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Xcel Energy’s electric carbon emissions reduction trajectories in the context of 1.5°C and 2°C warming pathways

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Brian O’Neill

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Executive Summary[1]

In 2015 the Paris Agreement established the goals of limiting global average warming to well below 2°C and pursuing efforts to limit warming to below 1.5°C. A large and growing number of scenarios have been developed by the climate research community that explore global energy and emissions pathways that would achieve those goals. We draw on the most recent database of such scenarios to update a previous analysis of Xcel Energy's emissions reduction goals[2] in light of evolving climate science. We assess the outlook for the role of the US electricity sector in current economy-wide and global emissions pathways and compare it to Xcel Energy's near-term resource plans to 2030.

We find that global scenarios that achieve the 1.5°C goal span a range of US/North America electricity sector emissions reductions by 2030 of about 65-85%. Xcel Energy's emissions reductions to date have exceeded those of the US electricity sector as a whole, and its projected trajectory to 2030 under current approved resource plans falls within the range of global scenarios that achieve 1.5°C. Scenarios achieving the 2°C goal have a wider range of reductions (about 40-85%). In scenarios achieving either goal, electricity sector emissions fall faster than economy-wide emissions, a robust feature of mitigation scenarios, which typically rely on low carbon electricity to achieve climate targets.

The new scenarios also show that due to the minimal progress on global emissions mitigation over the past decade, it is increasingly difficult for the climate change science community to develop feasible scenarios that achieve the 1.5°C goal. Emissions in these scenarios fall relatively rapidly after 2030 to reach net zero between 2035 and 2045. Furthermore, the 1.5°C goal remains plausible only by overshooting that temperature level and returning to it later in the century. Even in this case, there are few scenarios that achieve it and those that do can raise concerns about the feasibility of technology deployment assumptions for CCS, renewables, and nuclear by 2030.

We do not assess Xcel Energy's 2030-50 future pathway in this analysis. Historical trends, climate science and our understanding of global scenarios continue to evolve, so this analysis is best understood as an evaluation based on current information. Xcel Energy's planning scenarios will likewise continue to develop as the science, technology, policy landscape, and system needs change.

Methods: This study draws on a large scenarios database from the Scenario Compass Initiative,[3] an activity organized by the scientific community to collect, evaluate, and make available greenhouse gas emissions scenarios. SCI evaluates these scenarios for consistency with recent global energy and emissions trends and feasibility of assumptions about near-term global technology deployment.[4] For this analysis, a subset of these scenarios is selected that is consistent with recent trends, reports results for the US or North America regions, and does not assume substantial net negative emissions in the electricity sector.

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[1] *Xcel Energy's electric carbon emissions reduction trajectories in the context of 1.5°C and 2°C warming pathways*. Brian O'Neill, Pacific Northwest National Laboratory, June, 2026.

[2] *Xcel Energy carbon emissions targets and limiting warming to less than 2 degrees C*. Brian O'Neill and Steve Hedden, University of Denver, 2018.

[3] Scenario Compass Initiative (SCI), https://scenariocompass.org/.

[4] *Mitigation benchmarks from the 2025 community update of global emissions pathways*. Keywan Riahi et al., Research Square, 2026.

1.0 Supporting Analysis

The methodology for this analysis is described in detail in section 2. Briefly, it assesses long-term, global scenarios produced by the climate change science community that achieve either the 1.5°C or 2°C Paris Agreement goals. These scenarios are developed with computer models that project emissions for regions around the world. The projections are based on simulating the production and consumption of energy, food, transportation and other goods. The analysis focuses on model results for the US and, when US results are not available, North America (defined as the US + Canada). These two model regions are the closest match to Xcel Energy's geography. Scenario results can be interpreted as average outcomes for these regions as a whole.

A key feature of the analysis is that it is based on a large database of scenarios from the Scenario Compass Initiative (SCI, 2025) that has been evaluated for consistency with recent global energy and emissions trends, feasibility of assumptions about near-term global technology deployment, and implications for several measures of sustainability (Riahi et al., 2026). Using only scenarios that are consistent with recent trends avoids the problem that many outlooks have already become out of date by assuming substantial global emissions mitigation has already begun and missing the rapid real-world rates of change in technology costs and deployment. What constitutes an up-to-date scenario will evolve over time, and the SCI plans to release annual updates to its evaluation of the database.

For this analysis, a subset of these historically vetted scenarios is selected that reports results for the US or North America regions, is consistent with recent electricity sector emissions in those regions, and does not assume substantial net negative emissions in the electricity sector. The subset consistent with the 1.5°C goal consists of four scenarios from the Network for the Greening of the Financial System (NGFS) – specifically, their Net Zero 2050 and Low Demand scenarios (implemented in two different models). As described further in section 1.2, although these scenarios are consistent with recent global emissions and energy system trends, the SCI feasibility evaluation raised concerns about their assumed CCS, renewables, and nuclear capacity in 2030. The set of selected scenarios that are consistent with the 2°C goal is larger (26 scenarios) and from a wider variety of sources.

The following sections describe global emissions pathways, the comparison of Xcel Energy's electric emissions reduction trajectory to regional electricity sector emissions pathways, and related results for economy-wide emissions, negative emissions, and electricity demand in these scenarios.

1.1 Global emissions in scenarios achieving 1.5°C and 2°C goals

Contrasting global scenarios based on up-to-date assumptions with those that are now out of date illustrates the increasing challenge of achieving the 1.5°C and 2°C goals. Scenarios that are consistent with recent global emissions and energy system trends have higher near-term emissions and therefore steeper emission reductions before 2050 in order to achieve these goals, especially for 1.5°C (Figure 1). Most notably, scenarios in which substantial reductions have already begun to occur are inconsistent with recent experience. These scenarios were the only ones that were able to achieve the 1.5C goal with no or limited overshoot of that warming level. As a result, only scenarios with more substantial overshoot remain feasible (Riahi et al., 2026).

1.2 Comparison of Xcel Energy trajectory to 1.5°C and 2°C scenarios

Starting with the sets of globally vetted scenarios that achieve the Paris Agreement goals, a subset of each was selected as suitable for comparison to Xcel Energy's emissions reduction trajectory based on currently approved resource plans through 2030 (see section 2.2 for the selection methodology). The comparison (Figure 2) shows that 1.5°C scenarios span a range of US/North America electricity sector emissions reductions by 2030 of about 65-85%. Xcel Energy's emissions reductions to date outpace those that occur in these scenarios as well as observed reductions in historical data.[1] Its emissions trajectory to 2030 aligned with current approved resource plans[2] falls within the scenario range. Emissions in these scenarios fall relatively rapidly after 2030 to reach net zero between 2035 and 2045. This is earlier than found in an analysis of electricity sector emissions in a previous generation of 1.5°C scenarios, in which net zero was reached beyond 2045 (O'Neill and Hedden, 2018). Scenarios achieving the 2°C goal have a wider range of electricity sector reductions in 2030 (about 40-85%) and reach net zero somewhat later.

It is noteworthy that there are only four model runs suitable for the 1.5°C analysis, despite the more than 200 scenarios that achieve the 1.5°C goal in the SCI database and report results for the US or North America. As described in section 2.4 (see Table 3), the scarcity of suitable model runs is mainly a result of the large number of scenarios that did not pass the SCI vetting procedure because they are inconsistent with recent emissions and energy system trends. Up-to-date scenarios in the scientific literature that can achieve this goal are scarce. As mentioned above, there are no such historically vetted scenarios that achieve 1.5°C with no or limited overshoot of that warming goal. There are only 23 model runs that achieve it with higher overshoot and report results for either the USA or North America. Only four of those do so without substantial net negative emissions in the electricity sector.

These four runs are for two models (REMIND, MESSAGE) simulating two scenarios each: the Net Zero 2050 and the Low Demand scenarios from the Network for Greening of the Financial System (NGFS; Table 1). The Net Zero 2050 scenario features ambitious mitigation with rapid electrification combined with decarbonization of electricity production, including through the use of CCS. The Low Demand scenario shares these characteristics but also explores the implications for mitigation efforts of significantly lower energy demand. Although all four model runs based on these scenarios passed the SCI vetting criteria, they were flagged by the SCI with concerns about the feasibility of the technology deployment assumptions for CCS, renewables, and nuclear. These concerns are the result of projected capacities in the near term that are inconsistent with existing capacities, current project announcements or market outlooks, and estimated project lead times (Riahi et al., 2026; see section 2.1 for more details). One model (MESSAGE) was assigned "high" concerns about assumed CCS deployment and "medium" concerns about nuclear, wind, and solar deployment in 2030. The other model (REMIND) was assigned "medium" concerns for assumed CCS, nuclear, and solar deployment. This limited set of model runs reflects the increasing difficulty of designing feasible global scenarios to meet the 1.5°C warming goal as substantial global mitigation efforts are delayed.

The difficulty of identifying feasible 1.5°C scenarios also emphasizes the importance of assessing 2°C scenarios for context. The SCI database includes 26 model runs across the US and North American regions suitable for that analysis (Table 3). However these scenarios also raise feasibility concerns: 19 of these model runs raise "high" concerns (mainly due to

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[1] Reductions in 2025 in the US electricity sector as a whole were about 48% relative to 2005 (EIA, 2026), compared to Xcel Energy's reductions of about 68%.

[2] Additional details on the trajectories are found in the Data Summary and resource plans are found in the Clean Energy Vision section of Xcel Energy's 2025 Corporate Sustainability Report.

assumptions about nuclear or CCS expansion), and another three raise “medium” concerns. The SCI team notes the lack of low emissions scenarios that meet plausibility criteria, calling for new modeling efforts to fill this gap (Riahi et al., 2026).

The rate of increase in electricity generation from renewables in both the 1.5 and 2C scenarios highlights the technology challenges represented by these mitigation pathways. Solar and wind in the US and North American regions increase rapidly (Figure 3). In the 1.5C scenarios, solar provides 10-30% of generation by 2030 and 30-50% by 2040, while wind increases nearly as fast, reaching 10-25% of generation in 2030 and 20-35% by 2040. In the 2C scenarios, increases are more moderate but still substantial, reaching about 10-20% for both technologies in 2030, and covering a wide range of 15-50% in 2040. For both climate targets coal and gas generation shares decline, although less rapidly in 2C scenarios.

1.3 Economy-wide emissions

To put the US/North America electricity sector emissions reductions in context, Figure 4 shows economy-wide carbon emissions reductions for the same set of scenarios. Economy-wide emissions decline more slowly than emissions in the electricity sector, reflecting the strong role that decarbonization of electricity plays in emissions reductions for the region. In the 1.5°C scenarios, economy-wide reductions reach 50-60% in 2030 (compared to 65-80% in the electricity sector), and net zero is achieved after 2045 (about a decade later than the electricity sector). In the 2°C scenarios, reductions are 15-55% by 2030 (compared to 40-85% in the electricity sector) and net zero is not reached until after 2050.

1.4 Net negative emissions and carbon capture and storage (CCS)

Scenarios that exclude net negative emissions in the electricity sector (see section 2.3 for a discussion of this metric), like those used in the comparison to Xcel Energy reductions, may differ systematically from those that include them. This is in fact the case for 1.5°C scenarios (Figure 5). Scenarios that exclude net negative emissions have deeper reductions through 2030 than those that do not, meaning that the Xcel Energy reduction trajectory is compared to the more stringent set of mitigation pathways. Specifically, the range of emissions reductions in 2030 across all vetted scenarios is about 40-85%, as compared to 65-85% for scenarios that exclude net negative emissions. The scenarios that lie above the 65-85% range in 2030 generally compensate for these higher emissions with negative emissions in later decades.

In 2°C scenarios, the difference is less clear. The range of reductions in 2030 with or without net negative emissions is similar, although the pathways that exclude net negative emissions are concentrated around deeper reductions by that time.

1.5 Electricity demand

Demand for electricity plays a critical role in electricity sector emissions pathways. Scenarios generally anticipate rising electricity consumption (Figure 6), mainly in the 20-60% range by 2050, with some higher and lower exceptions. These trends reflect the increasing electrification of energy demand in ambitious mitigation scenarios.

1.6 Figures and tables for the Supporting Analysis

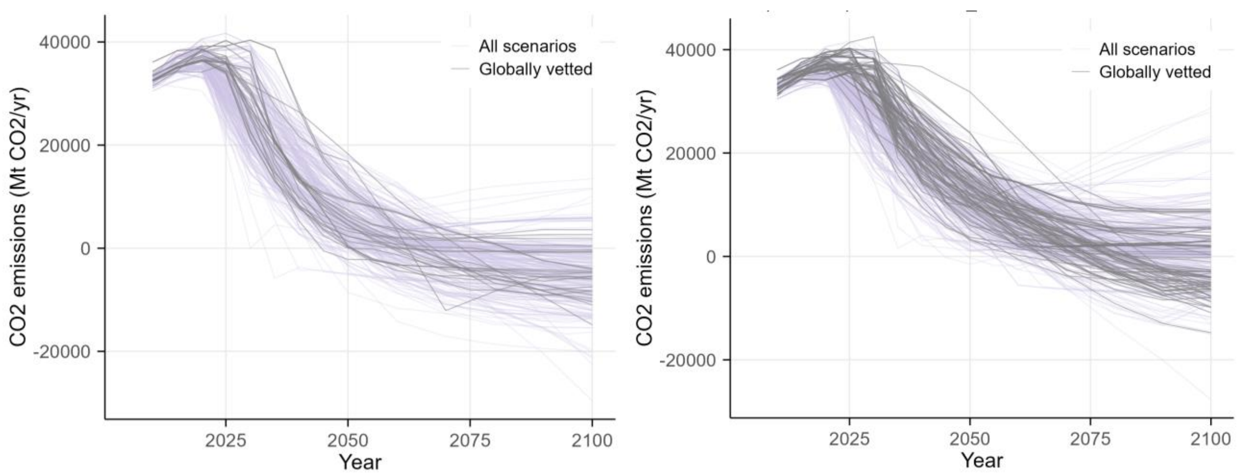

Figure 1: Global carbon emissions pathways with and without vetting

Emissions pathways are global carbon emissions from energy and industry for scenarios from the SCI database that are consistent with the 1.5°C (left) and 2°C (right) warming goals. Vetted emissions pathways (in gray) are consistent with recent global emissions and energy system trends. Other pathways (in purple) include out-of-date assumptions. Vetted pathways are higher in the near-term (2025-2030) and fall more steeply before 2050. These scenarios are inherently uncertain because they depend on model-based projections that assume specific future technology deployment rates, policy actions, and emissions reduction pathways that may prove infeasible or inconsistent with real world trends and constraints.

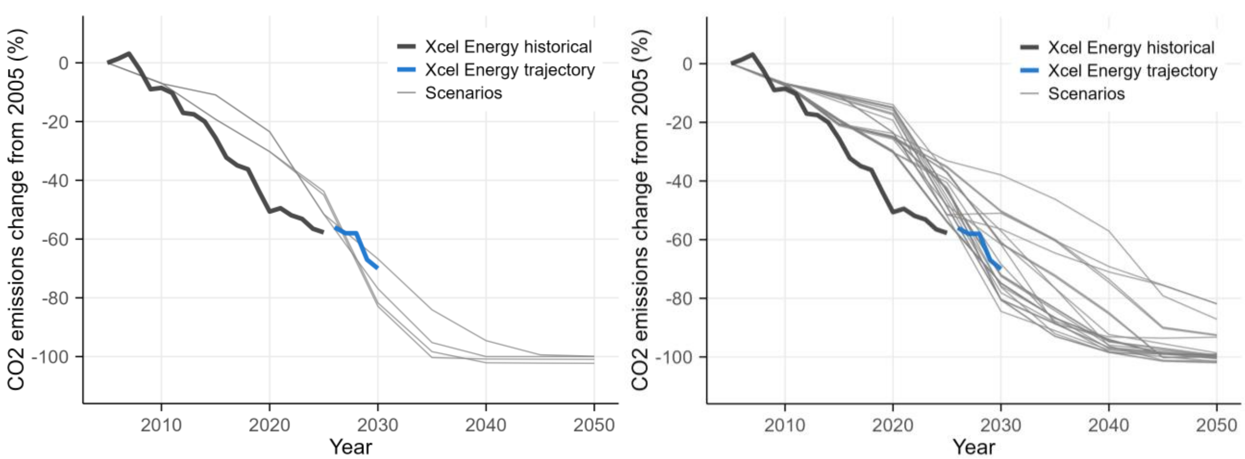

Figure 2: Xcel Energy carbon emissions reductions compared to SCI electricity sector emissions pathways

All emissions are expressed relative to their level in 2005 for comparability. Emissions pathways (scenarios) are for the US and North American electricity sector from global scenarios selected for this comparison that achieve the Paris Agreement 1.5°C (left) or 2°C (right) goals. Scenarios are from the Scenario Compass Initiative (SCI) database and are a subset of those used in Figure 1 that pass additional screening criteria as described in the main text.

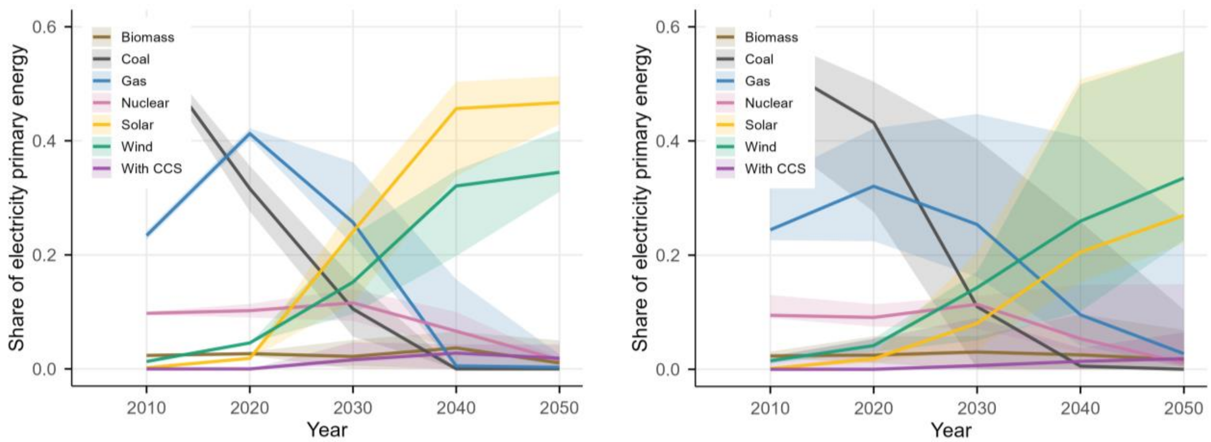

Figure 3: Shares of primary energy for electricity production by technology

Shares are for the US and North American electricity sector from global scenarios selected for this comparison that achieve the Paris Agreement 1.5°C (left) or 2°C (right) goals. Shaded areas show the range across scenarios; solid lines show the median share at each time point. The "With CCS" category cuts across all other categories. Scenarios are the same as those shown in Figure 2 for electricity sector emissions.

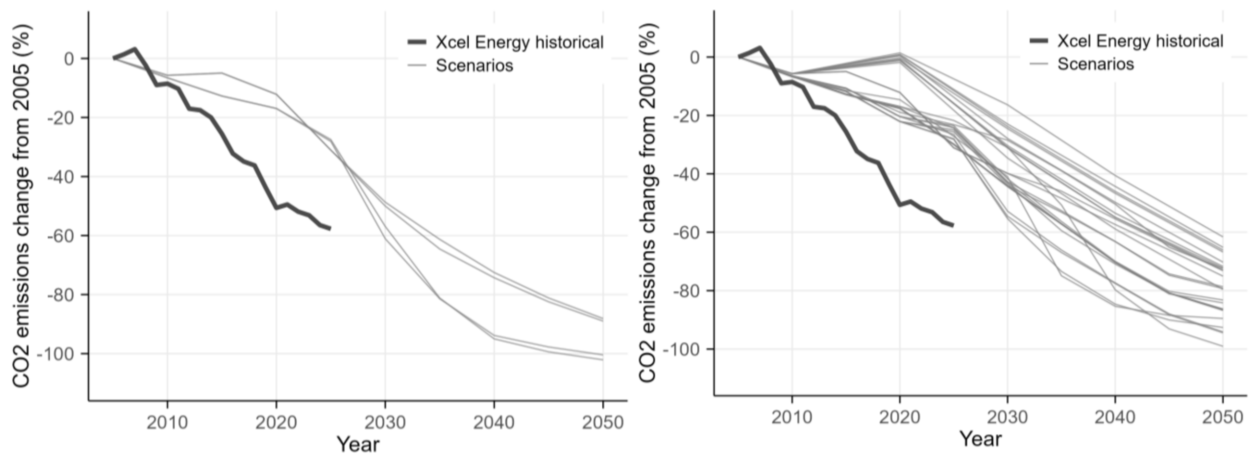

Figure 4: Economy-wide carbon emissions pathways

Emissions (except for Xcel Energy historical) are from energy and industry for the USA and North America regions in global scenarios that achieve the Paris Agreement 1.5°C (left) and 2°C (right) goals. Scenarios are the same as those shown in Figure 2 for electricity sector emissions.

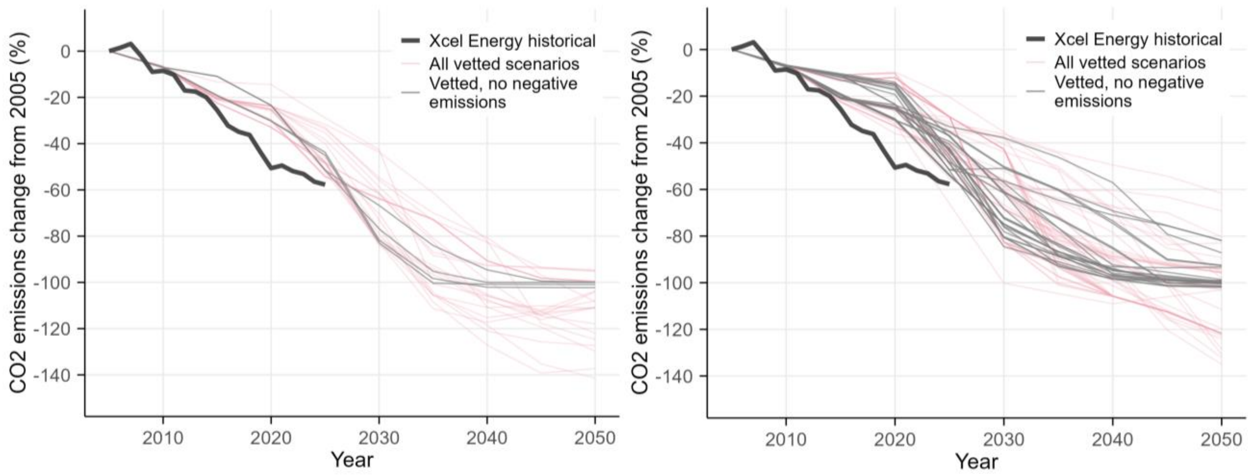

Figure 5: Electricity sector carbon emissions pathways with and without excluding net negative emissions

Emissions pathways in gray are from the same scenarios shown in Figure 2.

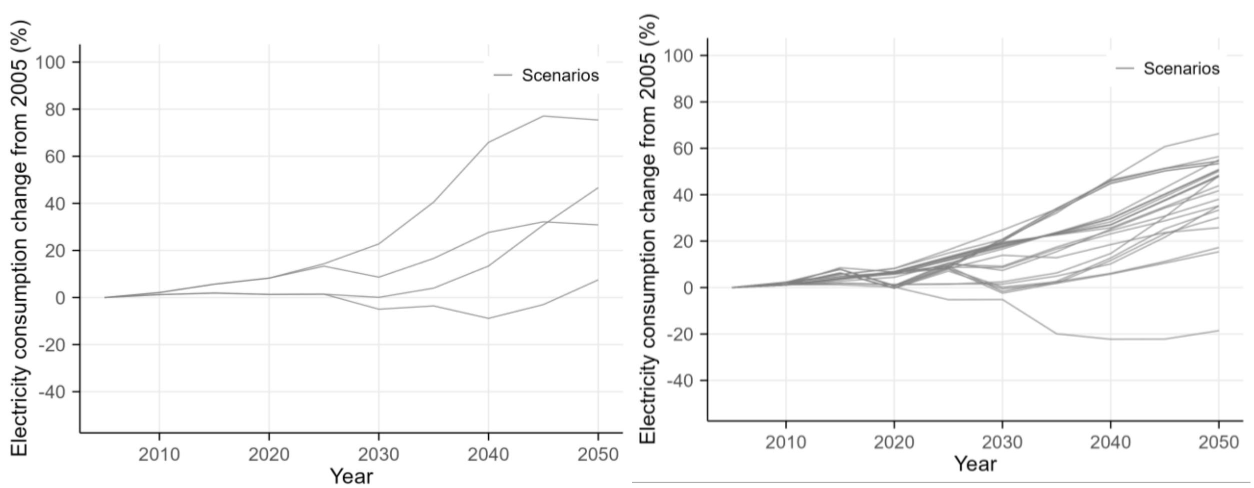

Figure 6: Electricity consumption pathways

Electricity consumption (final energy) is for the USA and North America regions in global scenarios that achieve the Paris Agreement 1.5°C (left) and 2°C (right) goals. Final energy is the amount of electricity consumed after it has been produced, transmitted, and distributed to consumers. Scenarios are the same as those shown in Figure 2 for electricity sector emissions.

Table 1: Model runs based on NGFS scenarios

Scenario	Model	Region	Description
NGFS Phase 5: Net-Zero 2050	MESSAGEix-GLOBIOM	NAM	A transition “as orderly as still possible;” ambitious climate policies introduced immediately; relies strongly on decarbonizing the electricity supply, increasing electricity use, increasing energy efficiency; carbon sequestration technologies used to accelerate decarbonization
	REMIND-MAgPIE	USA	
NGFS Phase 5: Low Demand	MESSAGEix-GLOBIOM	NAM	Similar to Net-Zero 2050, with additional significant behavioral changes in energy consumption leading to lower demand
	REMIND-MAgPIE	USA	

From Hayez et al., 2025, for Net Zero 2050; Richters et al., 2024, for Low Demand.

2.0 Methodology

This section provides a detailed description of the SCI database, its supplementation with the NGFS database, and the scenario selection process used in this analysis.

2.1 The SCI emissions scenario database

The Scenario Compass Initiative (SCI) is an activity organized by the scientific community involved in scenario development and use to collect, vet, and make available greenhouse gas emissions scenarios. It succeeds previous emissions scenario databases that were developed as part of assessment reports from the Intergovernmental Panel on Climate Change (IPCC). The SCI is intended as a continuously updated database with annual releases of vetted scenarios. The 2025 release, documented in Riahi et al. (2026), contains more than 1500 scenarios: all scenarios from the IPCC Sixth Assessment Report (AR6) database, plus more than 350 scenarios published more recently. Scenario data are publicly available through an online dashboard.[1]

The SCI vets scenarios for historical consistency, evaluates them for feasibility and sustainability, and also categorizes them according to warming outcomes. Historical vetting assesses scenarios for consistency with global CO_2 emissions from energy and industry, and with global energy system characteristics over the period 2010-2025. Emissions, total final energy, and primary energy from coal, oil, gas, and nuclear are all required to be within 25% of observed values (with a wider allowance for the Covid year of 2020). We employ only scenarios that have passed all criteria for historical vetting.

Evaluation of feasibility focuses on the assumed pace of technology deployment through 2030. Thresholds for build-out rates of nuclear, renewables, and CCS capacity are defined (with those for CCS extending to 2040) that trigger either medium or high feasibility concerns. These thresholds are based on data on current capacities and project announcements, estimates of typical project lead times, and, for technologies that can be deployed more quickly (wind, solar), market outlooks for near-term demand.

Evaluation of the sustainability implications of mitigation measures is based on bioenergy use, food security consequences of mitigation, and scale of geological carbon storage. Bioenergy use can result in loss of habitat and biodiversity; mitigation can raise food prices and therefore impact food security; and CCS comes with risks from storage including CO2 leakage and impacts to groundwater quality and environmental conservation (Gidden et al., 2025). The SCI evaluation sets literature-based thresholds for annual bioenergy use, annual food consumption, and cumulative CO2 storage in scenarios.

SCI also categorizes scenarios by warming outcomes, using an updated version of the IPCC AR6 categorization. Categories are based primarily on peak warming and secondarily on end of century warming. We define (and select) 1.5°C and 2°C scenarios using the SCI categories in Table 2.[2] These two groups of scenarios provide the starting point for the analysis.

[1] Scenario Compass dashboard: https://scenariocompass.org/scenario-dashboard

[2] Selecting scenarios based on the SCI categories gives slightly different results than selecting scenarios based directly on their peak and end of century warming levels. Based on correspondence with the database developers, this difference is likely due to SCI's use of smoothed versions of projected warming rather than the raw results available in the database.

2.2 Regional and sectoral pathway selection

From the group of all historically vetted 1.5°C and 2°C scenarios from the SCI database, we select scenario results at the regional and sectoral level that provide the closest comparison to Xcel Energy territory and electric emissions. Since the national level is the finest geographic resolution for which results are available, ideal outcomes are for the electricity sector in the US region. However, not all scenarios report results for the US because the models used to develop scenarios vary in their geographic representation. We therefore also consider results for North America which, defined as the US and Canada, is very similar to the US alone: the Canadian electricity sector is about 14% the size of the US sector in terms of final energy provision and only about 1% in terms of carbon emissions.[1] In addition, we consider the OECD, since a larger number of models report results for this aggregate region.

The SCI vets scenarios for consistency with recent emissions and energy system trends at the global level, but this does not exclude scenarios that may still be inconsistent at the regional and sectoral level of interest for this analysis. We therefore apply an additional vetting step at this level. Since the decadal US and North American electricity sector emissions trend has been downward since 2005, we exclude any scenarios that have an increasing emissions trend over a 10-year interval during the historical period (2010-2025). This excludes obviously inconsistent scenarios from the analysis.

2.3 Net negative emissions constraint

We further restrict scenarios to those without substantial net negative carbon emissions in the electricity sector in the region of interest at any time through 2100 (see Figure 5 for a comparison of scenarios with and without net negative emissions). The rationale for this restriction is to exclude pathways that delay emissions reductions in the first half of the century and compensate later with substantial negative emissions. Net carbon emissions are the sum of all absolute emissions from the electricity sector minus the amount of carbon captured and sequestered (via CCS) by the sector. CCS at fossil fuel-based power plants reduces emissions from those plants, potentially to zero. CCS at biomass-based power plants is considered a negative emissions technology. Without CCS, carbon emissions from biomass energy production are assumed to be zero, since they are offset by carbon uptake from the atmosphere in the production of the biomass fuel. With CCS, the carbon emissions are eliminated, so the net effect is atmospheric carbon removal.

Net negative emissions for the electricity sector as a whole therefore imply that at least some bioenergy CCS is employed by the sector. Net zero (or even positive) emissions may or may not be achieved with net negative emissions technology: bioenergy CCS could be employed but not at large enough scale to more than offset positive absolute emissions from other power plants. In the SCI scenarios selected for comparison to Xcel Energy's emissions reduction trajectory, no substantial net negative emissions are employed (Figure 7).

2.4 Selection process implications for scenario counts

The results of the scenario categorization and selection process are shown in Table 2. The number of model runs within a given climate goal category varies by the region of interest, since not all models report results for the same regional breakdowns. The larger (more aggregate) the region, the more results are available. For example, while there are 292 and 451 runs that report results for the World (for 1.5°C and 2°C, respectively), there are only 22 and 78 runs reporting results for the US. The SCI vetting process reduces these numbers substantially – to 6 and 16 available for the US for 1.5°C and 2°C scenarios, for example – reflecting the large

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[1] Based on data from EIA and CEDS, described in a section below.

number of scenarios in the IPCC AR6 database, as well as more recent scenarios, that are already out of date. Eliminating scenarios with inconsistent emissions trends in the electricity sector reduces this number further for 2°C scenarios; eliminating scenarios with substantial net negative emissions in the electricity sector reduces the number for both climate goal categories.

As a result, the final set of model runs suitable for this analysis that report results for the US is just 2 for 1.5°C and 8 for 2°C. As described above, we therefore also include results of model runs reported for North America (these are independent results, since no models report results for both the US and North America).[1] The analysis was also carried out including additional scenarios reported for the OECD region, but since it led to no changes in conclusions, final results are based only on the US and North America.

2.5 Extrapolation to 2005 base year

The earliest results for scenarios in the SCI database are generally reported for 2010. In order to express these scenarios relative to values in 2005, to be comparable with Xcel Energy's emissions reduction trajectories, they are extrapolated backward using historical data. Emissions data is taken from the Community Emissions Data System (CEDS, 2025), an ongoing activity by the scientific community to create a continuously updated database of greenhouse gas and air pollutant emissions at the national and sectoral level. Energy data is taken from the Energy Information Administration (EIA, 2026), which publishes annual, national-level energy data over the past several decades.

Extrapolation is done by calculating the difference between modeled and observed values in 2010 and adding that difference to observed values in 2005. This method makes the conservative assumption that model-observation differences are neither better nor worse in 2005 than they are in 2010.

[1] In the SCI database, results from the REMIND model for the NGFS scenarios were reported for both the US and North America, but the North America results were simply a repeated set of the US results and therefore were dropped from the analysis.

2.6 Figures and tables for the Methodology

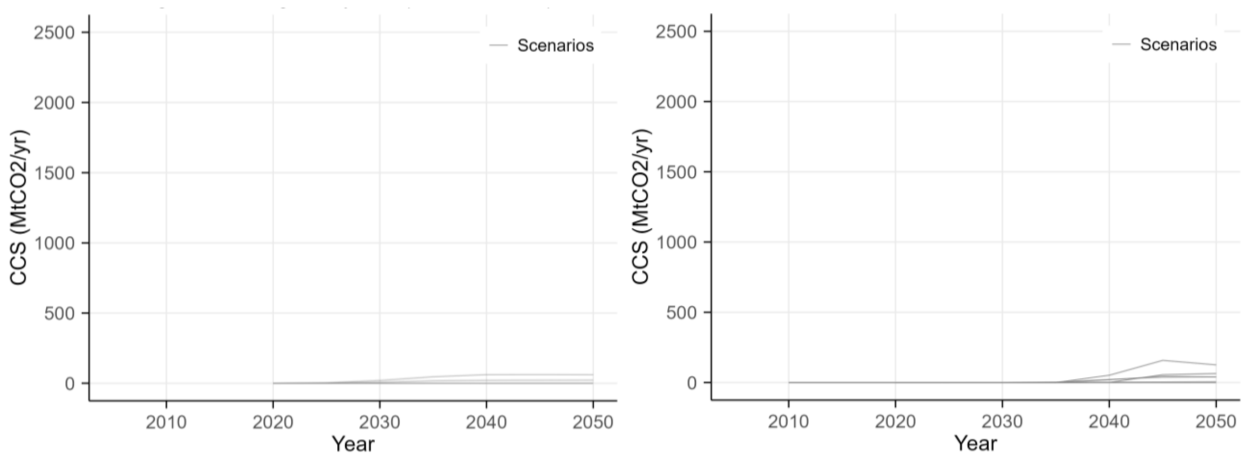

Figure 7: CCS deployment pathways

Emissions captured and stored through CCS technologies coupled with electricity production from biomass in 1.5°C (left) and 2°C (right) scenarios, for the same scenarios shown in Figure 2. The y-axis scale is consistent with Figure 2 for comparability. Data on electricity sector emissions captured with CCS were not available from SCI. They were obtained from the NGFS database and integrated into the SCI analysis.

Table 2: SCI scenario categorization

Category, this analysis	Category, SCI	Description
1.5 C	GW0	Below 1.5°C (50%) with no overshoot
	GW1	Below 1.5°C (50%) with limited overshoot
	GW2a	Below 1.7 °C (50%) returning to 1.5°C (50%)
	GW3a	Below 2°C (67%) returning to 1.5°C (50%)
2 C	GW2b	Below 1.7°C (50%) without returning to 1.5°C (50%)
	GW3b	Below 2°C (67%) without returning to 1.5 °C (50%)

Based on Riahi et al., 2026. Percentages in the description are the likelihood of being below each indicated warming level.

Table 3: Number of SCI model runs by region and type

Category, this analysis	Scenario type	USA	NAM	OECD	World
1.5C	All	22	221	287	292
	Pass global vetting	6	20	23	24
	Pass regional vetting	6	20	23	2
	No negative emissions	2	2	4	2
2C	All	78	366	450	451
	Pass global vetting	16	69	83	83
	Pass regional vetting	11	59	62	22
	No negative emissions	8	18	9	2

Numbers of model runs are defined by a unique combination of model and scenario. Scenario types are defined as:
All: all scenarios in the climate goal category;
Pass global vetting: scenarios passing the SCI global vetting criteria;
Pass regional vetting: scenarios passing the SCI vetting criteria as well as the criterion for historical electricity sector emissions in the region of interest;
No negative emissions: scenarios passing the SCI and electricity sector vetting criteria and also having no substantial net negative emissions in the electricity sector in the region of interest.

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Pacific Northwest National Laboratory

902 Battelle Boulevard

P.O. Box 999

Richland, WA 99354

1-888-375-PNNL (7665)

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