SMARTargets

A Methodology for Grounded and Actionable Climate Targets Aligned with Global Goals



SMARTARGETS SCIENTIFIC FOUNDATIONS: THE SCIENCE RELEVANT TO CORPORATE GREENHOUSE GAS EMISSIONS TARGET SETTING BASED ON SCIENCE

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1. INTRODUCTION

This document addresses a gap in the currently available technical guidance resources for corporate greenhouse gas (GHG) target setting. Missing is a resource that identifies the relevant science, and derives technical insights, principles, and requirements for science-based corporate climate target setting, target assessment, and transition risk assessment. A resource of this type is needed for informed and grounded expectations, dialogue, and methodologies.

To date, company-level GHG target setting and low-carbon transition risk assessment methodologies have selected as benchmarks one or two global GHG emissions pathways aligned with the Paris Agreement global average temperature goal to limit warming to "well below" 2°C, or even 1.5°C (e.g., SBTi, 2023, 2021; Moody's, 2024, 2020; PRI, 2021; TPI, 2023; Morningstar Sustainalytics, 2023). The global pathways are used as strict requirements or criteria for guiding or assessing corporate GHG targets and strategies. However, the limitations of global pathways are not being considered and the scientific literature on emissions and transition pathways consistent with climate goals is significantly more expansive.

Among other things, there are many consistent (or aligned) global and sub-global pathways. See, for instance, the global and national pathways assessed by the most recent reports by the Intergovernmental Panel on Climate Change (IPCC) and U.S. National Climate Assessment (Riahi et al, 2023; Byers et al, 2022; Lecocq et al, 2022; Davis et al, 2023). In addition, some methodologies have favored certain technology solutions, such as energy efficiency and renewables, while discouraging or precluding others, such as nuclear power, carbon dioxide removal (CDR), and other kinds of offsets. The scientific literature, however, offers important insights on the implications of favoring or restricting climate management options. Furthermore, given uncertainty about the future, other types of science are also relevant, such as that related to decision-making under uncertainty (e.g., Hall et al, 2012; Hallegate et al, 2012; Kalra et al, 2014).

This full set of relevant literature and its insights are germane and should inform how we think about, identify, and evaluate corporate GHG targets and strategies. Needed is a formal definition of the scientific requirements for targets based on science that is grounded in assessment of the full relevant literature. Such requirements will not only ensure alignment with the science but also provide well-grounded guidance for methodologies, targets, and strategies striving to be "science-based."

This document begins by framing the problem as one of needing to understand the relationship between a company and global temperature goal. Thus, we need to understand the factors that define the potential role, opportunities, and risks for a company in "well-below" 2°C and 1.5°C futures. We then identify the set of science relevant to understanding the company-global temperature relationship. Next, we discuss the key scientific observations that emerge from assessing the relevant science and note the implications of each observation for corporate GHG target setting and strategies. We then highlight additional company-level technical insights. Finally, we apply the set of scientific observations and insights to define scientific requirements for "science-based" company GHG target setting and strategies. We also derive science-based operational requirements for the methodology that provide guidance on the functionality needed.

Our overall approach for developing a GHG target setting methodology based on science is represented in Figure 1. It begins with assessment of the relevant science, from which we build a scientific foundation of observations. We then derive scientific requirements for a methodology based on the observations.

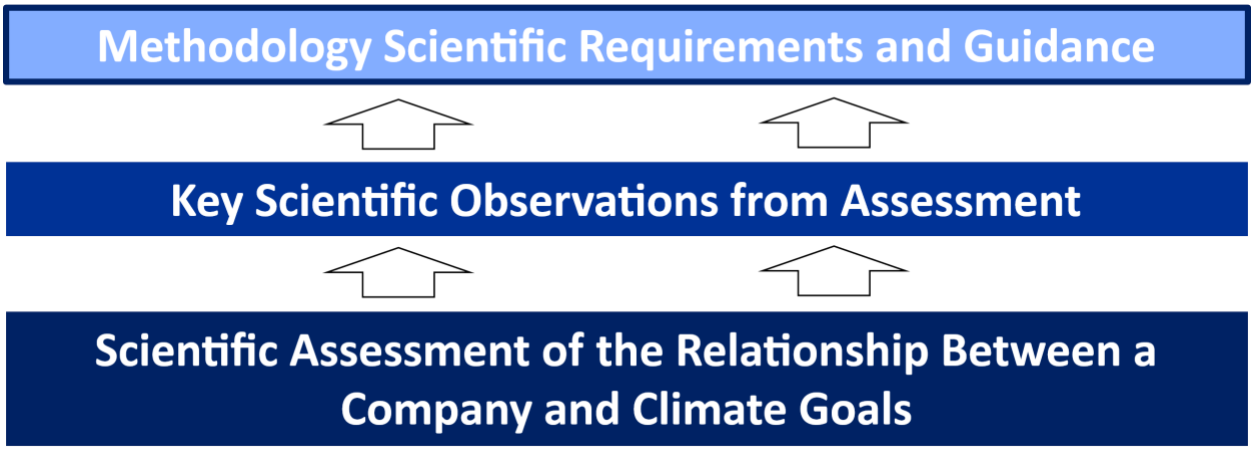


Figure 1. Deriving scientific observations and requirements for corporate GHG target setting from assessment of the relevant science

2. THE RELATIONSHIP BETWEEN A COMPANY AND GLOBAL TEMPERATURE GOAL AND THE RELEVANT SCIENCE

A few years ago, EPRI asked a fundamental question: what is the relationship between a global average temperature goal and a company (Figure 2)? A stream of research resulted assessing, advancing, and defining the scientific relationship between a climate goal and a company. This research, combined with assessment of the broader scientific literature, provides the technical foundation needed for grounded company analyses and decision-making on corporate climate targets and climate risks.

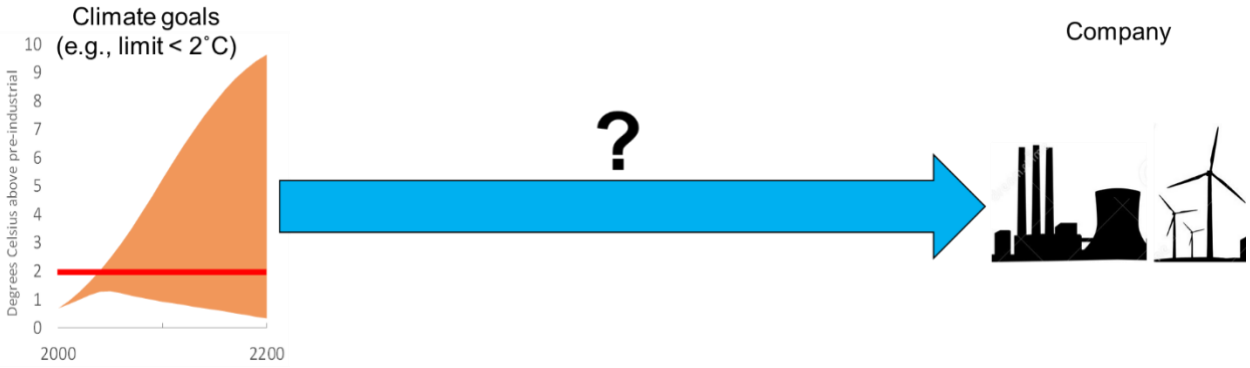


Figure 2. It is essential to understand the relationship between global climate goals and companies

Source: EPRI (2018)

Pursuing the temperature-company question in Figure 2 first requires identifying the relevant science. The factors that define the relationship in Figure 2 are the factors that define the potential opportunities and risks for a company in contributing and transitioning to a particular climate future. These factors are tiers of relevant physical, economic, and technological sciences and include the following:

- **Climate science:** potential global emissions consistent with a global temperature outcome,
- **Global transition pathways:** potential future global emissions and economies consistent with a global temperature outcome,
- **Sub-global transition pathways:** potential future sub-global (e.g., country, sector) emissions and economies consistent with a global emissions pathway,
- **Local transition pathways:** potential future sub-national (e.g., province, state, city) emissions and economies consistent with a sub-global emissions pathway, and
- **Company transition pathways:** potential company emissions and transitions (systems and activity levels) consistent with a local emissions pathway.

Setting a company target requires understanding of climate system dynamics and uncertainties and potential transition pathway dynamics, uncertainties, and relationships across scales—global, sub-global, local, and company level—that are consistent with limiting global warming to a temperature outcome. The tiers of science above highlight the possibility of there being more than one global emissions pathway consistent with a global temperature, more than one sub-global economy consistent with a global

emissions pathway, and so on. It is important to note that understanding transition pathways also requires considering emissions and the set of potential economic systems consistent with an emissions pathway. Here again, there could be more than one possibility as different types of economic activity could result in the same emissions outcome.

Overall, the presence of uncertainty in transitions also means that there is risk and the need to consider decision-making under uncertainty. The science clearly shows that the future is uncertain. Exploring and understanding uncertainty is therefore prudent. It is a critical component of grounded corporate decision-making and effective climate strategies. To identify and manage risks and make informed decisions, companies need to evaluate the spectrum of uncertainties they face, using the best available information. Managing climate risk means, not only acknowledging that the future is uncertain, but that action is still necessary. Flexible and robust strategies are needed that allow for adjustments as the future unfolds and new information emerges. Such strategies are needed so that companies can remain resilient, responsive, and aligned with long-term climate goals.

Below we discuss Key Scientific Observations relevant to company climate target setting that emerge from assessment of the relevant science. For each key observation, we provide examples and citations to support the finding and to allow the reader to explore the science and observation further. The citations include references to the broader scientific literature, as well as EPRI's research over the last few years that was focused specifically on informing the global temperature-company relationship question (Figure 2).

Below we summarize the Key Scientific Observations and implications for corporate target setting. Table 1 is a high-level representation of the observations and company implications. For instance, the many different transition pathways aligned with a global temperature (Key Scientific Observation #1) implies, among other things, that the science does not provide guidance regarding a specific transition pathway for a company. While the variation in transition opportunities by company (Key Scientific Observation #4) implies that each company needs to evaluate its own transition opportunities and risks.

Key Scientific Observations and Company Climate Target Setting Implications

1. **Many different transition pathways are consistent (aligned) with achieving a global temperature goal:** There is not a singular relationship between a global temperature objective and a company's emissions transition. Scientific evidence illustrates that there are wide range of global, country, sector, sub-national, and company emissions transition pathways scientifically consistent (aligned) with limiting global warming to any specific temperature threshold.
    a. ***Company Implications:*** There is no one pathway that can fully inform companies on potential transition opportunities. There are many Paris Agreement aligned future conditions and pathways for each company with the relationship to a global pathway weak. It is not a 1-to-1 relationship. Instead, there are many local pathways consistent with a global pathway. As a result, the science does not provide guidance regarding a specific transition pathway for a company, underscoring the need for a company to explore their set of transition options.

2. **Global pathways aligned with limiting warming to 2°C and 1.5°C have influential but uncertain assumptions:** Global emissions pathways aligned with limiting global average warming to 2°C and 1.5°C frequently have influential and unlikely policy and technology transition assumptions. These assumptions determine how emissions reductions are distributed across regions and sectors, and they significantly affect the feasibility of the pathway and the likelihood of achieving the corresponding temperature outcome.
    a. ***Company implications:*** Policy design and technology availability and deployment assumptions are important to identify and evaluate. They are uncertainties companies cannot ignore.

3. **Alternative future conditions can have very different transition implications:** Different future policy and non-policy conditions can have very different implications for companies in terms of transition opportunities, challenges, trade-offs, risks, and even pathway viability.
    a. ***Company implications:*** It is essential to evaluate transition implications uncertainties and risks, considering uncertainty in decarbonization incentives, options, and other conditions, and identify and manage the risks for climate targets.

4. **Transition opportunities vary by company:** Decarbonization transition opportunities vary by company due to differences in, among other things, assets, resources, infrastructure, systems, markets, regulations, and customers. As a result, their transition options and risks differ; and, the same future target across companies is not cost-effective for society.
    a. ***Company implications:*** Each company needs to evaluate its transition opportunities and risks.

5. **Global pathways provide high-level guidance but have significant limitations in informing companies:** Global emissions pathways have significant limitations as benchmarks for guiding or evaluating companies. For instance, global modeling does not model individual companies, their markets, or their potential transitions. However, global pathways can provide high-level guidance on aggregate levels of emissions reduction effort for a global temperature goal.
    a. ***Company implications:*** Global pathways can help identify aspirational levels of effort and facilitate coordination across companies and sectors, but it is important to recognize their limitations. In particular, it is impractical to expect all individual companies to achieve the aggregate outcomes or to evaluate companies relative to these outcomes.

6. **Practical issues defining a company's circumstances affect GHG abatement opportunities**: There are practical issues to consider when setting and pursuing GHG targets. For instance, adequate GHG inventories are needed and whether the emissions are regulated should be considered.
    a. ***Company implications:*** Assessment of target setting capacity and a company's current situation are necessary for informed setting and pursuing of targets.

Table 1. Key Scientific Observations and key company climate target setting Implications

	Key Scientific Observation	Key Company Climate Target Setting Implication
1	Many different transition pathways are consistent (aligned) with achieving a global temperature goal	The science does not provide guidance regarding a specific transition pathway for a company
2	Global pathways aligned with limiting warming to 2°C and 1.5°C have influential but uncertain assumptions	Policy design and technology deployment are uncertainties companies cannot ignore
3	Alternative future conditions can have very different transition implications	It is essential to evaluate transition implications uncertainties and risks
4	Transition opportunities vary by company	Each company needs to evaluate its transition opportunities and risks
5	Global pathways provide high-level guidance but have significant limitations in informing companies	Global pathways help identify aspirational levels of effort and facilitate coordination, but it is impractical to expect all individual companies to achieve the aggregate outcomes
6	Practical issues defining a company's circumstances affect GHG abatement opportunities	Assessment of target setting capacity and a company's current situation are necessary

Key Scientific Observation 1: Many different transition pathways are consistent (aligned) with achieving a global temperature goal

Summary: There is not a singular relationship between a global temperature objective and a company's emissions transition. Scientific evidence illustrates that there are wide ranges of global, country, sector, sub-national, and company emissions transition pathways scientifically consistent (aligned) with limiting global warming to any specific temperature threshold.

Company Implications: There is no one pathway that can fully inform companies on potential transition opportunities. There are many Paris Agreement aligned future conditions and pathways for each company with the relationship to a global pathway weak. It is not a 1-to-1 relationship. Instead, there are many local pathways consistent with a global pathway. As a result, the science does not provide guidance regarding a specific transition pathway for a company, underscoring the need for a company to explore their set of transition options.

Discussion

Global transitions

Understanding the relationship between a global temperature and a company begins with climate science and understanding how global emissions affect global temperatures, which is primarily a physics relationship. Figure 3 presents the latest scientific understanding from the IPCC on the relationship between cumulative global net CO_2 emissions over time, also known as CO_2 emissions budgets, and global average temperature change (IPCC WGI, 2021). As seen in Figure 3, lower global cumulative net CO_2 emissions are associated with lower global average temperature outcomes. The figure also illustrates that there are wide ranges of global CO_2 budgets consistent with any temperature outcome due to uncertainties in non-CO_2 climate forcings, earth system feedbacks, and the responsiveness of the climate system. The ranges widen the greater the temperature change, reflecting a broader set of potential

cumulative emissions futures options; however, even the range for 1.5°C exhibits significant variation. The information in Figure 3 can be used to identify a global CO_2 budget associated with a particular temperature outcome and probability; however, as discussed and illustrated below there are still ranges of CO_2 budgets consistent with any temperature-probability outcome due to uncertainties in the underlying socioeconomic conditions and resulting CO_2 and non-CO_2 climate forcings (Table 2).

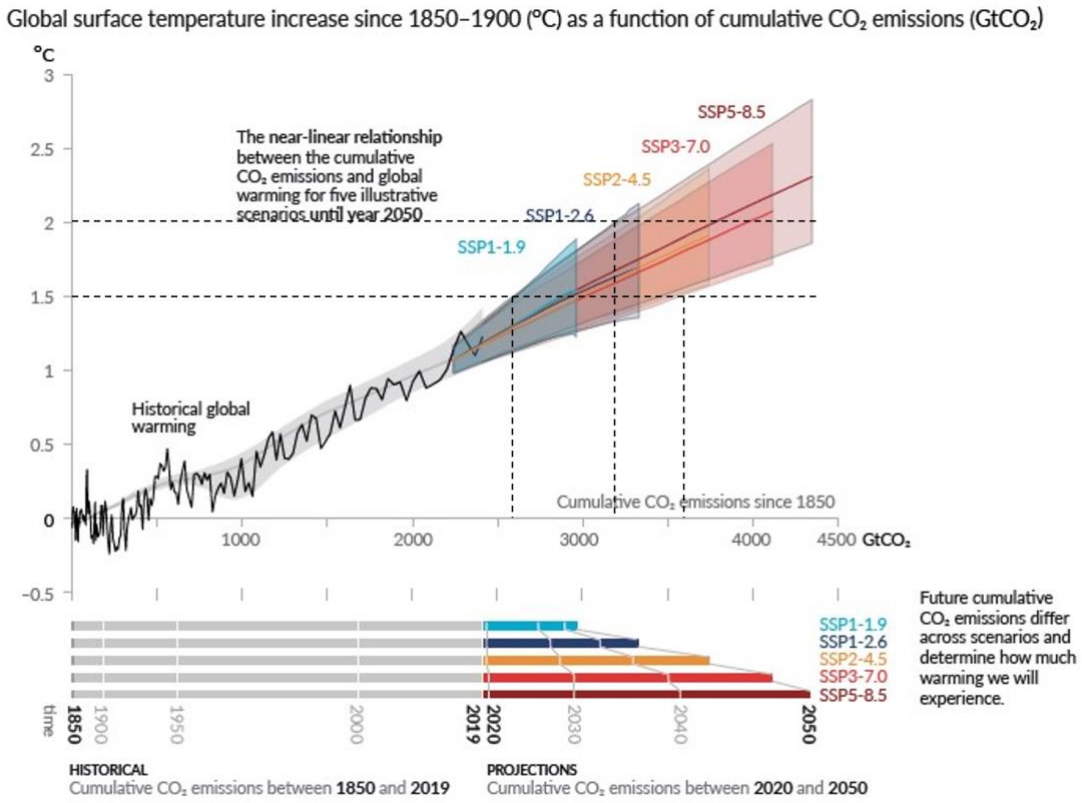


Figure 3. The relationship between global average temperature change and global cumulative net CO_2 emissions since 1850

Source: IPCC WGI (2021)
Figure note: Dotted lines added to communicate the cumulative net CO_2 ranges from 1850 associated with 1.5°C and 2°C global average temperature increases. The ranges shown are approximately 2,600 to 3,600 $GtCO_2$ and 3,200 to over 4,400 $GtCO_2$ respectively.

The IPCC assessments over the years have consistently shown wide ranges of global pathways and budgets associated with temperature outcomes due to uncertainties in both climate and socioeconomic systems (e.g., IPCC WGI, 2021; Riahi et al, 2022; IPCC WGI, 2014; Clarke et al, 2014). Both kinds of system uncertainties are discussed in EPRI's assessments as well (EPRI, forthcoming; EPRI, 2020; EPRI, 2018).[1] To

[1] EPRI (forthcoming) evaluates the global emissions pathway data used in IPCC's Sixth Assessment Report (Byers et al, 2022; Guivarch et al, 2022a), as well as IEA (2023, 2021), TPI (2023), and PRI (2021) pathways. EPRI (2020) evaluates the global emissions pathway data used in the IPCC's 1.5°C Report (Huppmann et al, 2019), as well as IEA

understand the relationship between a company and international climate goal, EPRI's research has evaluated approximately 3,300 global emissions pathways in the literature to date. Most recently, these included global emissions pathways from the IPCC Sixth Assessment Report decarbonization scenarios database (Byers et al, 2022; Guivarch et al, 2022a; Riahi et al, 2022), the International Energy Agency (IEA, 2023, 2021), the Transition Pathway Initiative (TPI, 2023), and the Principles for Responsible Investing (PRI, 2021).

An IPCC pathway database is comprised of emissions and socioeconomic pathways from different models and assumptions. Knowledge of the underlying data is important for properly interpreting and applying the pathway information. The IPCC assessments have consistently shown there are broad ranges of global emissions pathways, as well as global annual emissions reductions levels and cumulative emissions budgets, consistent with limiting warming to any global average temperature level (and specific probability and allowed overshoot). EPRI's assessments of global pathways (EPRI, forthcoming; EPRI, 2020; EPRI, 2018) have consistently shown these insights as well (Figure 4, Table 2). For instance, Figure 4 and Table 2 present the ranges for select global emissions summary characteristics for 1.5°C (with 50% likelihood) and 2°C (with 67% and 50% likelihoods) global emissions pathways based on the most recent global emissions pathways evaluated by the IPCC, as well as those from IEA, TPI, and PRI. Wide ranges are found in all the dimensions shown in Figure 4 and Table 2. For instance, the year global CO_2 emissions reach net zero in pathways consistent with limiting warming to 1.5°C (50% likelihood) and 2°C (67% likelihood) range from 2030 to 2076 and from 2035 to 2100 respectively. Similarly, the 2050 percent reductions in CO_2 emissions for these 1.5°C and 2°C pathways range from 73% to 126% and 43% to 100% respectively.

The ranges highlight that there are multiple possibilities for limiting warming to any temperature. The global emissions pathway ranges, like those shown in Figure 4 and Table 2, are due to different economic, technology, market, behavioral, non-CO_2 GHG, and other conditions. Different conditions with respect to each of these can change the cost-effective (i.e., least-cost) global decarbonization pathway and the relative decarbonization roles for countries, sectors, regions, technologies, and companies. Thus, they represent alternative conditions, opportunities, and risks for company low-carbon transitions.

Note that, Figure 4 and Table 2 show the full ranges for all the vetted IPCC analyzed pathways consistent with limiting warming to below 2°C. The vetted pathways were those the IPCC determined to meet minimum requirements for standardized temperature assessment and categorization.[2] In addition, the IPCC frequently shows percentile ranges (e.g., 5th to 95th percentiles); however, in this context, we need to consider the full ranges. First and foremost, we are interested in all the possibilities. All the pathways are relevant potential transitions unless we rule them out by additional criteria that would need to be

pathways (IEA, 2019, 2017a, 2017b). EPRI (2018) evaluates global emissions pathway data used in the IPCC's Fifth Assessment Report (IAMC, 2014).

[2] The assessed IPCC pathways for the Sixth Assessment Report were first vetted for consistency with a baseline period and for minimum data requirements (Riahi et al, 2022; Guivarch et al, 2022a).

transparently applied and communicated.[3] Second, statistical results, such as the median pathway, are not actual modeled pathways with structurally coherent and consistent system and market transitions across the variables (population, economic, energy system, etc.) over time. Finally, the underlying information is not a random sample and therefore does not support the derivation of statistics, such as percentiles, means, and medians (EPRI, forthcoming). Specifically, in the IPCC Sixth Assessment Report pathways, two (of 30) models are responsible for over 60% of the 1.5°C pathways and thus we do not have the random sample needed for deriving statistics. Statistics, like those noted, imply that some pathways are more likely, others less likely, and some are outliers. The underlying data, however, does not support conclusions like these.

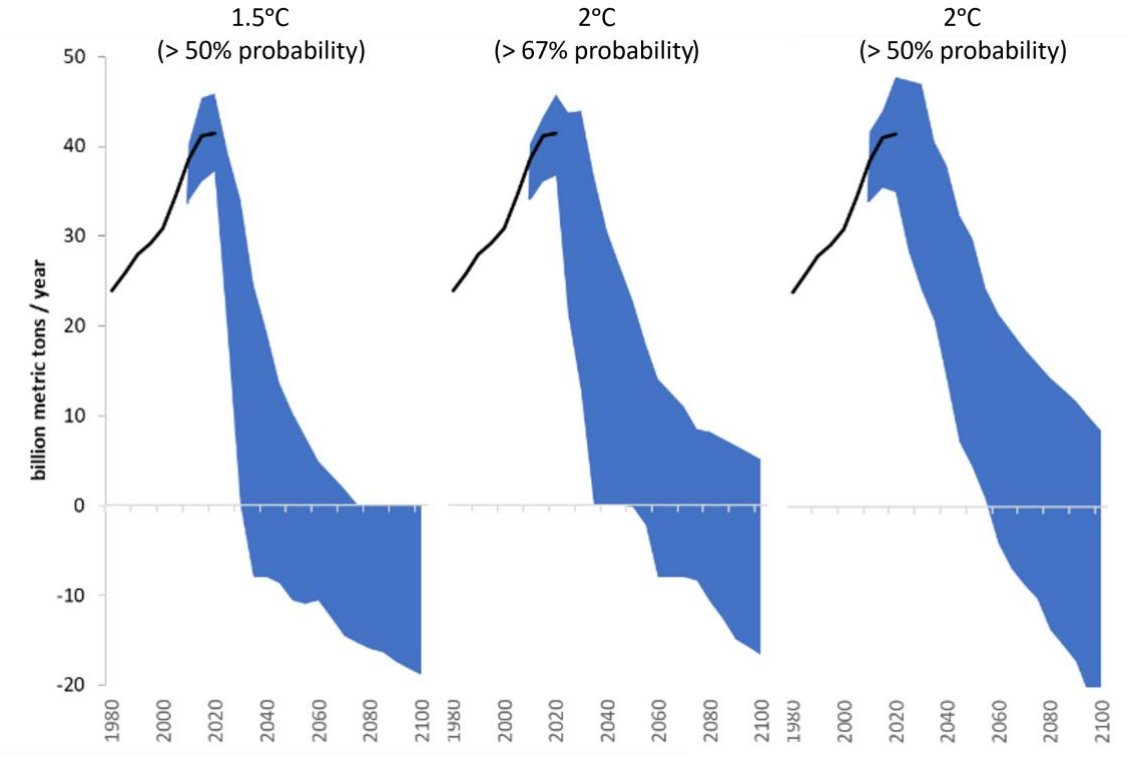


Figure 4. Global net CO_2 emissions pathway ranges consistent with limiting global average temperature to 1.5°C with a 50% likelihood with no or limited overshoot, 2°C with a 67% likelihood, and 2°C with a 50% likelihood

Source: EPRI (forthcoming)
Figure note: Results based on assessment of recent IPCC (Byers et al, 2022; Riahi et al, 2022; Guivarch et al, 2022a), IEA (2023, 2021), TPI (2023), and PRI (2021) pathways. The 1.5°C pathway range shown is for pathways categorized by Riahi et al (2022) as "no and low overshoot" of 1.5°C. Full ranges from IPCC vetted scenario data included since all are relevant possibilities.

[3] Additional selection criteria could be applied based on user-specified constraints related to characteristics of transitions. However, caution is merited not to preclude opportunities based on policy or technology preferences that should instead be evaluated for informed decision-making and dialogue.

Table 2. Ranges for select global emissions summary characteristics for 1.5°C and 2°C global emissions pathways

Source: EPRI (forthcoming)

Table note: Results based on assessment of recent IPCC (Byers et al, 2022; Riahi et al, 2022; Guivarch et al, 2022a), IEA (2023, 2021), TPI (2023), and PRI (2021) pathways. The 1.5°C results are for pathways categorized by Riahi et al (2022) as "no and low overshoot" of 1.5°C. Full ranges from IPCC vetted scenario data included since all are relevant possibilities. In addition, the cumulative (budget) CO2 ranges in the table are from 2015-2100, which can differ from some results presented by the IPCC with 2020 start years. * Including 1850-2015 historical emissions, the cumulative net CO_2 emissions ranges from 1850-2100 (versus 2015-2100 as shown in the table) are 2,259 to 3,205 $GtCO_2$, 2,835 to 3,768 $GtCO_2$, and 2,964 to 4,321 $GtCO_2$ for 1.5°C, 2°C with 67% likelihood, and 2°C with 50% likelihood global emissions pathways respectively. ** The IEA modeling only models global energy CO_2 and therefore its results are only included in the energy CO_2 ranges.

Category	Peak net CO_2 year			Peak net CO_2 level ($GtCO_2$/yr)			Net-zero CO_2 year			Annual net CO_2 % change (from 2015)						Net CO_2 budget 2015-2100 ($GtCO_2$)*			Peak Energy & Industrial CO_2 year**		
										2030			2050								
1.5°C (> 50% probability)	2015	-	2020	37	-	46	2030	-	2076	-13%	-	-100%	-73%	-	-126%	-91	-	855	2015	-	2025
2.0°C (> 67% probability)	2015	-	2030	37	-	46	2035	-	not < 2100	10%	-	-67%	-43%	-	-100%	485	-	1418	2015	-	2030
2.0°C (> 50% probability)	2015	-	2030	36	-	48	2055	-	not < 2100	20%	-	-34%	-25%	-	-88%	614	-	1971	2015	-	2030

Overall, the IPCC data sampling issues include disproportionate representation of models and assumptions, truncated data, and incomplete sampling of the distribution of possibilities. These issues are common and have been consistently found in vintages of community global pathway databases (EPRI, forthcoming; EPRI, 2020; EPRI, 2018). Given these insights, Figure 4 and Table 2 include all the IPCC vetted pathways in each IPCC climate category, as well as the pathways from the IEA, PRI, and TPI.[4] See Key Scientific Observation #5 below for additional discussion regarding the underlying data and statistical inference.

In summary, assessment of the global emissions pathways highlights that there are many global emissions budgets (cumulative emissions over time) and transition possibilities for limiting warming to a temperature goal, with wide ranges of 2030, 2040, and 2050 global emissions outcomes and reduction percentages that should be considered. There are also many global budgets and pathways that are not aligned with a temperature goal, and we can see those as well by looking across the pathways associated with different temperature outcomes (Table 2). The ranges tell us that there are alternative global transition conditions to consider in the pursuit of any temperature goal, and a single pathway (or budget) ignores these alternatives. Furthermore, a single global pathway (or budget) that is scientifically more likely or important than the others cannot be robustly determined.

Sub-global transitions

There are not only broad ranges of global emissions pathways consistent with limiting warming to *any* global average temperature, but there are broad ranges of consistent sub-global pathways (regional, national, sectoral, and sub-national). For example, Figure 5 shows ranges of sectoral emissions transition outcomes in the recent IPCC global pathways consistent with limiting temperature to 1.5°C and 2°C (Byers et al, 2022; Riahi et al, 2022). Similar results are found in previous global emissions pathways as well (e.g., IAMC, 2014; Clarke et al, 2014). In Figure 5, we find wide ranges, with negative to positive future emissions through mid-century and beyond to be consistent with limiting warming to below 2°C. We also see that the temperature outcomes are being achieved with net CO_2 emissions reductions in all sectors, including from land activities. These results are due in large part to the immediate and comprehensive global decarbonization climate policy being assumed (see Key Scientific Observation #2). Figure 5 also illustrates the significant variation in potential global electricity transitions for any global temperature outcome. Finally, Figure 5 illustrates that the sub-global transition ranges shift with the global temperature outcome. A similar insight emerges from Figure 6 (discussed next).

Newer research has found that there are many sub-global pathways consistent with any individual global emissions pathway (Rose et al, forthcoming). For instance, Figure 6 shows distributions of potential sub-global economic conditions in 2050 that are compatible, or consistent, with a single 2°C global emissions pathway. Represented are the results from evaluating 1,200 alternative global climate policy design and non-policy conditions. Specifically, the analysis evaluated three policy design contexts from optimistic to more pessimistic policy incentives, cooperation, and decarbonization options with, in each policy context, 400 non-climate-policy conditions that consider uncertainties in, among other things, population growth, economic growth, technology cost improvements, resource availability, and behavioral responses.

[4] The IEA modeling only models global energy CO_2 and therefore its results are only included in the energy CO_2 ranges. For comparison to the results in the table, the IPCC's 5th to 95th percentile net-zero year ranges for the 1.5°C (> 50% likelihood), 2°C (> 67% likelihood), and 2°C (> 50% likelihood) pathways are 2035 to 2070, 2055 to not before 2100, and 2055 to not before 2100 respectively (Riahi et al, 2022).

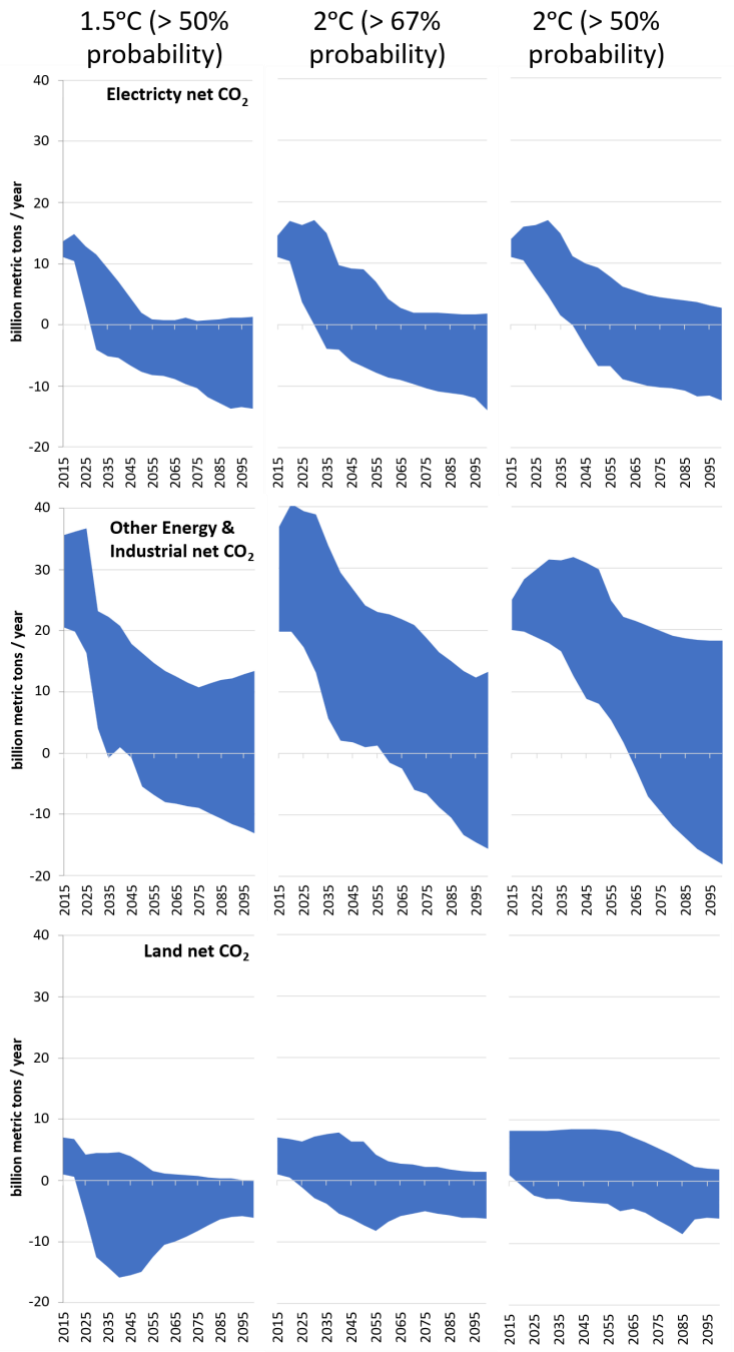


Figure 5. Net CO_2 transition ranges for electricity, other energy & industrial, and land emissions for limiting global average temperature to 1.5°C with a 50% likelihood, 2°C with a 67% likelihood, and 2°C with a 50% likelihood

Source: EPRI (forthcoming) assessment of the most recent IPCC scenario database (Byers et al, 2022; Riahi et al, 2022).
Figure note: The 1.5°C pathway range shown is for pathways categorized by Riahi et al (2022) as "no and low overshoot" of 1.5°C. Full ranges from IPCC vetted scenario data included since all are relevant possibilities.

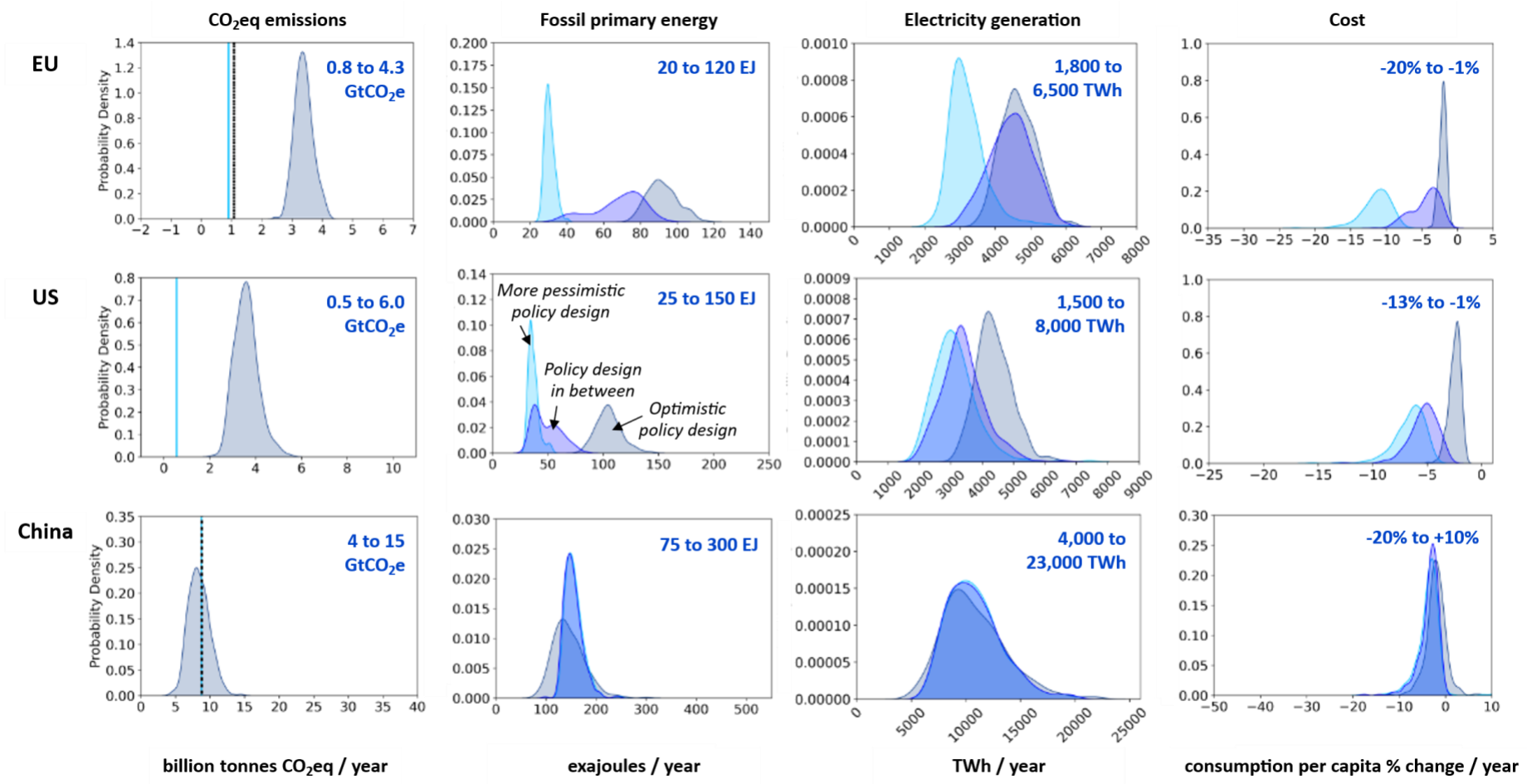


Figure 6. Potential United States (US), European Union (EU), and China 2050 distributions of cost-effective (least-cost) outcomes for GHG emissions, fossil primary energy, electricity generation, and decarbonization costs that are consistent with a single 2°C global emissions pathway considering climate policy design and non-climate-policy uncertainties

Source: Rose et al (forthcoming).

Figure note: Represented in the figure are kernel density estimate distributions from 1,200 different possible cost-effective transition outcomes based on three global climate policy design futures and 400 possible non-policy future conditions. The policy futures are "Optimistic" (grey) with global economy-wide coverage and cooperation, carbon dioxide removal, and global land GHG abatement policies; "More pessimistic" (light blue) with unilateral regional GHG abatement, no carbon dioxide removal, and no global land abatement policy; and, "In between" (purple) which is the more pessimistic policy with carbon dioxide removal available through bioenergy with CCS. The numerical ranges noted in charts are representative of the range of possible outcomes. The dotted line in the regional CO_2eq emission charts indicates each region's assumed 2050 emissions reduction goal. x-axis' ranges vary by country. y-axis' units are probability densities for kernel density estimate distributions.

Overall, Figure 6 highlights that there is significant transition uncertainty, and risk, for regional economies and sectors in transitioning to a 2°C future, with significant differences between regions. For instance, the size of the U.S. electric sector in 2050 ranges from about 40% smaller than today's system to 100% larger (1,500 to 8,000 TWh of electricity generation), with significant uncertainty in the composition of the generation portfolio underlying the alternative systems. The "Optimistic" policy design conditions with a global economy-wide policy and cooperation, carbon dioxide removal (CDR), and global land emissions abatement result in a larger U.S. electric sector, while the "More pessimistic" conditions without global cooperation and key abatement technologies result in the need to reduce U.S. electricity output and overall energy consumption to achieve the climate outcome. Similarly, fossil primary energy use in the EU in 2050 ranges from 20 exajoules (EJ) per year to six times larger than that, with EU economic transition costs in 2050 ranging from 1% to 20% per year in terms of potential reductions in annual aggregate household consumption per capita.

Furthermore, many sub-national emissions transitions are found to be consistent with a national net-zero goal (e.g., Larson et al, 2021; EPRI, 2023; EPRI, 2022a). Figure 7 shows that a wide range of sub-national cost-effective emissions transitions are consistent with pursuing a U.S. net-zero by 2050 economy-wide goal (EPRI, 2023). The variation in transitions between regions is due to differences in sub-national decarbonization conditions, such as resources, infrastructure, and markets. Company-level analysis also finds different company GHG emissions reduction levels to be consistent with achieving an industry wide net-zero emissions goal (EPRI, 2025; EPRI, 2022a).

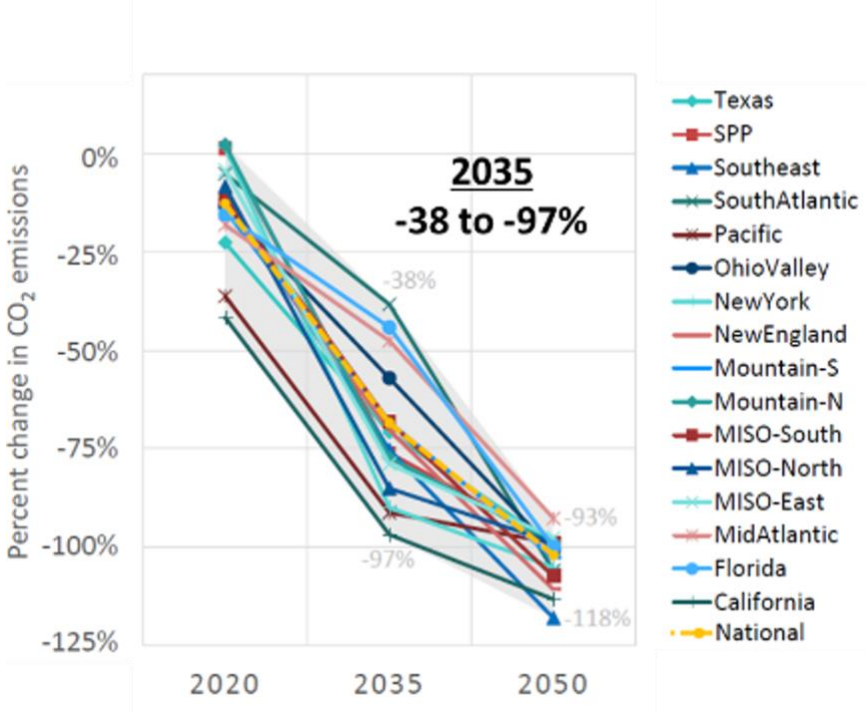


Figure 7. Potential U.S. regional cost-effective (least-cost) electric power sector CO_2 emissions transitions for achieving a U.S. economy-wide net-zero CO_2 by 2050 goal

Source: EPRI (2023).
Figure note: See EPRI (2023) for other U.S. regional emissions transitions for a U.S. economy-wide net-zero CO_2 by 2050 outcome due to different decarbonization conditions. A U.S. economy-wide net-zero CO_2 by 2050 policy constraint is assumed for the results shown. Percent reductions are relative to 2015.

Sub-global transition distributional results like those in Figure 6 are novel. The broader scientific literature thus far has not focused on formal characterizations of the uncertainty in sub-global transitions. However, the literature still exhibits substantial regional transition variability for a given global temperature or emissions outcome simply from alternative ad hoc assumptions and models (e.g., Davis et al, 2023; EPRI, 2023; Bistline et al, 2024). While these results only provide a partial characterization of the uncertainty, without probabilistic interpretation, they confirm that there are ranges of possible regional and sectoral transitions consistent with limiting warming to any temperature.

Overall, these observations lead to an important conclusion that the quantitative relationship between global and local pathways is weak. A one-to-one relationship between a global and local pathway does not exist. Instead, different levels of warming imply shifts in the distribution of local transition possibilities. Specifically, as illustrated in Figure 6, broad ranges of national pathways are found to be consistent with a global temperature; however, the distribution (location and shape) of possibilities shifts with the temperature. Furthermore, the same analysis also finds that one outcome can be consistent with transitioning to multiple global temperatures. For instance, Rose et al (forthcoming) found that 0.5 $GtCO_2eq$ emissions in Mexico in 2050 is in the distributions of outcomes consistent with limiting global average warming to 2.5°C, 2°C, between 1.5°C and 2°C, and 1.5°C (Figure 8). Not only does this imply a weak relationship between global and local pathways, but it implies an even weaker relationship between local pathways and global average temperature.

Note that many of the global and sub-global results discussed are cost-effective outcomes. They reveal the least-cost emissions reduction strategy across sources for a given global, national, or sectoral objective. Other potential social priorities (e.g., affordability, reliability, equity, development) are not applied in these analyses. However, the results include information across variables related to other priorities that facilitate discussion of risks and trade-offs between priorities. See, for example, Schipper et al (2022) in the latest IPCC report for an illustration of regional economic development, air quality, and energy and food security transition trade-offs by global temperature outcome. See also results like Figure 6 and its analysis for individual global emissions pathways, and EPRI (2023) for an illustration of insights regarding U.S. sub-national transition non-emissions implications, trade-offs, and risks for a U.S. net-zero CO_2 by 2050 transition.

The discussion above not only illustrates that there are broad ranges of scientifically consistent (aligned) sub-global, sub-national, and company transitions for any temperature due to climate policy design and non-policy uncertainties, but it also highlights two additional key points. First, there are commonalities in the form of qualitative transition features that are robust across models and assumptions that provide transition guidance, such as reductions in fossil energy and increased use of electricity. See Key Scientific Observation #5 for discussion of robust global transition insights. Second, understanding the role of assumptions associated with limiting warming to below 2°C helps us identify the enabling conditions that are associated with realizing the climate outcomes. For instance, Figure 6 illustrates how pursing more optimistic policy design conditions and the availability of CDR would help with managing transition risks, such as transition costs and energy system transformation challenges (e.g., rates of change, the size of systems, the shifts in energy source dependence).

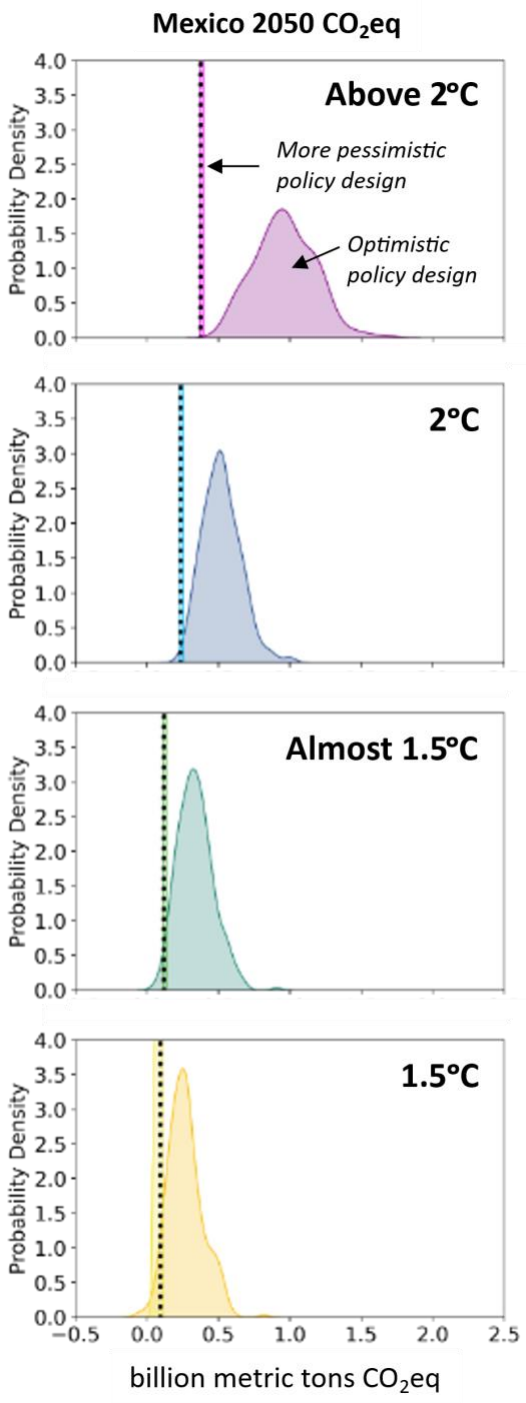


Figure 8. Potential Mexico 2050 distributions of cost-effective (least-cost) outcomes for GHG emissions that are consistent with increasingly ambitious individual global emissions pathways aligned with limiting global average warming to 2.5°C, 2°C, between 1.5°C and 2°C, and 1.5°C considering climate policy design and non-climate-policy uncertainties

Source: Rose et al (forthcoming).

Figure note: See note for Figure 6 for modeling details. The dotted line in the regional CO_2eq emission charts indicate the assumed 2050 emissions reduction goal. y-axis' units are probability densities for kernel density estimate distributions.

In summary, assessment of sub-global pathways highlights that there are many local and company-level emissions and activity transitions aligned with limiting warming to the Paris Agreement goals. The relationship between a global emissions future and local transitions is not 1-to-1. Instead, there are many local transition possibilities consistent with a global emissions pathway. Thus, the science does not provide guidance regarding a specific pathway for a company. Furthermore, the rate and composition of local transitions consistent with a global future can be very different from the global transition rate and composition. In the end, the Paris Agreement aligned cost-effective emissions outcome for a company is uncertain and highly variable, but bounded.

Key Scientific Observation 2: Global pathways aligned with limiting warming to 2°C and 1.5°C have influential but uncertain assumptions

Summary: Global emissions pathways aligned with limiting global average warming to 2°C and 1.5°C frequently have influential and unlikely policy and technology transition assumptions. These assumptions determine how emissions reductions are distributed across regions and sectors, and they significantly affect the feasibility of the pathway and the likelihood of achieving the corresponding temperature outcome.

Company implications: Policy design and technology availability and deployment assumptions are important to identify and evaluate. They are uncertainties companies cannot ignore.

Discussion

Global emissions pathway results scientifically consistent with limiting global average warming to 2°C and 1.5°C typically assume an unlikely immediate and comprehensive global climate policy with GHG abatement pressure globally and economy-wide—across countries, sectors, and all GHGs. They also typically assume globally cost-effective abatement coordination and have rapid advanced low-carbon technology deployment results, such as the early and substantial use of CDR, like bioenergy with carbon dioxide capture and storage (BECCS) or global afforestation (IPCC, 2018; Huppmann et al, 2019; Bauer et al, 2018; Riahi et al, 2022; Byers et al, 2022; EPRI, forthcoming, 2020, 2018). Note that global pathways to date have also tended to be too pessimistic about some adoption and cost decline assumptions, for example for wind, solar, and storage (e.g., Krey et al, 2019; Luderer et al, 2021).

Both policy design and technology assumptions are influential in the national and sectoral outcomes found in global pathways. For instance, these assumptions notably contribute to results suggesting decarbonization of global electricity faster than the rest of the economy, along with significant increases in the use of electricity in decarbonizing the rest of the economy. See, for instance, the recent 1.5°C global pathways assessed by the IPCC (Riahi et al, 2022; Byers et al, 2022), which by 2050 project approximately 100% to 300% increases in global electricity demand and dependence on electricity by the global economy—electricity's share of overall energy consumption (Figure 9). Similar results have also been found in earlier global emissions pathways consistent with the Paris Agreement temperature goals (EPRI, 2020, 2018). The assumed global, economy-wide decarbonization policy is incentivizing the use of low-carbon electricity, contributing to an increase in electricity demand and share, and supporting more rapid emissions reductions in the electric sector than the rest of the economy. In addition, the assumption of global abatement cooperation further accelerates electricity sector emissions reductions in lieu of more challenging and expensive reductions in other sectors around the world.

Sub-global analyses directly evaluating economy-wide versus sectoral decarbonization policies confirms this dynamic (e.g., EPRI, 2022b; SMARTargets Methodology Appendix B electricity generation emissions target setting example). These analyses consistently find more rapid decarbonization of the power sector when there is an economy-wide decarbonization by 2050 policy versus a power sector only decarbonization by 2050 policy. The economy-wide policy creates demand for low-carbon electricity and provides revenues that support more rapid low-carbon investments in the power sector and faster electric sector decarbonization.

The technology assumptions are also influencing the relative decarbonization roles of countries and sectors. For example, optimistic assumptions about the availability, compliance eligibility, cost, and public acceptability of CDR result in significant CDR deployments inside and outside the electric sector that influence national and sector emissions transitions by offsetting emissions throughout the world. Figures 6 and 8 are examples of how the distributions of potential transition system and cost implications can shift due to alternative policy designs—with global versus unilateral action and coordination, and the availability or not of CDR and land-related abatement.

The importance of policy design and technology uncertainty and the sensitivity of low-carbon transitions to alternative assumptions has been well studied and evaluated from global to company scales. In addition to the references above, see additional examples of global insights from Clarke et al (2014), Krey at al (2014), Clarke et al (2009), and Rose et al (forthcoming); regional and national insights from Calvin et al (2012), Cui et al (2021), EPRI (2023), Fawcett et al (2014), Schmalensee and Stavins (2013), and Weyant et al (2013); and company level insights from EPRI (2025, 2022a).

In summary, when using global emissions pathways, the assumptions need to be considered. In particular, global emissions pathway results for limiting global warming to 2°C and 1.5°C are based on policy assumptions and technology deployments that are highly uncertain. Future policy and technology conditions are important drivers of transition outcomes and essential uncertainties for companies to evaluate with impacts on transition challenges, trade-offs, risks, and viability for the power sector and across the economy.

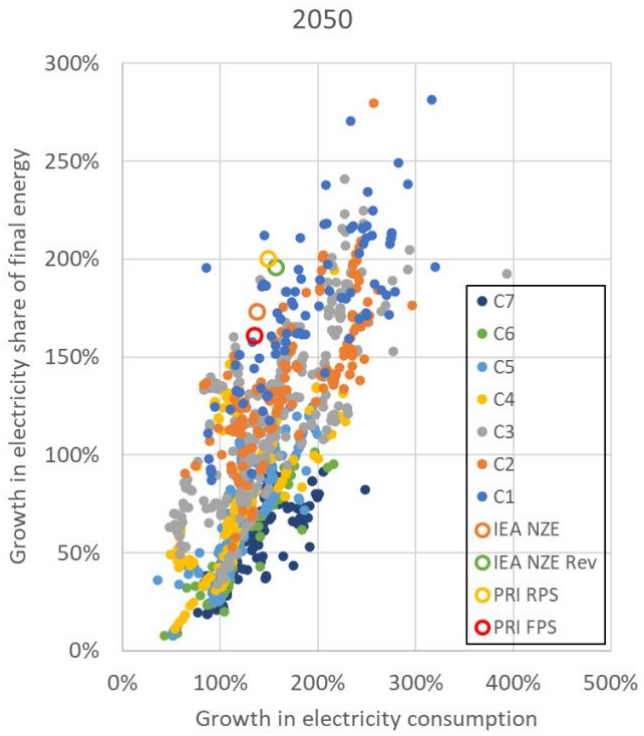


Figure 9. Global electricity consumption and share of final energy growth by 2050 by global temperature outcome

Sources: EPRI (forthcoming).
Figure note: Results based on assessment of recent IPCC (Byers et al, 2022; Riahi et al, 2022), IEA (2023, 2021), TPI (2023), and PRI (2021) pathways. Growth relative to 2015. C1 through C7 indicate the global average temperature outcome resulting from the emissions pathway scenario: C1 = limit warming to 1.5°C with no or low overshoot (>50% likelihood), C2 = return warming to 1.5°C after high overshoot (>50%). C3 = limit warming to 2°C (>67%), C4 = limit warming to 2°C (>50%), C5 = limit warming to 2.5°C (>50%), C6 = limit warming to 3°C (>50%), C7 = limit warming to 4°C (>50%), C8 = exceed warming of 4°C (≥50). C1 through C7 results from Byers et al (2022) and Riahi et al (2022); IEA NZE from IEA (2021); IEA NZE Rev from IEA (2023); PRI RPS and FPS from PRI (2021).

Key Scientific Observation 3: Alternative future conditions can have very different transition implications

Summary: Different future policy and non-policy conditions can have very different implications for companies in terms of transition opportunities, challenges, trade-offs, risks, and even pathway viability.

Company implications: It is essential to evaluate transition implications uncertainties and risks, considering uncertainty in decarbonization incentives, options, and other conditions, and identify and manage the risks for climate targets.

Discussion

The alternative global and local pathways consistent with limiting warming to the Paris Agreement temperature goal, or any global average temperature level, vary in their technological, energy system, and economic implications, as well as challenges, and even viability. See, for instance, examples for potential global transitions (e.g., Riahi et al, 2022; Bauer et al, 2018; IPCC, 2018; Clark et al, 2014; Krey et al, 2014; Clarke et al, 2009; EPRI, forthcoming, 2020, 2018; Rose et al, forthcoming), regional transitions (e.g., Bistline et al, 2024; Moreno et al, 2023; Calvin et al, 2012; Cui et al, 2021, EPRI, 2023; Fawcett et al, 2014; Weyant et al, 2013), sub-national transitions (e.g., Larson et al, 2021; EPRI, 2023; EPRI, 2022b), and company transition (e.g., EPRI, 2025, 2022a). Understanding the implications of alternative pathways empowers decision-making and dialogue by elucidating opportunities, trade-offs, and risks, and identifying enabling conditions and risk management strategies, including opportunities for collaboration.

Figure 6 above provides one example of the variation in implications. It shows wide distributions of possible electricity and energy system sizes in 2050 in each of the three regions shown for limiting warming to 2°C, as well as large variation in the potential regional economic transition costs. Likewise, behind the range of global net CO_2 emissions transition results shown earlier (Figure 4) are wide ranges of potential fossil energy and electrification transitions. For example, as shown in Figure 9 above, growth by 2050 in global electricity consumption and electricity dependence ranges from 90% to 320% and 90% to 280% respectively in IPCC 1.5°C (50% likelihood) pathways. Similarly, large variation in the growth in global fossil energy consumption and dependence as a share of total energy consumption from 2015 ranges from –15% to –90% and –30% to –90% respectively in IPCC 1.5°C scenarios (EPRI, forthcoming). These diverse outcomes for the same climate represent a wide array of potential electric and energy systems with their own transformation opportunities and challenges.

As already illustrated, policy design is another important factor. Different climate policy incentives and decarbonization options are consistently shown in the literature to have notably different impacts on emissions pathways, as well as technology deployments and retirements, low-carbon transition portfolios, and the economic transition implications. For example, Figure 6 above illustrates how different global policy designs can have a significant impact on the potential regional transition possibilities. In Figure 6, an optimistic policy with global economy-wide coverage and cooperation, global land carbon sequestration incentives, and energy-system CDR available, results in greater use of electricity, greater use of fossil energy, and lower economic transition cost risk. Meanwhile, a more pessimistic global policy design without these three policy design elements results in lower electricity use, lower fossil energy use, and significantly greater economic cost risk for some regions, such as shown for the EU, US, and China.

Sub-national and company-level analyses generate similar insights on the importance of policy design to decarbonization strategies, trade-offs, and risk (e.g., Larson et al, 2021; EPRI, 2025, 2022a, 2022b, 2023).

Global and national analyses frequently evaluate decarbonization transitions with different assumptions regarding available decarbonization options (e.g., Riahi et al, 2022; Davis et al, 2023; Blanford et al, 2022; Larson et al, 2021; Rose et al, forthcoming; Bauer et al, 2018; Krey et al, 2014; Clarke et al, 2014; Weyant et al, 2013). These analyses consistently find that more limited decarbonization option portfolios result in higher costs and more challenging system transitions for achieving the same emissions or climate objective.

Global pathway studies have also found increasing occurrences of model infeasibilities when attempting to limit global warming to 2°C and below with fewer decarbonization options (e.g., Bauer et al, 2018; Krey et al, 2014). Model infeasibility refers to when a model is unable to find a solution given the assumptions. Table 3 provides an example from one multi-model study that illustrates how the fraction of models that could solve decreased as the decarbonization options became more constrained. Results such as these highlight the importance of evaluating uncertainty in the availability of decarbonization options and understanding the implications of not having options, including the enabling role an option can play in facilitating achievement of a climate goal, the balancing of trade-offs, and the identification of robust strategies. See Key Scientific Observation #5 for discussion of robust strategies associated with below 2°C global transitions.

Table 3. Examples of feasible and infeasible scenario results from one multi-model global low-carbon pathways study

Source: Developed from Krey et al (2014).

Table note: Row labels refer to increasingly more stringent global climate policy in terms of CO_2 equivalent atmospheric concentrations in 2100. Column labels refer to sensitivities on low-carbon energy technology assumptions. Each box reports the number of feasible scenario results and the number of models attempting the scenario (i.e., # feasible / # attempted). * The specification for this scenario also included an assumption of faster improvements in the energy intensity of economic growth compared to baseline improvements. For additional scenario specification details and results, see Krey et al (2014).

Stanford Energy Modeling Forum 27th Study							
	Full default technology	CCS unavailable (fossil and bioenergy)	New nuclear unavailable and phase out of existing	Solar and wind electricity share constrained	Biomass supply constrained	CCS and new nuclear unavailable*	CCS and new nuclear unavailable, and solar, wind, and biomass constrained
Higher atmospheric concentration target (550 ppm CO_2eq)	13/13	12/12	11/11	11/11	13/13	12/12	6/9
Lower atmospheric concentration target (450 ppm CO_2eq)	10/11	4/11	9/10	9/10	9/11	6/11	0/10

Transition uncertainty affects potential outcomes and GHG targets for companies as well. For example, EPRI (2025 and 2022a) evaluated 2050 GHG target strategies for illustrative electric power companies and found that the emissions reduction outcomes varied with policy design and non-policy conditions, as well as varied between companies.

Uncertainty for setting a target implies that, once set, the costs and other implications of the target are uncertain, and thus there are risks that need to be assessed and managed. In setting targets, therefore, companies are in a decision-making under uncertainty situation (e.g., Tversky and Kahneman, 1974; Morgan, Henrion, and Small, 1992; Raiffa, 1997; Lempert, Popper, Bankes, 2003; Kalra et al, 2014; Morgan, 2017). In such circumstances, scenario analysis and robust decision-making (RDM) are valuable approaches for evaluating alternative potential outcomes and identifying robust strategies that occur consistently across futures. RDM evaluates strategies against possible futures to identify those that perform well across a wide range of scenarios. Furthermore, decision making under uncertainty, specifically with respect to climate management strategies, is an important application (e.g., Aldy and Gianfrate, 2019; Hall et al, 2012; Hallegatte et al, 2012; Heal and Millner, 2014; Manne and Richels, 1992; Schmalensee and Stavins, 2013).

In summary, companies need to evaluate the implications of different future conditions and transitions to understand and characterize the trade-offs and risks. Planning for one future is risky because other futures are plausible and imply different outcomes and strategies. Note that setting a target does not manage transition risk, but transition risk assessment can inform target setting. Furthermore, companies should evaluate and manage the risks associated with having GHG targets, including the risks from having and not having decarbonization options, which can affect the feasibility of targets. Finally, planning under uncertainty requires exploring different scenarios to identify possible strategies. Robust transition insights can be gleaned looking across the range of transitions and understanding the role of assumptions to identify enabling conditions and risk management strategies.

Key Scientific Observation 4: Transition opportunities vary by company

Summary: Decarbonization transition opportunities vary by company due to differences in, among other things, assets, resources, infrastructure, systems, markets, regulations, and customers. As a result, their transition options and risks differ; and, the same future target across companies is not cost-effective for society.

Company implications: Each company needs to evaluate its transition opportunities and risks.

Discussion

Global, sub-national, and company analyses have found that decarbonization opportunities, uncertainties, and risks vary by global region, national region, and company (e.g., Moreno et al, 2023; Riahi et al, 2022, Larson et al, 2021; Rose et al, forthcoming; EPRI, forthcoming, 2025, 2023, 2022a, 2020, 2018; Clarke et al, 2014; Rose et al, 2017). This is evident in differences in emissions reduction rates and in the different transitions in systems (e.g., energy and economy).

See Figure 7 above and Figure 10 below for examples of differences in sub-national electric power sector CO_2 emissions and electricity generation transitions respectively within the U.S. when transitioning to a

net-zero U.S. economy.[5] In Figure 7, for example, regions within the U.S. have different cost-effective (least-cost) CO_2 emissions transition starting points, transitions, and 2050 ending points. Similarly, in Figure 10, regions within the U.S. have very different low-carbon electricity generation transitions from 2020 to 2050 in terms of total generation and the mix of generation technologies. Also, in Figure 10, we observe that the regional low-carbon generation transitions are sensitive to the decarbonization options available, with the magnitude of the sensitivity varying by region. For instance, we find significantly greater use of electricity in all regions when decarbonizing the economy without CDR available (NZ-A versus NZ-L in Figure 10), but significant variation in the size of the responses and shifts in low-carbon generation mixes in the western U.S. versus the middle of the country versus the eastern U.S. The differences in sub-national decarbonization opportunities and sensitivity are due to differences in endowments (e.g., wind and solar irradiance resources, CO_2 underground storage capacity, energy infrastructure) and future options (EPRI, 2023). The regional differences in sensitivity to the alternative conditions imply that there are regional differences in transition risk.

Variation in decarbonization opportunities is evident for global regions in global emissions pathways data and company analysis as well (e.g., Byers et al, 2022; Huppman et al, 2014; IAMC, 2014; EPRI, 2025; EPRI, 2022a). Regardless of the model and assumptions, the cost-effective global solutions for limiting warming to 2°C and 1.5°C consist of different regional emissions transitions and contributions due to regional differences in endowments and future opportunities. For example, the cost-effective regional GHG reduction rates in 2050 differ from each other and from the global rate regardless of the model, assumptions, or global temperature target level (EPRI, 2025).

Meanwhile, analysis of illustrative companies that vary in size, energy use, emissions intensity, and growth opportunities, find differences in their decarbonization transitions and cost-effective contributions to aggregate emissions goals (EPRI, 2025). The cost-effective outcome for achieving a sector or economy-wide GHG goal is for individual company GHG reduction efforts to vary (EPRI, 2025). Thus, it is not cost-effective for the emissions outcomes to be identical across companies within a sector, within a country, or across countries. Deviating from the cost-effective solutions, by definition, will be more expensive for society and have additional trade-offs (cost and other). While typically not modeled, differences in other trade-offs across countries, regions, and companies, such as reliability, equity, and other societal goals, and how they are managed, can also contribute to different GHG strategies (e.g., Moreno et al, 2023). Furthermore, external feasibility factors can also vary by region and company, where some emissions reduction levels can be infeasible due to, among other things, regulatory constraints, or local trade-off related constraints, such as energy specific affordability and reliability priorities.

The results illustrating the differences in regional opportunities also highlight the enabling role policy can play. With uniform emissions reductions across companies not cost-effective for society (EPRI, 2025), policies that recognize company decarbonization opportunity differences and facilitate coordination can realize the cost-effectiveness benefits and help manage decarbonization transition costs. The differences in decarbonization opportunities also bring attention to one of the problems with company-level targets.

[5] The results in Figure 7 and Figure 10 are derived assuming a U.S. economy-wide emissions constraint, which reveals the least-cost role of individual regions within the U.S. for a given set of market, technology, and other assumptions.

On their own, they do not readily facilitate coordination across companies, sectors, and other actors, including regulators, policy-makers, customers, investors, and others that could be impacted.

In summary, regions, as well as companies, have different decarbonization transition opportunities and risks. As a result, it is not cost-effective, and may not be feasible, for all companies in a sector, or across sectors, to have the same GHG outcome. Companies should evaluate their individual low-carbon transition opportunities and risks; and, the public should expect, and want, companies to have different low-carbon transition and risk management strategies. Different strategies will emerge for different companies, and it is socially desirable to have companies with targets and strategies that consider their opportunities and differences. Asking companies to have the same outcome will result in additional transition costs and affect other societal priorities, like affordability, reliability, and just transitions, as well as potentially being intractable for some.

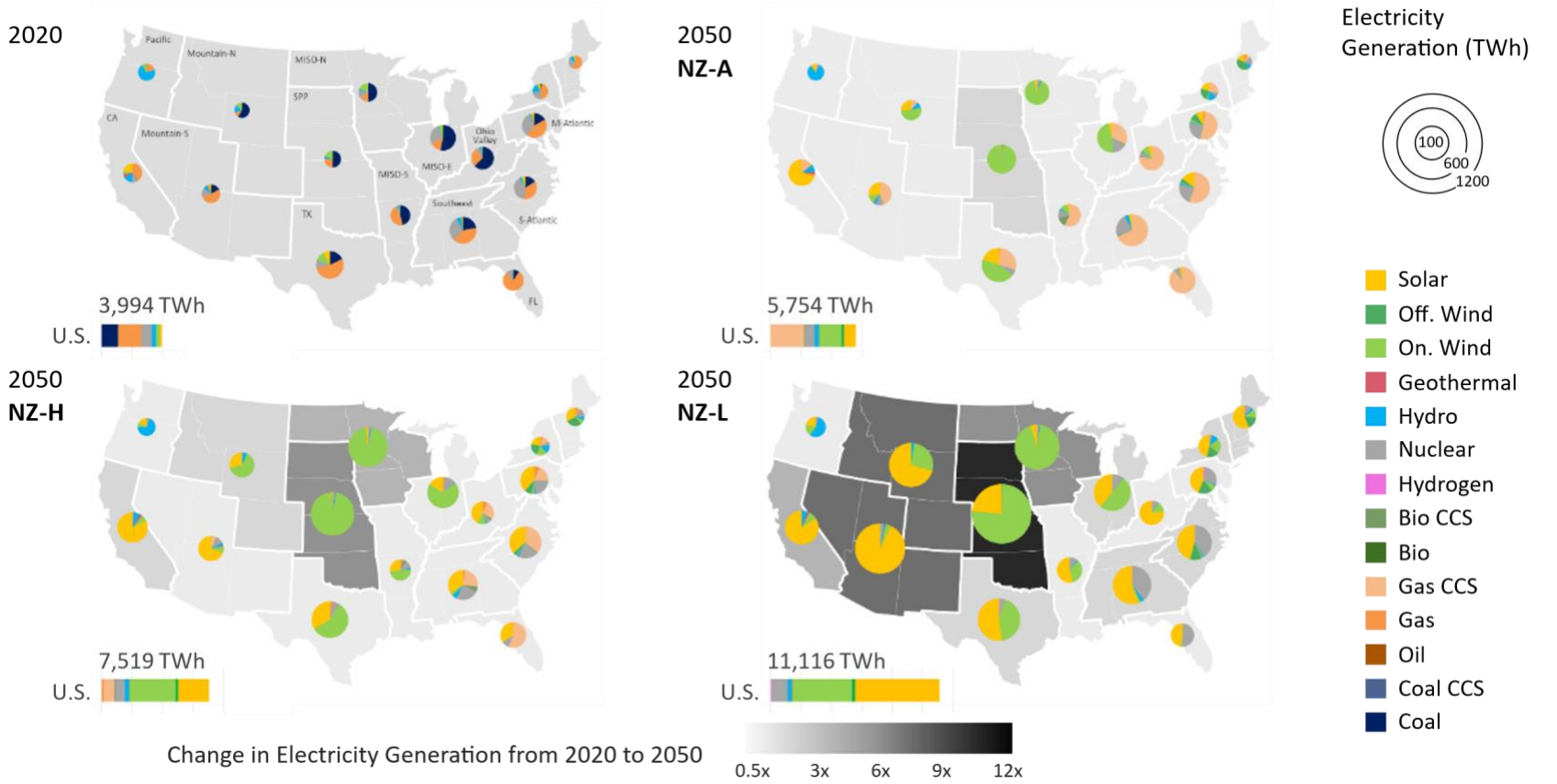


Figure 10. Three potential cost-effective U.S. regional electric power sector generation transitions for achieving a U.S. economy-wide net-zero CO_2 by 2050 goal under different technology conditions

Source: EPRI (2023).

Figure note: NZ-A is a "Net Zero-All options" future that assumes the availability of a broad set of decarbonization options. NZ-H is a "Net Zero-Higher cost" future that assumes higher costs for geologic storage of CO_2 (Carbon dioxide Capture and underground Storage, CCS), natural gas supplies, and biomass feedstock supplies. NZ-L is a "Net Zero-Limited options" future that assumes geologic storage of CO_2 (CCS) is unavailable and biomass feedstock supplies are limited. See EPRI (2023) for regional results for the full set of energy, economic, and environmental results. These results are derived assuming a U.S. economy-wide net zero emissions constraint, which reveals the least-cost role of individual regions within the U.S. for a given set of other assumptions. Low-carbon technologies are deployed on a least-cost basis taking into account input and output market conditions and emissions and deployment constraints.

Key Scientific Observation 5: Global pathways provide high-level guidance but have significant limitations in informing companies

Summary: Global emissions pathways have significant limitations as benchmarks for guiding or evaluating companies. For instance, global modeling does not model individual companies, their markets, or their potential transitions. However, global pathways can provide high-level guidance on aggregate levels of emissions reduction effort for a global temperature goal.

Company implications: Global pathways can help identify aspirational levels of effort and facilitate coordination across companies and sectors, but it is important to recognize their limitations. In particular, it is impractical to expect all individual companies to achieve the aggregate outcomes or to evaluate companies relative to these outcomes.

Discussion

Global modeling and pathways are not designed to inform or evaluate company decision-making. They can provide guidance and facilitate cooperation on aggregate levels of decarbonization needed to meet global temperature goals. They can also provide qualitative strategic guidance. However, their limitations with respect to companies must be considered in applying and interpreting comparisons to global pathway results. In particular, since global pathways do not reflect individual company markets and transition opportunities, companies will need to evaluate their specific opportunities. Furthermore, the public should expect companies to follow transitions consistent with their opportunities and risk management that will, more often than not, be different from the transitions found in global pathways.

Global pathway limitations

Evaluations of the thousands of global emissions pathways in the literature (IPCC, IEA, and more) has shown that the pathways have the following significant limitations as benchmarks for guiding or evaluating company emissions strategies (EPRI, forthcoming; EPRI, 2020):

1. They do not model companies and their actual markets,
2. Applying the same aggregate benchmark implies inefficient uniform action,
3. Some companies operate in more than one sector and are not represented by the sector aggregation modeled,
4. Broad ranges of outcomes are consistent with a climate goal,
5. The results are contingent on the policy and technology assumptions,
6. The results are missing important company-level uncertainties (e.g., policy design, local conditions),
7. The below 2°C pathways have unattainable characteristics, and
8. Sub-global results are particularly problematic (e.g., sector, region, technology).

These insights on the limitations of global pathways follow from the key observations above and the global, sub-global, sub-national, and company pathways literature that was assessed, including Byers et al (2022), Riahi et al (2022), Bauer et al (2018), Davis et al (2023), Larson et al (2021), Rose et al (forthcoming), EPRI (forthcoming, 2023, 2022a, 2022b, 2020, 2018), Huppmann et al (2019), IPCC (2018), Fawcett et al (2014), IAMC (2014), Clarke et al (2014), Krey et al (2014), Luderer et al (2014), and Weyant

et al (2013), Clarke et al (2009), Bistline et al (2024), Moreno et al (2023), Calvin et al (2012), Fawcett et al (2014).

First, and foremost, a key limitation of global pathway modeling in informing corporate strategy is that companies are not modeled. Global pathways modeling does not represent individual companies, their markets, or their transition opportunities. Only hypothetical, aggregate markets and decisions are modeled, not actual markets and the company decision-makers in those markets. For instance, a global model might portray a U.S. nationwide electric sector, which is very different from the actual regional power markets in the U.S. and the individual utilities in each of those regional markets. Individual companies, their markets, their regulatory constraints, and their decarbonization transition opportunities and potential decisions are therefore not captured or evaluated in global pathways.

Furthermore, applying global modeling results to all companies within an economic sector implies economically inefficient identical action by all companies. It does not consider company differences and implicitly suggests uniform company decarbonization action that is not cost-effective, and potentially infeasible for some. This ignores differences in opportunities and risks between companies.

In addition, as discussed above, and shown in Figure 4 and Table 2, there are many global emissions pathways consistent with any climate goal; thus, it is difficult to justify choosing one as a definitive benchmark. Also, as noted, global pathway results are contingent on policy and technology assumptions that are uncertainties companies should evaluate and address in planning. Additional uncertainties relevant to companies are also not represented in the global pathway result ranges (e.g., local policies and operational conditions).

Attainability assessment of pathway characteristics, assumptions, and outcomes has also found many of the Paris Agreement consistent global emissions pathways in the literature to be difficult to attain. See, for instance, the 2015 to 2020 net CO_2 emissions peaking years found in the global emissions pathways consistent with limiting global warming to 1.5°C (Table 2). This peaking profile is inconsistent with observed historical emissions and trends (Figure 4). Furthermore, as discussed, the pathways are based on an unlikely climate policy assumption with immediate and comprehensive global economy-wide coverage and cooperation, which is inconsistent with current policies and trends and highly unlikely in the foreseeable future.

There are also substantive challenges in trying to translate global emissions pathways into actions for nations and sectors, and even more so for companies. Sub-global results from global modeling (e.g., sector, country, technology) are tempting points of comparison; however, they are even more problematic as benchmarks than aggregate global results. First, as discussed, there is not a 1-to-1 relationship. Instead, there are many sub-global transitions consistent with a global emissions pathway (Key Scientific Observation #1). Second, not only are the global pathway issues noted above also relevant sub-globally (i.e., not modeling companies, many pathways, unattainable pathways, etc.), but sub-global results are dependent on the global and economy-wide assumptions modeled, including regional technology availability and change, regional policy stringency and design, market conditions, and demands for good and services. The sub-global results from global pathways have these assumptions baked in. They are contingent on them. Instead, these assumptions are uncertainties that companies should be evaluating.

Equally important is that comparing to sub-global results, like electric sector emissions intensity or energy supply results from a global scenario, can be misleading. As discussed earlier (Key Scientific Observation #2), the global scenarios typically exhibit strong electric sector decarbonization and electrification growth responses that are dependent on (a) assumed global economy-wide policies that incentivize the use of low-carbon electricity, (b) global trading of emissions allowances that identify the lowest cost decarbonization globally, and (c) optimistic assumptions regarding the deployment of advanced low-carbon technologies. National-level emissions and economy transition results (total and sectoral) have been shown to be heavily influenced by global emissions permit trading, economy-wide cooperation, and the relative technology availability and improvement assumptions.

Use of and guidance from global pathways

Despite their limitations for guiding or evaluating companies, the global pathways can be useful for identifying aggregate, generic aspirational levels of effort, facilitating coordination, and identifying types of transition strategies. However, the ranges consistent with a temperature goal cannot be ignored.

When using global emissions pathways, ranges are the most scientifically defensible representation of the set of information available in the literature. This conclusion was found to be robust from assessing subsequent vintages of global emissions pathway data from the IPCC's 1.5°C Report, the IPCC's Fifth Assessment Report, and the IPCC's Sixth Assessment Report (EPRI, 2018, 2020, and forthcoming respectively).

This conclusion is a result of the underlying multi-model global pathway data not being amenable to the calculation of statistics, which is required for identifying more (and less) likely outcomes in which we would have greater (less) confidence. Specifically, the underlying data is not a random sample due to sampling issues. The sampling issues include disproportionate representation of models and assumptions, truncated data, and incomplete sampling of the distribution of possibilities. For instance, in the IPCC's Sixth Assessment Report data (Byers et al, 2022; Riahi et al, 2022; Guivarch et al, 2022a) only two models (of over 30 in the literature) are providing 63% of the 1.5°C low to no overshoot pathways (EPRI, forthcoming). Thus, these two models have a disproportionate influence on the transition insights and conclusions. Furthermore, only an ad hoc set of potential future conditions are represented. The data is not fully sampling potential future conditions and there is uneven consideration of alternative assumptions by models. As such, the data is truncated, incomplete, and imbalanced. As a result, there is unequal consideration of models and assumptions across climate levels and limited representation of uncertainty, which complicates characterization of potential outcomes and uncertainty, as well as comparison across categories to evaluate the implications of different climate outcomes.

These data sampling issues imply that the data is not the random sample needed to allow for identifying means and medians, as well as percentile ranges (e.g., 5^{th} to 95^{th} and 25^{th} to 75^{th} percentiles) and outliers. While not necessarily intended, percentile ranges imply lower weight and importance to values outside those ranges. The data, however, do not support assigning lower weight to values outside the percentiles or labeling those results as outliers.

Together, the data issues imply that the full range of results should be used when communicating transitions consistent with a global average temperature outcome. EPRI (2020) and EPRI (2018) found the same sampling issues in evaluating previous IPCC global emissions pathway datasets (Huppmann et al,

2019; IAMC, 2014) and drew the same conclusion that ranges were the most defensible way to communicate the variation in results.

There are two ways to use the global ranges—quantitatively and qualitatively. Quantitatively, the ranges identify some of the potential global transitions consistent with a climate goal and, as such, can provide aggregate, generic aspirational guidance. Thus, in seeking or evaluating corporate alignment with any global temperature, we must recognize that there is more than one way to be aligned, conditions could be different than those assumed, and the different conditions imply different aligned pathways and challenges. The last point is particularly important. It implies that global pathways can help identify aspirational goals and coordinate effort; however, we must recognize what they do not tell us. Specifically, they provide no information at all about a company's actual transition opportunities. Thus, global pathways can be helpful in providing direction, but we need to acknowledge their limitations. In particular, we should not expect companies to be able to achieve the global outcomes, nor necessarily want them to for economic efficiency reasons, given differences in opportunities. In addition, companies need to evaluate their individual opportunities, challenges, and risks to be able to identify what they can do under different uncertain conditions.

The global pathways, however, do not provide robust quantitative strategy guidance to individual companies. The set of figures and tables above showing wide ranges of sub-global outcomes and shifts in outcomes due to alternative assumptions (policy and non-policy) and models illustrate the sensitivity of sub-global results, as well as how misleading it can be to pick one or two sets of results as benchmarks. In addition, sub-global and sector modeling has shown that stylized structural elements and dynamics typical in global modeling can influence the decarbonization transition results. For example, the decarbonization portfolio can be impacted by the temporal resolution of the electric sector modeling (Bistline, 2021).

Qualitatively, the pathways highlight the importance of considering uncertainty and differences in opportunities due to different conditions globally and sub-globally. They also provide qualitative strategic guidance. Global pathway results highlight the role that comprehensive GHG policies and coordination can play in facilitating cost-effective transitions and achieving global temperature ambitions. They also provide robust qualitative transition guidance for companies.

While the specific values from global emissions pathways should not be interpreted as requirements or guides for companies, analyses have found robust insights across global low-carbon transitions that can be helpful to company thinking and strategy development, as well as stakeholder understanding and evaluation of corporate targets and strategies (e.g., Byers et al, 2022; Riahi et al, 2022; Davis et al, 2023; DeAngelo et al, 2021; EPRI, forthcoming; EPRI, 2018; Clarke et al, 2014). The robust insights are types of transitions that consistently occur regardless of the model or assumptions. For instance, as shown in previous figures and tables, there are large ranges of quantitative transition outcomes (emissions, energy, economic) consistent with limiting global warming to 2°C or 1.5°C. However, regardless of the model or assumptions, the results consistently find increasing reliance on electricity, increasing low-carbon technology deployments, use of carbon dioxide removal, and energy conservation and efficiency improvements. Global pathways also find decreasing but continued reliance on fossil fuels. In addition, results consistently show that there is substantial uncertainty in the levels, rates, and composition of the transition in terms of technology portfolios, energy systems, and the structure of economies. Improving use of multi-model global emissions pathway ensembles to identify robust insights has also been discussed by others (Guivarch et al, 2022b).

In summary, global pathways have significant limitations as quantitative benchmarks for company climate targets and strategies. However, global emissions pathways provide generic aspirational quantitative guidance for companies, as well as robust qualitative insights. Overall, when using global emissions pathways quantitatively to inform corporate strategy, the full ranges of the pathways consistent with a global temperature outcome should be used and the limitations of the global pathways considered. Among other things, this means recognizing that global pathways do not represent companies; thus, opportunities, challenges, and strategies will vary from the global pathway and by company and uncertainties and risk need to be evaluated.

Furthermore, in assessing the consistency of company targets with international goals, it is more appropriate to compare to the relevant global total net CO_2 or non-CO_2 pathway ranges. Sub-global emissions results from global pathways are problematic. Results like electric power CO_2 emissions or intensities, or oil and gas methane (CH_4) emissions, are too heavily dependent upon global policy and non-policy assumptions that are uncertainties companies need to evaluate. Using the sub-global results as benchmarks would require the assumed conditions to be true. Instead, using total global emissions pathways can help provide high-level guidance on the level of emissions needed for a given temperature goal and guide economy-wide decarbonization efforts. Qualitatively, robust types of transitions represent reliable guides for the types of company strategies consistent with Paris Agreement aligned global emissions futures.

Key Scientific Observation 6: Practical issues defining a company's circumstances affect GHG abatement opportunities

Summary: There are practical issues to consider when setting and pursuing GHG targets. For instance, adequate GHG inventories are needed and whether the emissions are regulated should be considered.

Company implications: Assessment of target setting capacity and a company's current situation are necessary for informed setting and pursuing of targets.

Discussion

In addition to the scientific observations discussed thus far that are relevant to setting and pursuing GHG targets, there are high-level practical issues for companies to consider in deciding whether and how to set a target for a given emissions source category (EPRI, 2022c, 2022d, 2022e). Specifically, the following conceptual and practical issues should be considered by a company:

- Can GHG accounting approaches adequately support target setting?
- Are the emissions material to the company's GHG accounts?
- Is the emissions source regulated by Paris Agreement aligned policy?
- Does the source have a target, and is it a SMARTarget?
- Does the company have sufficient control or influence over the emissions?

These issues suggest that the practicality of setting targets for some sources should be considered first. Below, we briefly discuss each issue. Note that, a company need only consider these issues with respect to each emissions category (not emissions at the individual source, asset, or facility level).

Can GHG accounting approaches adequately support target setting?

A GHG inventory is a pre-requisite for GHG target setting. A company needs to characterize its historical and current emissions to be able to track their evolution, as well as the company's progress towards future GHG targets. A GHG inventory could include a company's direct and indirect emissions, where direct emissions, referred to as scope 1 emissions, are emissions from sources that are owned or controlled by the company; and, indirect emissions are emissions that occur at sources not owned or controlled by the company that are either associated with purchased or acquired electricity, steam, heating, and cooling (scope 2) or are associated with other activities upstream and downstream from a company that represent "value chain" emissions (scope 3).[6]

GHG inventory approaches and capabilities can facilitate, bound, and/or hinder GHG target setting. In general, target setting should be consistent with GHG accounting methodologies. Sources that are more difficult to characterize due to, for instance, methodology or data limitations, present challenges that should be considered by companies in setting targets. Inventorying methods and capabilities need to be taken into account. Indirect GHG accounting approaches are based on assumptions about markets and technologies (e.g., demand, prices, fuel mixes, emission intensities, marginal emissions). Depending on the company, indirect emissions may also be challenging to calculate due to the need to coordinate and gather data from beyond the company's boundaries. For instance, it may not be feasible for a reporting entity to calculate some of the categories of scope 3 indirect emissions simply due to the lack of data—activity data or emissions factors. Reporting companies will need to consider data availability (i.e., are they able to collect high-quality data?) in determining whether to include a scope 3 source (WRI/ WBCSD, 2011). Emissions categories difficult to calculate due to data limitations can preclude target setting, but they also represent opportunities for data development and collection that can enable future target setting.

There are also different accounting approaches, and different ways of categorizing GHG emissions based upon business models, which creates reporting and communications inconsistencies (while at the same time providing flexibility). For instance, T&D utilities account for line loss emissions as scope 2, while vertically-integrated utilities might include these emissions under scope 1. In addition, there are gaps in current accounting methods on how to account for emissions of "common carrier" energy infrastructure, such as natural gas pipeline and electric system transmission and distribution infrastructure, which complicates target setting for these assets (EPRI, 2024).

Finally, there is also the issue of scope 3 emissions double counting. It is impossible to prevent double counting of some indirect scope 3 emissions, as the scope 3 emissions of different entities are linked through markets and overlap under existing accounting approaches (EPRI, 2022c). This raises economic inefficiency issues as well for trying to manage emissions (discussed below). For more details on issues on GHG accounting for electric power and gas utilities, see EPRI (2021b).

[6] Whether emissions are categorized as direct or indirect depends on the organizational boundary approach selected by a company for its GHG inventory. Under the GHG Protocol, companies can choose between the equity share approach or the control approach—where control can be defined as either operational or financial. This choice determines which operations are included in the inventory and, consequently, whether emissions from those operations are classified as direct (Scope 1) or indirect (Scopes 2 and 3).

Are the emissions material to the company's GHG accounts?

Another important consideration is the materiality of the emissions. Note, however, that emissions materiality is a different concept from the financial materiality of emissions. The former refers to the significance of a source in a company's GHG inventory. The latter refers to the potential financial implications of having emissions. For example, in the case of the latter in the electric power industry, emissions from purchased power that may not be controlled by the buyer should be evaluated for financial materiality, possibly using an analysis of low-carbon transition risks like that discussed in Step 4 of the SMARTargets Methodology. If the risk from purchased power is found to be financially material, the company might consider setting a target as a means of managing the risk. Emissions on their own are not good risk indicators. They simply indicate that a company might have a risk and it should be evaluated. Determining transition risk and its materiality requires transition risk analysis to identify risks and risk management strategies, as well as to evaluate their implications and determine their materiality.

On the other hand, the materiality of emissions is used to refer to whether an emissions category's share of total emissions is significant enough to justify the resources needed for developing a target and management strategy[7]. For example, a company may choose not to manage their emissions from waste generated in operations (scope 3, category 5) if it accounts for less than 5% of their total emissions footprint. The Climate Registry and the European Union Emissions Trading Scheme (EU ETS) use 5% materiality thresholds for assessing emissions reports (The Climate Registry, 2019; European Commission, 2020). Currently, however, there is no universally agreed upon emissions materiality threshold.

Is the emissions source regulated by Paris Agreement aligned policy?

Climate policy and regulations can affect emissions across the economy. Policy and regulations also affect company decarbonization opportunities. Economic efficiency (i.e., cost-effectiveness) in reducing emissions over time is an important issue given the deep decarbonization implied by the Paris Agreement temperature goal and, therefore, the need to manage costs. There are two economic efficiency issues to consider:

- Valuing/managing the same emissions multiple times, and
- Managing goods and services versus emissions directly.

First, an emissions source may already be regulated or priced, or will be in the near future, via policies such as standards, GHG taxes, or emissions caps. If so, it would be economically inefficient for a company to manage these emissions as well. The CO_2 externality is already internalized into the company's decision-making by the policy and the company target could constrain regulatory compliance (EPRI, 2021a). Valuing the same carbon multiple times is not economically efficient. The result is increased costs without additional emissions reduction benefits. There are numerous examples of multiple pricing of the same CO_2 molecule with policies applied across the value chain—from fossil resource extraction pricing of carbon content, CO_2 valuation at the point of combustion, and valuing implied production emissions associated with procured goods and services.

[7] In the context of GHG inventory development and verification, materiality refers to a threshold above which error or omission could affect the reliability of the inventory report.

Thus, in deciding on whether to set a target, a company should first consider whether the category is regulated; and, if so, if the emissions reductions due to the regulation are aligned with the Paris Agreement temperature goal. If so, the company could communicate that the source is already managed through Paris Agreement aligned policy. If a company, however, still wishes to set a target for a source already under policy, the company would want the target to be cost-effective and therefore set to be consistent with the policy. This could be achieved in low-carbon transition risk analysis that evaluates GHG targets taking into account regulation as a reference condition or exploring it as an uncertainty for the future.

Furthermore, the economics literature shows that pricing/constraining emissions directly is more cost-effective than indirect management of those emissions, where the latter occurs when trying to manage emissions through technology preferences, such as renewable or clean energy standards, or goods and services procurement and sales, such as purchased and sold electricity and gas (e.g., Fawcett et al, 2014). From a societal cost point of view, strategies and policies focused directly on the emissions sources are more cost-effective and preferred. Also, this inefficiency becomes even more severe when the source emissions are highly uncertain. It is more difficult and less efficient to manage an uncertain and variable source indirectly than directly.

Does the source have a target, and is it a SMARTarget?

Some emissions, by definition, are associated with the activities of others. Do these sources have targets? If so, a company would want to consider the targets and communicate them to others. Are the source targets SMARTargets that consider uncertainty and company-specific opportunities and align with science and the Paris Agreement? If so, a company might conclude that, given the direct source's targets, and efficiency considerations, a separate target is not needed. However, if a company still wished to set a target, they would want to consider coordinating their target with the direct source's target for cost-effectiveness.

Does the company have sufficient control or influence over the emissions?

Some companies do not control some sources of emissions. For example, a company may own all or part of a GHG emitting asset but they may not fully control its utilization, and therefore they do not fully control its emissions. In some cases, power system operators determine when generation units owned by utilities are dispatched and operated. For instance, the PJM regional transmission organization in the U.S. operates in thirteen states plus Washington D.C. and includes over 1,200 power plants owned by multiple power companies. In this competitive wholesale power generation market, power is dispatched across the many power plants by PJM based on least cost. Thus, individual plant and company emissions are out of company control. This environment highlights control, as well as emissions reduction coordination and economic efficiency challenges. Companies can replace the emitting resources with low-carbon alternatives or offset the emissions, but each of those options has its own implications for customers and system reliability, not to mention that offsetting uncertain emissions means uncertain offset expenditures.

Another example of lack of control is when emissions are dependent on the size of the market, which is determined by forces beyond a company's control. For example, the GHG emissions associated with the distribution of gas and electricity, such as fugitive methane emissions or transmission line losses respectively, are a function of the volume and composition of the gas and electricity respectively being

moved through the market, which is determined by other decision makers (suppliers, consumers, system operators) and drivers, such as policies affecting supply and demand. Additional lack-of-control examples include regulations that mandate the provision of service to new customers, system operator retirement protocols and reliability reserve requirements, consumer consumption or technology preferences, and assets that are jointly owned.

Setting and pursuing a GHG target for emissions a company does not control is more challenging. Among other things, it runs up against the economic efficiency issues noted above that are associated with managing indirect and uncertain emissions over time.

Companies, however, may be able to influence emissions they do not control by, for example, procurement choices or informing policy. They may also be able to address these emissions by purchasing emissions offsets or collaborating with those in control to coordinate and encourage reductions. To properly inform a company's thinking, they could consider scenarios to evaluate the implications of emissions reductions for uncertain conditions out of their control. In general, control and influence realities should inform how to set targets and strategies for achieving them.

In summary, companies need to consider practical issues in deciding whether and how to set a target, such as whether GHG accounting is sufficient, whether the emissions are significant enough to merit targets and strategies, whether and how emissions are impacted by regulation or a source's targets.

3. REQUIREMENTS FOR A SCIENCE-BASED METHODOLOGY

Based on assessing all the relevant science and the key scientific observations above, we can derive scientific and operational requirements for any corporate target setting, target evaluation, or transition risk assessment methodology to be science-based, or more accurately informed by science since the science provides guidance but is not able to tell us exactly what each company should do.

Scientific Requirements

From the scientific assessment above, the following scientific requirements emerge for a methodology to be "science-based" (Figure 11):

- **The methodology must have science-based alignment with a global temperature.** This entails recognizing the following: there are broad ranges of global and sub-global pathways consistent with a global temperature goal, assumptions matter and are uncertainties that need to be evaluated, the different pathways aligned with a global temperature vary in their implications, and global pathways in general have severe limitations as company benchmarks but the pathways can provide high-level guidance. The limitations of global pathways as benchmarks include that they do not represent individual companies, their markets, or their transition opportunities and the global pathways are missing company-relevant uncertainties, such as policy design and local factors (e.g., market, customer, resource, policy). Global pathways, however, can help identify aspirational goals and coordinate effort even though they do not provide information about actual company opportunities and risks.

- **The methodology must facilitate science-based decision-making.** Insights from the relevant science highlight that science-based decision-making requires consideration of uncertainty regarding potential future conditions; recognition that companies have different transition opportunities due to differences in, among other things, assets, markets, regulatory structure; accounting for and informing the multiple social priorities that a company is responsible for beyond decarbonization, such as affordability and reliability; providing companies with flexibility to respond as the future unfolds; and, supporting company resilience by helping a company identify robust overall strategies to different futures.

In more detail, the five elements for science-based decision-making in Figure 11, and the Key Scientific Observations from which they emerge, are as follows:

1. **Consider uncertainty** – A company needs to consider uncertainty about the future when setting a target. Specifically, a company needs to consider the plausible alternative futures because different conditions can imply different practical GHG targets, transitions, and strategies, as well as risks. *Follows from Key Scientific Observations 1, 2, 3, and 4.*
2. **Recognize uniqueness** – A company needs to consider its transition opportunities and constraints and risks, which can vary by region and company due to differences in endowments, assets, systems,

markets, regulatory structure, future options, and more. *Follows from Key Scientific Observations 4 5, and 6.*

3. **Account for multiple priorities** – A company needs to consider the set of objectives and social priorities that they are supporting, which could include affordability, reliability, economic development, equity, and sustainability. *Follows from Key Scientific Observations 3 and 4.*
4. **Provide flexibility** – With the future uncertain, a company needs flexible strategies, with contingency plans and options available, to allow the company to respond and adjust to the different futures that could unfold. *Follows from Key Scientific Observations 1, 2, 3, and 4.*
5. **Support resiliency** – A company's GHG target should be consistent with overall corporate risk management and support company resilience to potential futures. *Follows from Key Scientific Observations 1, 2, 3, and 4.*

Many existing company GHG target setting and assessment methodologies do not include the above elements. They do not consider uncertainty about future potential conditions and risks, differences in low-carbon transition opportunities between companies, other societal priorities and opportunities for balancing trade-offs, and potential strategies for managing risk. All of these elements are required for identifying science aligned and actionable company targets and strategies. Together, the five elements ensure that real-world factors are taken into consideration from which practical solutions can be developed that can facilitate progress.

Note that, while considering the elements above allows companies to evaluate their unique decarbonization opportunities and risks, companies with similar business activities, emissions, uncertainties, and objectives, might have similarities in how they address the elements. For instance, they may consider targets for similar emissions categories, evaluate similar types of policy design and non-policy uncertainties, and have similar objectives. However, differences can still exist in how they specify their uncertainties, their decarbonization options, their regulator and customer priorities, and in what they perceive as a risk.

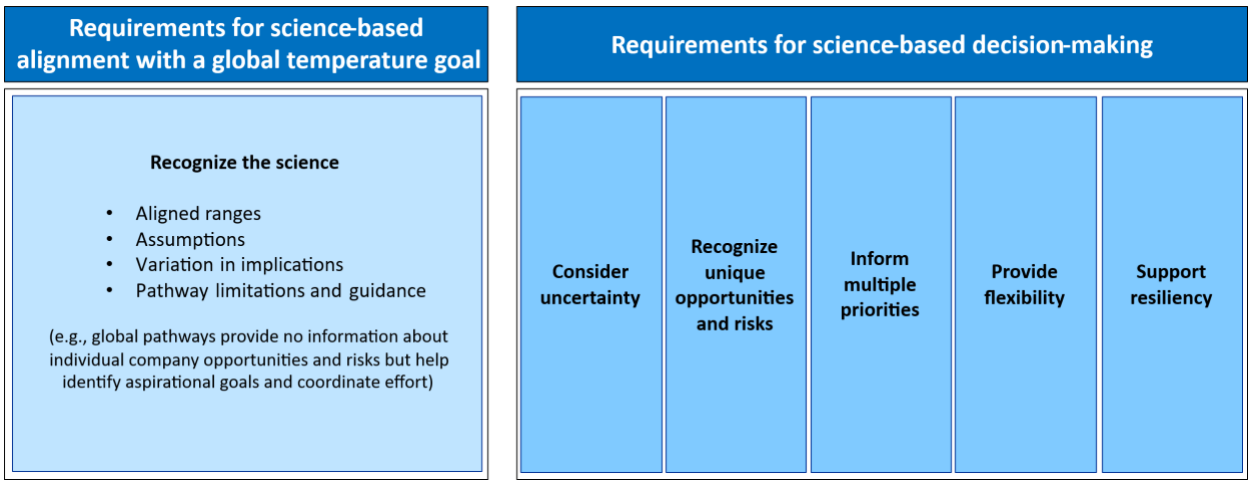


Figure 11. Requirements for a methodology to be "science-based"

The scientific requirements above follow from the Key Scientific Observations. They also follow from a set of key technical principles for target setting and low-carbon transition risk methodologies that EPRI had

derived previously from assessing the science. These principles have been found to be robust across assessment of different vintages of global emissions pathways (EPRI, forthcoming, 2020, 2018). Specifically, the following technical principles have already served as a helpful checklist for educating stakeholders, evaluating existing methodologies, and developing new methodologies (e.g., EPRI, 2022d; TCFD, 2020; EPRI, 2018):

1. Are the following uncertainties considered and how?
    a. Uncertainty in the relationship between global average temperature and emissions
    b. Uncertainty in the attainability of global emissions pathways
    c. Uncertainty regarding future climate policy designs
    d. Uncertainty regarding future non-climate-policy conditions (e.g., markets, technology)
2. Are global scenario results used and how are the problematic issues addressed?
3. How is the company-specific context considered?
4. Is a uniform GHG target explicitly or implicitly imposed across companies, or are goals allowed to vary from one company to the next?
5. Given uncertainties, does the approach provide flexibility for adjustment over time?
6. Is quantitative comparison of alternative potential strategies possible?
7. What is the approach for evaluating strategy robustness?
8. How are the set of company and societal objectives considered?

Operational Requirements

The Key Scientific Observations and scientific requirements above, along with the needs of business integration, also provide guidance on the functionality required from a science-based methodology. Specifically, the methodological design needs to achieve the following:

1. Inform the identification of actionable targets and strategies for each company,
2. Help a company assess and manage low-carbon transition risk,
3. Help a company integrate GHG abatement into strategic planning,
4. Help a company communicate the most ambitious level of GHG reductions they can achieve under different conditions and the role of enabling conditions for greater ambition,
5. Assist with climate-related transition risk disclosure, and
6. Facilitate cost-effective economy-wide decarbonization.

For instance, the first operational requirement follows from the need to recognize individual company uniqueness in transition opportunities. The second and fourth operational requirements, on the other hand, follow from the need to consider uncertainty, provide flexibility, and support resiliency, as well as recognition of the limitations of global pathways. The third requirement is based on the need to integrate with existing corporate planning processes, as is the requirement for supporting climate risk disclosure.

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