

Figure 10 uses the same cumulative emissions data as Figure 9, showing the 1.5, 2.0 and 2.5 C budget best estimates and uncertainty bands. This figure is based on the generation-based estimate of TEP's fraction of the U.S. utility sector (0.290%), which results in a lower carbon budget compared to the estimation in Figure 9. *Note: the cumulative emissions totals are identical for the portfolios in Figures. 9-10, only the warming targets best estimate and bands have moved.*

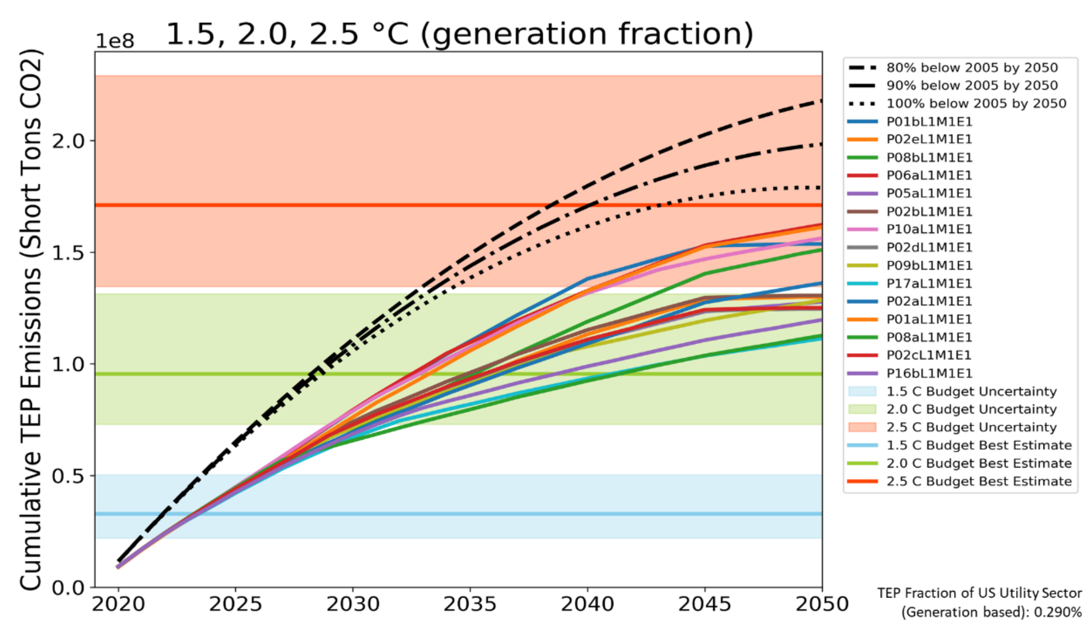

Figure 10 - Cumulative Emissions - 1.5, 2.0, 2.5 C Warming Targets (Generation Based Calculation)

Figure 11 estimates the global warming through 2050 for the portfolio scenarios in Figure 9 using an emissions-based estimate of TEP's fraction of utility emissions (top) and the portfolio scenarios in Figure 10 based on the generation-based estimate of TEP's fraction of utility emissions (bottom). Note: The portfolios in Figures 9-11 are the same portfolios, and the two methods for estimating TEP's fraction do not change the relationship between portfolios (i.e., the order of the portfolios listed, from lowest warming estimate to highest is the same, only the range of values changes)

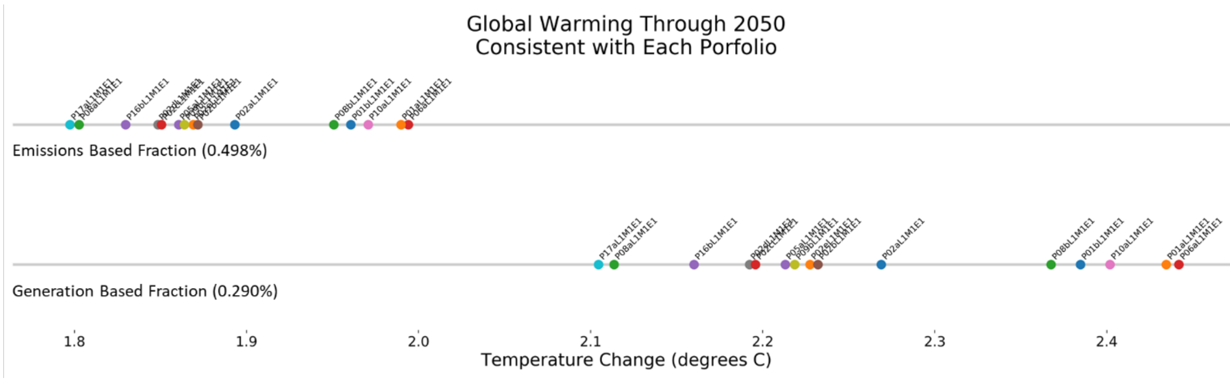

Figure 11 - Global Warming Through 2050 Consistent with Each Portfolio - Emissions (top) & Generation (bottom) Based Estimates

GitHub repository and transparent, replicable framework

We used a transparent modeling process – all the assumptions, code, documentation, and results are available on our public GitHub repository.

https://github.com/CLIMAS-UA/tepcarbon/

The code is open source and fully transparent. Anyone can replicate, test, or improve our analysis, or update it based on new information or data.

Key Report Takeaways

Cumulative Emissions and Carbon Budget Analysis

Cumulative emissions offer a robust and quantitative method to assess the warming impact of these portfolio scenarios. They assess both the timing and intensity of emissions reductions and highlight the additional emissions reductions that result when reductions move more quickly than a straight linear reduction. This emphasizes that the way these targets are achieved may be just as important as the targets themselves. The cumulative emissions framework also emphasizes that utilities have flexibility in how they meet the budget and does not prescribe anything about technologies or interim goals. This flexibility also takes into account the lack of certainty associated with future U.S. policies, the availability and feasibility of new or updated low carbon or renewable resources, and the market conditions that will drive many of these adaptations and innovations.

All of the portfolios presented demonstrate a lower amount of estimated global warming than the linear 80%, 90%, and 100% reduction of 2005 emissions by 2050. Based on the cumulative emissions approach and the assumptions embedded therein, the estimated warming for many of the presented portfolios is consistent with a well below 2 C target using the estimation based on TEP's emissions based fraction of the U.S. utility sector, while none of the generation based estimates of TEP's fraction fall in the well below 2 C range. It is again important to note; these estimations only include modeled uncertainty for the TCRE calculation and do not include modeled uncertainty for the F_{US} or F_{USElec} terms of the equation. As such, they are an as-current best estimate using available data and information for these estimations of warming. These estimates are useful guides for ranges of estimated warming and decision support regarding future climate impacts. Still, they are not a definitive forecast for the warming associated with these portfolios. There is room to improve how we define these terms and to incorporate modeled uncertainty for these terms in future analyses, both of which will improve our understanding of a) the warming associated with the portfolios, and b) the uncertainty associated with these estimations.

A note on emissions vs. generation based estimates of carbon budgets: The generation method allocates a carbon budget to utilities regardless of their actual emissions, so utilities with low-emissions fleets will have excess budget and utilities with high-emissions fleet may struggle to meet the budget. We speculate that the emissions method may be more appropriate when each utility sets its own goals, while the generation method may be more appropriate under a coordinated system such as cap and trade. We present both estimations, as they serve as a useful range of estimations of global warming through 2050 consistent with each portfolio.

Based on the cumulative emissions approach and the assumptions embedded therein, none of the presented portfolios are consistent with a limit to 1.5 C warming, and this is subject to the same caveats about uncertainty described above. With the warming observed since the pre-industrial period (calculated here at approximately 1.0 C), this is not unexpected given there is only 0.5 C warming remaining for the 1.5 C target. This is consistent with the literature on warming targets and emissions, which suggest that negative emissions (e.g. carbon sequestration, carbon capture and storage) are a necessary element of hitting the 1.5 C warming target (IEA 2020). The cumulative emissions associated with 80-,90-, and 100-percent linear reductions of 2005 levels by 2050 help validate the results of the cumulative emissions calculation. We would expect that the cumulative emissions associated with an 80% reduction would fall in the 2-3 C warming range, while the 90% linear reduction is associated with a 2C to well-below-2C warming limit.

Percent Reduction vs. Cumulative Carbon Emissions and Budgets

Our cumulative emissions and carbon budget approach addresses both the quantity and timing of emissions reductions and sets a budget for carbon emissions for TEP. This identifies the amount of carbon emissions allowed to stay under the warming targets, and facilitates an assessment of these carbon budgets in terms of their temperature targets. Emissions reduction targets (e.g. 80% by 2005, etc.) that do not account for the timing of those reductions could lead to higher emissions and more warming despite hitting the target. A key finding from our analysis is a wide range of portfolios could reach a similar percent reduction in emissions based on the 2005 baseline (see Figure. 5, above). The cumulative emissions framework highlights the benefit of starting those reductions sooner. Essentially how you get to those percent reductions targets may be just as important as the targets themselves.

The cumulative carbon budget framework represents an empirical approach that estimates the expected warming for each of the portfolios, rather than relying on the estimated correspondence between a percent reduction target and these warming targets. The percent reduction targets are a useful point of comparison, especially across companies and sectors. By adding this cumulative carbon budget framework, this encourages an assessment of the discrete impacts of a given range of portfolios. This focuses expected warming under a range of scenarios, rather than relying solely on the percent reduction framework.

A note on portfolio composition vs. cumulative emissions. In terms of reducing contributions to warming, the absolute reduction of cumulative emissions is the most effective way to limit warming. The specific portfolio composition (percent clean energy, percent renewables, etc.) or the mechanisms that reduce cumulative emissions (timing of coal retirements, etc.) are less important than the absolute reduction in cumulative emissions. Portfolio characteristics are still useful for communications and setting tangible goals, but the cumulative emissions framework emphasizes that utilities have flexibility in how they meet the budget and does not prescribe anything about technologies or interim goals.

Electrification

Increased electrification of other sectors is a fundamental part of the various scenarios advanced by the IPCC and IEA, and others that are anticipated to limit warming to at most 2 C, and ideally well below 2 C (or even 1.5 C)[2]. This increased electrification will increase the load for electrical utilities. Under most decarbonization scenarios, power generation bears a much larger reduction in overall emissions compared to other sectors that may be harder to decarbonize (See Figure 3, above). It is important that companies identify strategies that anticipate this increased load, and to minimize the emissions associated with this increased load such as increased use of renewables or plans for coordinated charging. Otherwise, the expected load increases associated with electrification and demographic growth could lead to higher emissions inconsistent with a well below 2 C warming target.

Electrification also presents opportunities for carbon emissions reductions in the transportation sector, as light-, medium- and heavy-duty internal combustion engine vehicles (ICEVs) are replaced by battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). This carbon emissions reduction may counteract increased carbon emissions for the load required to charge these vehicles. Coordinated charging and increased use of renewables could even lead to a net reduction in emissions despite the

[2] Numerous assumptions are embedded within these scenarios, and while most see increased electrification as a necessary step in reducing overall carbon emissions, the timing and speed of these transitions is difficult to predict

increased load (Jansen et al., 2010). This has potential positive impacts on local air quality (particularly NOx and Ozone) if local emissions from conventional vehicles are reduced as the vehicle mix includes more BEVs and PHEVs and fewer ICEVs (see Holland et al. 2016). Recent literature addresses carbon balance, increased load associated with electrification, and the counterbalancing effect of reduced carbon emissions (Jiusto et al., 2006; Graff et al., 2014). There is considerable potential for additional work in this arena: specifically, a precise accounting of net emissions associated with increased load for BEVs and PHEVs, the decreased emissions associated with reduced use of ICEVs, and the impact of this shift on local air quality (particularly in areas where Ozone attainment status is an ongoing concern).

Negative Emissions and the 1.5 C Warming Target

Given the historical warming to date of approximately 1.0 C, a warming target of 1.5 C is difficult to envision with emissions reductions alone. Most of the scenarios that achieve the 1.5 C limit to warming include aggressive decarbonization and call for changes as soon as possible. 1.5 C consistent scenarios also generally include negative emissions such as carbon sequestration (removal of emitted carbon from the atmosphere) and carbon capture and storage (capture and storage of point source carbon emissions) (see Hausfather and Peters, 2020). These technologies are not yet available to scale, but there is optimism that these technologies will become financially viable either as costs go down, or the social/economic cost of carbon emissions increases (or is included at all in company financial and risk management planning). For more information on negative emissions see Minx et al. (2018), Fuss et al. (2018), and Nemet et al. (2018).

Coordinated Emissions Reductions Efforts and Ambition of Warming Targets

The cumulative carbon budget calculation is based on an empirical calculation of TEP's fraction of the global emissions carbon budget (based on their cascading share of the U.S. utility sector emissions, the U.S. utility sector's share of U.S. national emissions, and the U.S. share of global emissions).

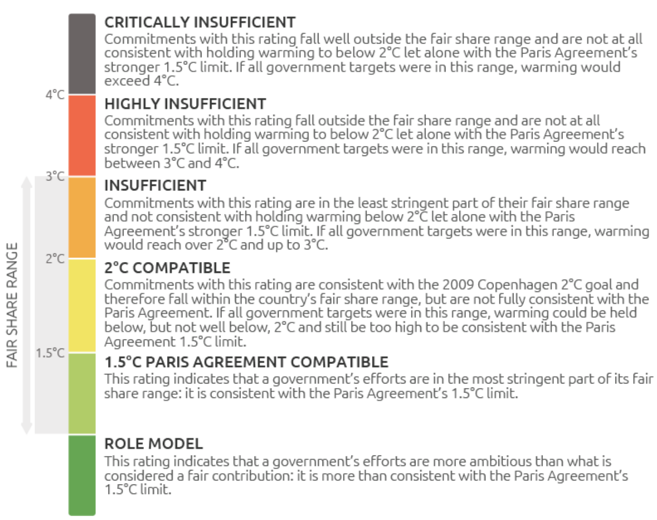

Figure 12 - Climate Action Tracker - Reductions Rating Tool

This corresponds with the "fair share range" described by the Climate Action Tracker (Figure 12), and maps onto the ranges described by Hausfather and Peters (2020) and shown Fig. 1 (above). Essentially this argues that if all parties (companies, sectors, nations) contributed the least stringent reductions within their "fair share" range, we can roughly expect warming between 2 C and 3 C. This is again consistent with the current outlook suggested by both current and pledged policies in Hausfather and Peters (2020). More stringent action within the fair share range is more likely to limit warming to below 2 C, while the most stringent action in the fair share range is consistent with the Paris Agreement targets.

This does not mean that only the most aggressive reductions are consistent with a well below 2 C world, but it does mean that earlier and more aggressive action is more likely to lead to a well below 2 C world, especially if these actions are implemented across sectors.

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