Benefit and Cost Impacts of Reaching Clean Energy and Carbon Emissions Reduction Goals in Wisconsin

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RENEW WISCONSIN

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EXECUTIVE SUMMARY

This benefit-cost report examines the impacts of meeting emissions reduction goals by 2050 using two benefit-cost analytical approaches. This report builds upon energy modeling led by Evolved Energy Research and economic modeling led by Cambridge Econometrics by analyzing the cumulative benefits and costs of reaching 100% clean electricity and net zero economy-wide goals in Wisconsin. The **100% Clean Electricity** scenario in the energy modeling includes a target for all electricity generated and used in Wisconsin to be generated from carbon-free sources by 2050. The **Net Zero Economy-Wide** scenario includes the same 100% clean electricity goal and a target to reach net zero carbon dioxide emissions in all economic sectors by 2050. This benefit-cost report finds that reaching either of these goals results in net benefits for the state, including increased gross state product and jobs.

The first approach of this report uses Evolved Energy Research's (Evolved Energy) Wisconsin modeling results[1] to compare the costs and benefits of decarbonization. This approach involves classifying impacts as costs or benefits, monetizing these impacts, and then comparing total benefits and costs. As a result, we can present a ratio of benefits to costs for each scenario, which provides a simple way to understand how the benefits and costs compare to one another.

The second approach of this report summarizes Cambridge Econometrics' (Cambridge) econometric modeling results.[2] The Cambridge modeling holistically assesses the macroeconomic impacts of decarbonizing Wisconsin's energy systems. This report provides a summary of the Cambridge macroeconomic modeling to understand how different economic sectors change as a result of decarbonizing Wisconsin's economy. The summary also provides additional context for the first benefit-cost analytical approach described above.

The authors of this benefit-cost report determined that the results of their modeling efforts cannot be combined into a single analysis for the purposes of benefit-cost analysis. The Evolved Energy and Cambridge models focus on different scales and outcomes (direct vs. indirect costs and benefits). Furthermore, the Cambridge macroeconomic modeling uses Evolved Energy model results as inputs. Thus, combining the two model outputs would result in double counting benefits.

The benefit-cost analysis in this report shows that considering all benefits, the **100% Clean Electricity** scenario and the **Net Zero Economy-Wide** scenario have benefit-cost ratios above one. The benefits outweigh the costs, and positive macroeconomic impacts include increased jobs. This analysis uses cumulative costs and benefits between 2023 and 2050. In the **100% Clean Electricity** scenario, the benefits are about five times the costs (a benefit-cost ratio of 4.88), and the net benefits (total benefits minus total costs) are $46 billion. In the **Net Zero Economy-Wide** scenario, the benefits are about two times the costs (a benefit-cost ratio of 2), and the net benefits (total benefits minus total costs) are $111 billion.

[1] See report Achieving 100% Clean Energy in Wisconsin.
[2] See report The Economic Impacts of Decarbonization in Wisconsin.

While reaching 100% clean electricity involves less economic costs due to focusing on coal unit retirements, the net benefits are smaller than reaching net zero economy-wide emissions. This is because the **Net Zero Economy-Wide** scenario extends decarbonization to Wisconsin's transportation and building sectors, while the **100% Clean Electricity** scenario assumes a limited, incremental adoption of EVs, heat pumps, and other electrification measures. While decarbonizing the entire economy involves more significant investment costs, the avoided fossil fuel costs, health benefits, and benefits from avoided carbon dioxide emissions are greater in volume because emissions are reduced in sectors across the economy beyond the electricity sector.

This analysis focuses on four categories of costs and benefits for emissions reduction scenarios: energy system costs and benefits, health benefits, carbon dioxide emissions reduction benefits, and macroeconomic impacts. Other goals may be important to policymakers or stakeholders, including environmental concerns and environmental justice priorities. This analysis does not include these concerns explicitly but provides a starting point of costs and benefits for future analysis to build upon with unique policy and program goals.

The benefit-cost analysis in this report shows that considering all benefits, the '100% Clean Electricity' scenario and the 'Net Zero Economy-Wide' scenario have benefit-cost ratios above one. The benefits outweigh the costs, and positive macroeconomic impacts include increased jobs.

SUMMARY OF RESULTS

The tables below provide a high-level summary of the costs and benefit impacts of achieving decarbonization in Wisconsin by 2050. The first table provides benefits, costs, and benefit-cost ratios associated with Evolved Energy's modeling of the **Net Zero Economy-Wide** and **100% Clean Electricity** scenarios. Benefits and costs are presented in cumulative 2023-2050 net present value. The second table provides key findings from the Cambridge modeling results. More detailed results and further descriptions can be found below in the full report, with results of other scenarios presented in Appendix A.

These tables show that both the **100% Clean Electricity** and the **Net Zero Economy-Wide** scenarios are projected to yield net benefits (benefits exceed costs) compared to the baseline when all benefit categories are included in the analysis. The **100% Clean Electricity** scenario has a high benefit-cost ratio value because the energy system costs are relatively low compared to the high health benefits of retiring coal units. While the **Net Zero Economy-Wide** scenario has a smaller benefit-cost ratio, the net benefits are larger than the **100% Clean Electricity** scenario. The **Net Zero Economy-Wide** benefits are also higher when including indirect benefits of increased gross state product and additional jobs (Table 2).

SCENARIO	BENEFITS INCLUDED	PRESENT VALUE BENEFITS (billion $)	PRESENT VALUE COSTS (billion $)[3]	RATIO
Net Zero Economy-Wide	System Benefits	110.63	111.12	0.996
	System Benefits + Avoided Health Costs [4]	178.69	111.12	1.61
	System Benefits + Avoided Health Costs + Avoided CO2 Costs	222.15	111.12	2.00
100% Clean Electricity	System Benefits	8.75	11.88	.74
	System Benefits + Avoided Health Costs	48.39	11.88	4.07
	System Benefits + Avoided Health Costs + Avoided CO2 Costs	57.54	11.88	4.84

Table 1: Summary of Benefit-Cost ratios for key decarbonization scenarios

SCENARIO	GROSS STATE PRODUCT INCREASE BY 2050	NET JOB GROWTH BY 2050
Net Zero Economy-Wide	3.0%	68,500 additional jobs
100% Clean Electricity	0.5%	7,320 additional jobs

Table 2: Summary of Cambridge Econometrics economic impact findings

[3] Net present value of the costs includes only the costs of system investments.
[4] The estimate of avoided health costs in this table are the high estimates of the range detailed in this report.

INTRODUCTION

In 2019, Wisconsin Governor Evers signed Executive Order #38, which established a goal for Wisconsin to reach 100% carbon-free electricity by 2050. Following this order, the Public Service Commission of Wisconsin (PSCW) opened an investigation to develop a roadmap to achieve 100% clean electricity by 2050. The Wisconsin Office of Sustainability released a Clean Energy Plan focused on policy and program strategies to meet clean electricity goals. These actions show commitment to and momentum toward these goals.

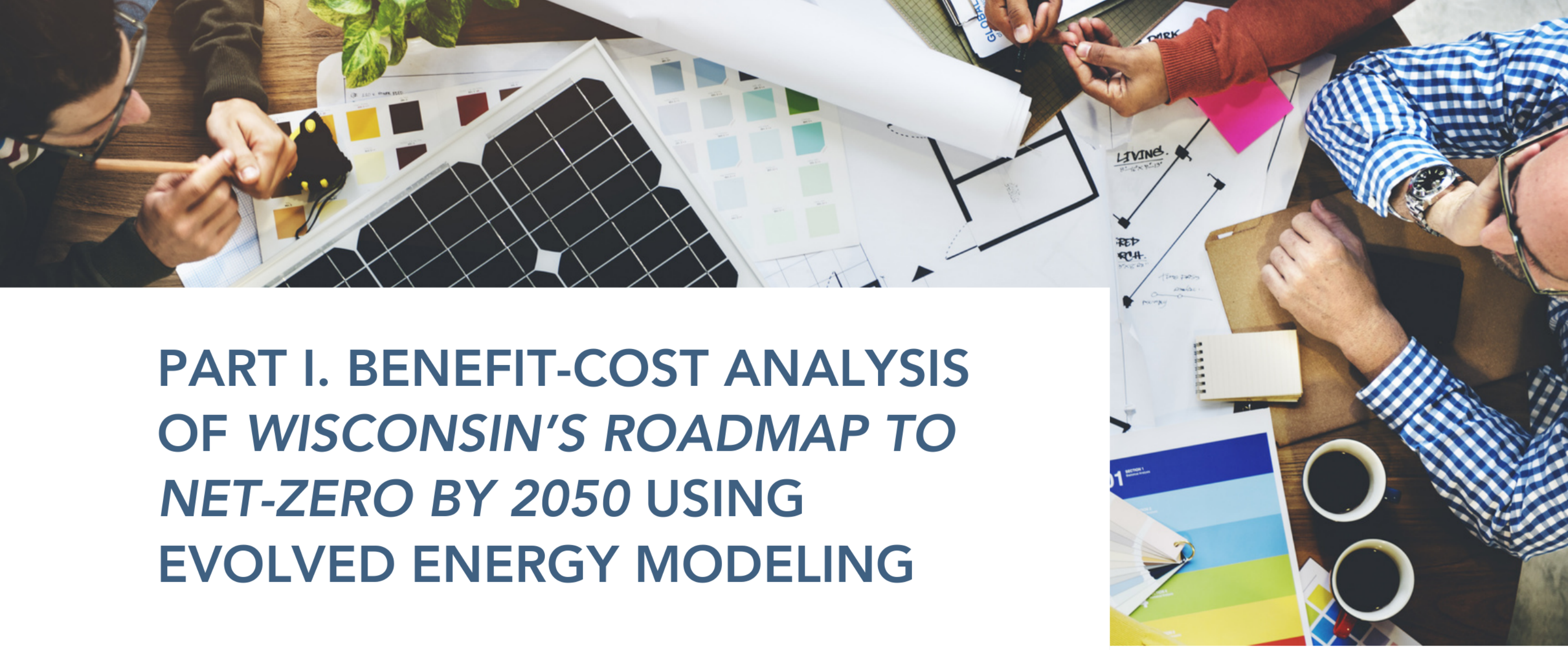
To better understand the impacts of these goals, RENEW Wisconsin partnered with Clean Wisconsin, Evolved Energy, Gridlab, and Cambridge to study the impacts of different scenarios to reach clean electricity and energy goals by 2050. This partnership resulted in two reports. The first report, *Achieving 100% Clean Energy in Wisconsin* (Evolved Report), analyzes several pathways to reach 100% clean electricity and net zero economy-wide targets. This report focuses on modeling the energy changes necessary to meet these goals and the associated health benefits and carbon dioxide reductions associated with energy system changes. The second report, *The Economic Impacts of Decarbonization in Wisconsin* (Cambridge Report), analyzes the macroeconomic impacts of meeting 100% clean electricity and net zero economy-wide goals.

RENEW Wisconsin partnered with Clean Wisconsin, Evolved Energy, Gridlab, and Cambridge to study the impacts of different scenarios to reach clean electricity and energy goals by 2050.

APPROACH

This report presents the impacts of two scenarios, **100% Clean Electricity** and **Net Zero Economy-Wide.** It is based on the outputs of the Evolved report and Cambridge report (mentioned above), with analyses of additional scenarios included in Appendix A. It is broken into two sections: the first measures the benefit-cost ratios of the two scenarios using Evolved Energy modeling, and the second summarizes the economic impacts of each scenario using Cambridge modeling results. The results from the Evolved report and the Cambridge report cannot be combined for a single benefit-cost analysis because the Cambridge economic modeling uses the Evolved Energy model results as an input to assess the economic impacts, which would double-count the benefits of the energy transition. Additionally, the economic modeling does not result in gross benefits and gross costs but rather in total impacts on the economy that assesses how economic impacts interact. For example, an investment counted as a cost in energy modeling might result in impacts that both increase and decrease the gross state product, resulting in an overall net cost or impact rather than broken-out costs and benefits of the investment.

In short, the Evolved Energy modeling results show the direct economic costs of energy system changes (i.e., the price of energy infrastructure upgrades) and the direct economic benefits of energy system changes (i.e., the avoided cost of operating fossil fuel energy sources). In contrast, the Cambridge macroeconomic modeling results show the overall economic activity changes and employment impacts of energy infrastructure changes, including direct and indirect jobs and changes in consumer purchasing. The economic impacts of these two modeling results are distinct but interrelated and thus cannot be fully separated and combined into one benefit-cost analysis. As a result, we use two benefit-cost analytical approaches that refer to the Evolved Energy and Cambridge results separately. The analysis in this benefit-cost report calculates benefit-cost ratios and net benefits from the Evolved Energy modeling study in Part I and summarizes the Cambridge macroeconomic report in Part II. A summary of Part I and Part II can be found in the Executive Summary. Appendix A includes **Net Zero Economy-Wide** sub-scenario results and Appendix B includes the additional social cost of carbon analysis.



PART I. BENEFIT-COST ANALYSIS OF *WISCONSIN'S ROADMAP TO NET-ZERO BY 2050* USING EVOLVED ENERGY MODELING

ABOUT THIS STUDY

RENEW Wisconsin worked with partners Clean Wisconsin, Evolved Energy, and GridLab, to develop a report, *Achieving 100% Clean Energy in Wisconsin by 2050*. The Evolved report includes results from Evolved Energy modeling of several scenarios to reach 100% clean electricity or net zero economy-wide carbon emissions. The model used in the Evolved Energy study focuses on changes to the energy sector and resulting costs incurred, cost reductions, emission reductions, and health benefits by 2050 to reach these goals. The project team also provided a *Summary Report* highlighting key energy modeling findings and policy recommendations to rapidly reduce emissions in Wisconsin.

The analysis in this benefit-cost report builds upon the Evolved Energy technical report by focusing on the costs and benefits associated with two scenarios, **100% Clean Electricity** and **Net Zero Economy-Wide**, with benefit-cost calculations for additional scenarios included in Appendix A. Comparing the benefits and costs through a benefit-cost analysis provides an estimate of net benefits and a ratio of benefits to costs for each scenario. These ratios include direct economic costs and benefits of energy system changes but not economic impacts such as changes in consumer purchases, changes in employment, or economic trade-offs between energy investments.

The benefit-cost results are presented below in three levels for each scenario. The first level of analysis includes direct costs and benefits associated with energy system changes. The second level analysis includes monetized health benefits attributed to energy system changes. The third level analysis adds benefits associated with avoided carbon dioxide emissions. These metrics are detailed below.

BENEFIT-COST ANALYSIS AND RATIOS

A benefit-cost analysis compares a single scenario's total benefits and costs and compares these results across scenarios or options. To perform this analysis, we identified general categories of costs and benefits, discounted each monetized value for future years to current values, and summed the values to determine cumulative costs and benefits. The costs and benefits of each scenario are compared to the baseline scenario (business as usual). This benefit-cost analysis results in two main findings for each scenario: a calculation of net benefits and a calculation of the benefit-cost ratio.

Net benefits are derived by broadly subtracting the total cost from the total benefits of reaching a policy goal or implementing a program. Positive net benefits indicate that the benefits of that scenario exceed the costs, whereas negative net benefits indicate that the costs exceed the benefits.

Benefit-cost ratios compare the relative amount of benefits and costs in each scenario. A benefit-cost ratio greater than 1 means that the scenario generates more benefits than costs, whereas a ratio of less than 1 means that the scenario generates fewer benefits than costs. For example, a benefit-cost ratio of 2 tells us that the scenario generates more benefits than costs. It also tells us that every $1 in investment for system upgrades results in $2 of benefits across the categories described below (avoided fossil fuel costs, avoided health impacts, and avoided carbon dioxide emissions).

The benefit-cost ratios in this report are generated from an analytical approach distinct from other benefit-cost analyses. While this analysis compares meeting different decarbonization targets to baseline, other analyses focus on the costs and benefits of implementing a specific policy or program. For example, the evaluator of the Wisconsin Focus on Energy (Focus) program uses a modified total resource cost test (TRC) to establish benefit-cost ratios associated with implementing energy efficiency and renewable energy incentives. The TRC ratios created by the Focus evaluator concentrate on energy and demand savings benefits and consider carbon reduction benefits. However, net economic benefits (such as the macroeconomic benefits used in part two of this study) are not included in the scope of evaluating Focus costs and benefits. Additionally, while Focus program administration and incentive costs are the direct costs associated with Focus evaluation, these cost types are not included in the benefit-cost analysis in this report. This is because Wisconsin does not have a state regulatory agency overseeing carbon reduction requirements or an administrative program providing decarbonization incentives.[5] While meeting the decarbonization goals described in this report would likely require implementing policies and programs that may benefit from additional analyses to compare net benefits or benefit-cost ratios, this report focuses on comparing the broader costs and benefits of these goals.

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[5] Cadmus, Apex Analytics, and Resource Innovations. "Focus on Energy Calendar Year 2021 Evaluation Report: Volume 1," May 20, 2022. https://s3.us-east-1.amazonaws.com/focusonenergy/staging/inline-files/WI_Focus_on%20Energy_CY_2021_Volume_I.pdf.

DATA SOURCES

All values used in this analysis are outputs of the modeling report completed by Evolved Energy. Evolved Energy modeled the energy system needs to reach goals in different scenarios: **100% Clean Electricity by 2050** and **Net Zero Economy-Wide** (as well as several sub-scenarios). The projected changes in the energy system also included projected changes in air pollutants and carbon dioxide emissions due to energy system changes.

DESCRIPTION OF CATEGORIES

COST: ENERGY SYSTEM COSTS

The costs of energy system investments to meet the goals of various scenarios include several categories:

- The Clean Fuels category includes the production of fuels, including fuels derived from hydrogen and biomass. The costs of clean fuels are based on the production of these fuels, and we assume that they will be transported using infrastructure currently used for fossil fuel transport.
- The Demand Side Equipment category includes the cost of technologies that use electricity to replace fossil-fuel-run equipment, such as electric vehicles and heat pumps.
- The Electric Sector category costs include building new clean energy infrastructure such as solar energy, wind energy, and storage.
- The Other category includes the cost of carbon sequestration to offset emissions.

BENEFIT: AVOIDED FOSSIL FUEL COSTS

This analysis counts the avoided costs of using fossil fuels as a benefit. In the **Baseline** scenario, Wisconsin uses fossil fuels for electricity and other energy uses. Comparing several scenarios to the baseline requires measuring the avoided costs of using fossil fuels, which is measured as a benefit to the economy as Wisconsin is importing and transporting less fossil fuels, thus saving money compared to the baseline. Wisconsin spent $13.1 billion on imported fossil fuels (petroleum, natural gas, and coal) in 2021.[6]

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[6] U.S. Energy Information Administration. "Wisconsin State Profile and Energy Estimates: Consumption & Expenditures By Source," March 18, 2023. https://www.eia.gov/state/data.php?sid=WI#ConsumptionExpenditures.

BENEFIT: AVOIDED HEALTH COSTS

Transitioning the energy system from relying primarily on fossil fuels to clean energy results in health benefits due to lower levels of criteria air pollutants from fossil fuel combustion. Criteria air pollutants are regulated due to their direct impact on human health and are distinct from greenhouse gas emissions (such as carbon dioxide). These criteria air pollutants have a direct impact on human health, whereas carbon dioxide warms the planet, which causes an indirect impact on human health. This benefit category focuses on reducing criteria air pollutants, not greenhouse gas emissions.

The benefits of reduced fine particulate matter (PM2.5), an air pollutant with adverse health impacts, are modeled through the Environmental Protection Agency (EPA) CO- Benefits Risk Assessment (COBRA) model. The model uses emissions data from the energy modeling on electricity, vehicles, and other economic sectors, to determine the health impacts of reducing air pollutants in each scenario. We used a 3% discount rate for the COBRA estimates for this analysis. COBRA estimates annual ambient fine particulate matter concentrations from direct PM2.5 emissions and PM2.5 that form from atmospheric reactions of nitrogen oxide and sulfur dioxide emissions. The model then estimates health impacts, including infant mortality, non-fatal heart attacks, respiratory and cardiovascular hospital admissions, acute bronchitis and respiratory symptoms, asthma exacerbations and emergencies, and restricted activity and work loss days. These impacts are then converted to monetized benefits through the value of statistical life, cost of illness, hospital charges, willingness to pay to avoid illness, activity restriction, and lost workdays. Most of the monetized health benefits are due to the reduction in premature mortality. The COBRA model results in a high and low estimate of monetized health benefits associated with avoided air pollution.

BENEFIT: AVOIDED CARBON DIOXIDE EMISSIONS COSTS

All scenarios modeled include a decrease in carbon dioxide emissions compared to the **Baseline** scenario due to a decrease in fossil fuel use. Neither the Evolved study nor the Cambridge study included a monetization of avoided carbon dioxide emissions. In this benefit-cost study, we monetize the avoided carbon dioxide emissions for each scenario compared to the baseline.

To measure the impact of avoided carbon dioxide emissions, researchers often apply a cost of carbon that captures the economic impacts of climate change associated with emitting an additional ton of carbon dioxide, called a 'social cost of carbon.' This measure is used in benefit-cost analysis and modeling to monetize the value of both negative and positive climate change impacts. Estimates of the social cost of carbon include changes in net agricultural productivity, human health effects, property damage from increased flood risk, changes in the frequency and severity of natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services.[7] Estimates for the social cost of carbon vary.

In addition to using a social cost of carbon value, other analysts use a value of carbon aligned with the cost of carbon in current or future carbon trading markets. Focus on Energy currently uses a $15 value in anticipation of a forthcoming report ordered by the PSCW. That report will provide research on market-based alternatives for the value of carbon. It will be presented to the PSCW in September 2023, when the commission will select the updated value.

The Biden Administration uses a $51 per ton metric for policy analysis, while recent academic research estimates carbon per tonne costs closer to $185.[8] The $51 value is an interim value recommended by the Interagency Working Group (IWG) for analyzing federal policies and programs. The working group comprises several federal agencies to develop a social cost of carbon. The Environmental Protection Agency (EPA) has recently calculated the social cost of carbon to be $190 per ton, which aligns more with academic research estimates.[9]

For this analysis, we use a value of the cost of carbon (not a social cost of carbon) of $15 per ton, the value used by Focus in Wisconsin as of January 2023, as the low carbon cost estimate. For the high estimate, we use the $51 per ton social cost of carbon value from the IWG. We use these two measures in the main analysis since they are used in state and federal decision-making processes. However, we include a supplementary analysis in Appendix B using the $190 value from the above mentioned EPA report.

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[7] U.S. Environmental Protection Agency. "Supplementary Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, 'Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review': EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances." Washington, DC, September 2022, p. 4. https://subscriber.politicopro.com/eenews/f/eenews/?id=00000184-77c6-d07e-a5fd-f7df41f80000.

[8] A note on tonnes and tons of carbon dioxide: A metric tonne (1000 kg) is often used outside of the United States, whereas a short ton is a metric often used in the United States. A short ton (2,000 pounds) is smaller than a metric ton: 1 short ton is equivalent to about 0.91 metric tonnes.

[9] The $190 value is estimated using a 2% discount rate from 2020 value.

This analysis does not include the cost of inaction in addressing climate change by reducing carbon dioxide emissions. For example, in the **100% Clean Electricity** scenario, there is no accounting of the costs of not reducing carbon dioxide emissions in sectors beyond the electricity sector. Instead, this analysis monetizes the avoided carbon dioxide emissions and treats this value as a benefit. However, it does not monetize the remaining emissions in the economy as a cost. Such monetization can be considered a cost of inaction to mitigate emissions. Because this analysis does not include this step, the **100% Clean Electricity** scenario costs might be lower than if this cost of inaction were included.

In addition, this analysis does not monetize all greenhouse gasses, particularly methane and nitrous oxide, which are more potent warming gasses but are less prevalent than carbon dioxide. Both methane and nitrous oxide are emitted through fossil fuel production, transport, or combustion. This study does not monetize the benefit of avoided greenhouse gasses since the energy modeling measures only carbon dioxide emissions. Including the monetization of all avoided greenhouse gasses would likely increase all scenarios' net benefits and benefit-cost ratios.

DESCRIPTION OF SCENARIOS

All Evolved Energy scenarios are modeled from 2022–2050. For this benefit-cost analysis, we start the analysis in 2023. The Evolved study that produced these results took place in 2022 and used 2020 as the base year. For this analysis, we zeroed out investments modeled in 2022 because these investments were not actually made, though projected values for the year were included in the original modeling.

This benefit-cost report analyzes the costs and benefits and calculates benefit-cost ratios for two main scenarios: **100% Clean Electricity** and **Net Zero Economy-Wide**. Descriptions and calculations for four additional scenarios with an overall goal of net zero economy-wide emissions reductions as well as additional constraints or goals, are included in the Appendix. For a complete account of the assumptions made in the Evolved study that produced these data, see the technical report prepared by Evolved Energy.

BASELINE

The baseline scenario is a “business as usual” scenario with no additional policies on electricity supply, electricity use, or greenhouse gas emissions.

100% CLEAN ELECTRICITY

This scenario includes a target for 100% clean electricity by 2050, meaning all electricity generated and used in the state would come from carbon-free sources.

NET ZERO ECONOMY-WIDE

This scenario includes a target for 100% clean electricity by 2050 and a target to reach net-zero emissions by 2050 in all economic sectors - not only electricity.

ASSUMPTIONS

Beyond assumptions made in the modeling results we use as inputs to this analysis, we make additional assumptions for the benefit-cost analysis, detailed below.

- Carbon Dioxide (CO_2) Costs – To monetize avoided CO_2 costs, we use a $15 per ton Focus on Energy value for the low-value assumption and a $51 per ton federal value for the high-value assumption.
- Discount Rates – We use a 2% discount rate aligned with the discount rate used in the Evolved Energy modeling of energy system changes. Using a discount rate allows for comparison between costs and benefits that occur at different times. A discount rate accounts for future economic growth because a dollar saved or spent today is worth more now than in the future.
- Interpolation – The results from the Evolved Energy modeling gave annualized values every five years. To discount these results and calculate cumulative costs and benefits, we interpolate these results to yearly results using a linear interpolation between each five-year measure.

RESULTS: NET ZERO ECONOMY-WIDE SCENARIO

In the **Net Zero Economy-Wide** scenario, the energy system costs from 2023–2050, using a 2% discount rate, is about $111 billion in cumulative net present value, with most of the costs coming from demand-side investments and the cost of electric sector upgrades. Table 3.1 shows how system costs are divided between four categories. Energy system benefits in this scenario, measured as the avoided costs of fossil fuels, are similar in scale to the costs: $110 billion. This comparison is summarized in Table 3.2.

The first level of analysis for the **Net Zero Economy-Wide** scenario includes only direct costs and benefits borne out of energy system changes. The ratio of the benefits to the costs in this scenario is 0.996. This ratio reflects that costs and benefits accrued in the **Net Zero Economy-Wide** scenario are similar when only considering system costs and benefits. From 2023–2050, the cumulative system costs outweigh the system benefits by about $500 million, which equates to a benefit-cost ratio of about 1:1 if rounded to three significant digits. However, when health and CO2 benefits are added to our analysis in steps 2 and 3, the benefit-cost ratios go above 1 for the **Net Zero Economy-Wide** scenario. Table 3.3 shows the benefit-cost calculations using only system costs and benefits of the **Net Zero Economy-Wide** scenario.

When health and CO2 benefits are added to our analysis, the benefit-cost ratios go above 1 for the Net Zero Economy-Wide scenario.

NET ZERO ECONOMY-WIDE: ENERGY SYSTEM COSTS BY CATEGORY	
Cost of Clean Fuels	$4,222,260,011
Cost of Demand Side Investments	$42,362,035,001
Cost of Electric Sector	$63,471,975,599
Other Costs	$1,066,711,904
TOTAL	$111,122,982,515

Table 3.1. Energy system costs by category in the **Net Zero Economy-Wide** scenario from 2023–2050, compared to baseline.

NET ZERO ECONOMY-WIDE: ENERGY SYSTEM COSTS AND AVOIDED FOSSIL FUEL COSTS

NET ZERO ECONOMY-WIDE: COSTS AND BENEFITS		
Cost	Energy System Upgrade Costs	$111,122,982,515
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$110,633,127,434

Table 3.2. Total costs and benefits from 2023–2050 in the **Net Zero Economy-Wide** scenario compared to baseline.

NET ZERO ECONOMY-WIDE: SUMMARY			
TYPE OF CALCULATION	**CALCULATION**	**VALUE**	**ROUNDED VALUE**
Benefit : Cost Ratio	$110,633,127,434 / $111,122,982,515	0.996	1
Net Benefits	$110,633,127,434-$111,122,982,515	-$489,855,081	-$500 million

Table 3.3. Comparison of costs and benefits from 2023–2050 in the **Net Zero Economy-Wide** scenario compared to the baseline, only including energy system costs and benefits.

NET ZERO ECONOMY-WIDE: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, AND HEALTH BENEFITS

Accounting for the avoided costs of health impacts from fossil fuel combustion results in additional benefits in the **Net Zero Economy-Wide** scenario. From 2023–2050, these benefits are estimated to be between $30 billion and $68 billion, shown in Table 3.4. These values include a range because the underlying model used to estimate health benefits consists of a range of potential benefits.

Including these benefits results in a change to the benefit-cost ratio and net benefits of this scenario. The range of the benefit-cost ratios is 1.268–1.61, meaning that the benefits outweigh the costs in this scenario over time. This is shown in Table 3.5. Since the energy system costs and benefits are close, adding health benefits results in net benefits almost equal to the health benefits alone. These health benefits are associated with electricity generation and transportation changes that improve air quality. Burning coal has the worst health impacts due to the high sulfur dioxide emissions released through coal combustion, which react with other compounds in the air to form PM2.5.

NET ZERO ECONOMY-WIDE: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$111,122,982,515	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$110,633,127,434	
Benefit	Avoided health impacts	$30,254,052,782	$68,060,078,768

Table 3.4. Total costs and benefits from 2023–2050 in the **Net Zero Economy-Wide** scenario compared to baseline.

NET ZERO ECONOMY-WIDE: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$140,887,180,216 / $111,122,982,515	1.268	1
	Benefits - Costs	$140,887,180,216 -$111,122,982,515	$29,764,197,701	$30 billion
High	Benefit:Cost Ratio	$178,693,206,202 / $111,122,982,515	1.61	2
	Benefits - Costs	$178,693,206,202 - $111,122,982,515	$67,570,223,585	$68 billion

Table 3.5. Comparison of costs and benefits from 2023–2050 in the **Net Zero Economy-Wide** scenario compared to the baseline, including energy system costs and benefits, and health benefits.

NET ZERO ECONOMY-WIDE: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, HEALTH BENEFITS, AND AVOIDED CO2 EMISSIONS

The last benefit we add in this analysis is the benefits of avoided CO2 emissions. We assume two costs of carbon, a low and high estimate, to calculate a range of monetized benefits. For the low estimate, we use a $15 per ton cost of carbon, and for the high estimate, we use a $51 per ton cost of carbon. The avoided impacts in the **Net Zero Economy-Wide** scenario are between $13 billion and $43 billion, shown in Table 3.6.

Accounting for the energy system costs, avoided fossil fuel use, avoided health impacts, and avoided CO2 emissions results in a benefit-cost ratio of between 1.61 and 2.00. The net benefits range from $43 billion to $111 billion cumulatively from 2023–2050, as shown in Table 3.7.

NET ZERO ECONOMY-WIDE: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$111,122,982,515	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$110,633,127,434	
Benefit	Avoided health impacts	$30,254,052,782	$68,060,078,768
Benefit	Avoided CO2 impacts	$12,782,584,068	$43,460,785,830

Table 3.6. Total costs and benefits from 2023–2050 in the **Net Zero Economy-Wide** scenario compared to baseline.

NET ZERO ECONOMY-WIDE: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$153,669,764,284 / $111,122,982,515	1.61	2
	Benefits - Costs	$153,669,764,284 - $111,122,982,515	$42,546,781,769	$43 billion
High	Benefit:Cost Ratio	$222,153,992,031 / $111,122,982,515	2.00	2
	Benefits - Costs	$222,153,992,031 - $111,122,982,515	$111,031,009,516	$111 billion

Table 3.7. Comparison of costs and benefits from 2023–2050 in the **Net Zero Economy-Wide** scenario compared to the baseline, including energy system costs and benefits, health benefits, and avoided CO2 impacts.

RESULTS: 100% CLEAN ELECTRICITY SCENARIO

The **100% Clean Electricity** scenario focuses on reducing CO2 emissions solely from electric generation. In this scenario, the cost of changes to the energy system (assuming a 2% discount rate from 2023–2050) is about $12 billion. This cost is dominated by electric sector investments coming from the electricity supply costs from renewable energy sources. Table 4.1 shows the cost breakdown across three categories. The avoided cost of building and using fossil fuels (considered a benefit) is about $9 billion (shown in Table 4.2). These costs and benefits to the energy system are an order of magnitude smaller than in the **Net Zero Economy-Wide** scenario. This difference in scale is due to this scenario's focus on one sector of the economy, the electricity sector. It does not include system updates like electrification of the building and transportation sectors and the attributed clean electricity needed to supply the increased demand.

The first step to the benefit-cost analysis of the **100% Clean Electricity** scenario focuses only on the costs and benefits to the energy system, not including health impacts or impacts of reduced carbon dioxide emissions. The ratio of the costs and benefits in this scenario is 0.74; meaning costs outweigh the benefits when only considering changes to the energy system. The costs are about $3 billion more than the cumulative benefits from 2023–2050, shown in Table 4.3. As shown further in this analysis, the benefits outweigh the costs when health benefits are included and are further outweighed when avoided CO2 emissions are included.

100% CLEAN ELECTRICITY: ENERGY SYSTEM COSTS BY CATEGORY	
Cost of Clean Fuels	$565,294,660
Cost of Electric Sector	$11,212,694,940
Other Costs	$102,548,015
TOTAL	$11,880,537,615

Table 4.1. Energy system costs by category in the **100% Clean Electricity** scenario from 2023-2050, compared to baseline.

100% CLEAN ELECTRICITY: ENERGY SYSTEM COSTS AND AVOIDED FOSSIL FUEL COSTS

100% CLEAN ELECTRICITY: COSTS AND BENEFITS		
Cost	Energy System Upgrade Costs	$11,880,537,615
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$8,747,504,967

Table 4.2. Total costs and benefits from 2023–2050 in the **100% Clean Electricity** sector scenario compared to baseline.

100% CLEAN ELECTRICITY: SUMMARY			
TYPE OF CALCULATION	**CALCULATION**	**VALUE**	**ROUNDED VALUE**
Benefit:Cost Ratio	$8,747,504,967 / $11,880,537,615	0.74	1
Benefits - Costs	$8,747,504,967 - $11,880,537,615	-$3,133,032,648	-$3 billion

Table 4.3. Comparison of costs and benefits from 2023–2050 in the **100% Clean Electricity** scenario compared to the baseline, only including energy system costs and benefits.

100% CLEAN ELECTRICITY: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, AND HEALTH BENEFITS

The next addition of benefits in the analysis of the **100% Clean Electricity** scenario is to include the health impacts attributed to the reduction in fossil fuel use. Combusting fossil fuels creates air pollution that causes health issues, which result in hospital visits, missed work days, and premature death. The avoided health impacts associated with **100% Clean Electricity** from 2023–2050 is between about $17 billion and $40 billion (Table 4.4).

When including health benefits, the ratio of benefits to costs is between 2.2–4.1. This increase is due to the high health benefits. Fossil fuel combustion, particularly from coal generating units, produces air pollutants with negative health impacts, resulting in high benefits of avoiding these health impacts. The benefits of **100% Clean Electricity** (including avoided costs of fossil fuels and avoided health impacts) are between $14 billion and $37 billion (Table 4.5). The costs and benefits from this perspective are dominated by the health benefits associated with retiring coal units.

100% CLEAN ELECTRICITY: COSTS AND BENEFITS			
		LOW ESTIMATE	**HIGH ESTIMATE**
Cost	Energy System Upgrade Costs	$11,880,537,615	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$8,747,504,967	
Benefit	Avoided health impacts	$17,609,202,688	$39,642,755,778

Table 4.4. Total costs and benefits from 2023–2050 in the **100% Clean Electricity** scenario compared to baseline.

100% CLEAN ELECTRICITY: SUMMARY				
	TYPE OF CALCULATION	**CALCULATION**	**VALUE**	**ROUNDED VALUE**
Low	Benefit:Cost Ratio	$26,356,707,656 / $11,880,537,615	2.22	2
	Benefits - Costs	$26,356,707,656 - $11,880,537,615	$14,476,170,041	$14 billion
High	Benefit:Cost Ratio	$48,390,260,745 / $11,880,537,615	4.07	4
	Benefits - Costs	$48,390,260,745 - $11,880,537,615	$36,509,723,130	$37 billion

Table 4.5. Comparison of costs and benefits from 2023–2050 in the **100% Clean Electricity** scenario compared to the baseline, including energy system costs, energy system benefits, and health benefits.

100% CLEAN ELECTRICITY: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, HEALTH BENEFITS, AND AVOIDED CO2 EMISSIONS

The final addition to the **100% Clean Electricity** scenario analysis is the benefits of avoiding CO2 emissions. These benefits range from about $3 billion to about $9 billion cumulatively from 2023–2050, depending on the carbon cost of $15 per ton for the low estimate or $51 per ton for the high estimate (Table 4.6).

Including the costs of the energy system upgrades, the benefits of avoided fossil fuel use, health benefits, and CO2 benefits result in a ratio of benefits to costs between 2.5–4.8 (Table 4.7). Adding avoided CO2 benefits to the analysis increases the benefits-to-costs ratio and the net benefits of **100% Clean Electricity** between $17 billion and $46 billion. The costs of upgrading the energy system to achieve 100% clean electricity are relatively inexpensive ($12 billion) compared to the indirect benefits, including health benefits of between $18 billion and $40 billion, which causes a high ratio of benefits to costs (Table 4.7).

100% CLEAN ELECTRICITY: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$11,880,537,615	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$8,747,504,967	
Benefit	Avoided health impacts	$17,609,202,688	$39,642,755,778
Benefit	Avoided CO2 impacts	$2,691,784,097	$9,152,065,930

Table 4.6. Total costs and benefits from 2023–2050 in the **100% Clean Electricity** scenario compared to baseline.

100% CLEAN ELECTRICITY: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$29,048,491,753 / $11,880,537,615	2.45	2
	Benefits - Costs	$29,048,491,753 - $11,880,537,615	$17,167,954,138	$17 billion
High	Benefit:Cost Ratio	$57,542,326,676 / $11,880,537,615	4.84	5
	Benefits - Costs	$57,542,326,676- $11,880,537,615	$45,661,789,061	$46 billion

Table 4.7. Comparison of costs and benefits from 2023–2050 in the **100% Clean Electricity s**cenario compared to the baseline, including energy system costs and benefits, health benefits, and avoided CO2 impacts.

PART II. ECONOMIC IMPACTS OF DECARBONIZATION IN WISCONSIN OF WISCONSIN'S ROADMAP TO NET-ZERO BY 2050 USING CAMBRIDGE ECONOMETRICS MODELING

In addition to the energy modeling completed for the Evolved report, the project team partnered with Cambridge to study the impacts of two scenarios (**100% Clean Electricity** and **Net Zero Economy-Wide)** on the Wisconsin economy, including the impact on gross state product (GSP) and jobs. While the Cambridge study uses Evolved Energy modeling as inputs to its analysis, the Cambridge results must be considered distinct and separate from Evolved Energy modeling results and the benefit-cost analysis in this report. The Cambridge modeling focuses on the macroeconomic effects of changes to the energy system in Wisconsin and uses a separate model to calculate impacts (E3-US model). Below is a summary of the full Cambridge report, presented alongside the benefit-cost analysis in this benefit-cost report to provide further context for the impact of the energy system changes modeled in the Evolved report.

The summary below provides a snapshot of the Cambridge report. The full Cambridge report further outlines where job increases will likely happen in Wisconsin, what jobs are associated with energy system changes, and the sub-state economic impacts. The Cambridge report also includes more detail on the model used to estimate changes to the GSP and job changes.

NET ZERO ECONOMY-WIDE

MACROECONOMIC IMPACTS

Reaching net-zero emissions economy-wide by 2050 will substantially impact Wisconsin's economy. The Cambridge report estimates that meeting this target will result in a 3% increase in the GSP by 2050.

Three main factors drive this growth in Wisconsin's economy. First, clean energy manufacturing and renewable energy installations will expand the economy. Second, reduced spending on energy will increase spending in other areas of the economy. Third, while building new electricity generation to meet higher electricity demand will add costs, the electricity use is more efficient than other energy sources, which will mitigate investment costs.

JOB IMPACTS

Energy system and economic changes will result in additional jobs. In this model, reaching this goal will result in 70,000 additional jobs in Wisconsin. Half of these additional jobs are in electricity supply, construction, and manufacturing. When considering jobs lost that are directly related to fossil fuel sectors (about 2,000 jobs), the net job impact is about 68,500 added to Wisconsin's economy by 2050.

100% CLEAN ELECTRICITY

MACROECONOMIC IMPACTS

Achieving 100% clean electricity without meeting the net zero economy-wide goal results in more modest changes to Wisconsin's economy. The Cambridge modeling estimates that reaching 100% clean electricity by 2050 will grow Wisconsin's Gross State Product (GSP) by 0.5%. This growth is mainly through new electricity capacity built in the state.

JOB IMPACTS

The job impacts are also more modest to meet the **100% Clean Electricity** scenario than the **Net Zero Economy-Wide** scenario. The modeling estimates that about 7,320 new jobs will be added by 2050 under the **100% Clean Electricity** scenario. These jobs are primarily in the manufacturing and construction sectors to add new renewable energy technologies in the state.

About 2,000 people in Wisconsin are currently employed in the coal-fired generation industry. These jobs will be eliminated by phasing out coal plants in the **Baseline**, **100% Clean Electricity**, and **Net Zero Economy-Wide** scenarios.

CONCLUSIONS

The two parts of this benefit-cost report show different costs and benefits, but similar themes for net benefits can be seen in both the **100% Clean Electricity** and **Net Zero Economy-Wide** scenarios. When only considering the direct energy system costs and benefits, the benefit-cost analysis ratio for the **Net Zero Economy-Wide** scenario is 0.996. A ratio of about 1:1 reflects that system costs and benefits are nearly identical in the **Net Zero Economy-Wide** scenario. Adding in health impacts and carbon dioxide emission impacts increase the benefits of this scenario, showing that these benefits outweigh the direct costs of reaching **Net Zero Economy-Wide**. Additionally, the economic impacts from the Cambridge report show a 3% increase in Wisconsin's GSP and an increase in 68,500 jobs in the state for the **Net Zero Economy-Wide** scenario.

The benefits of meeting the 100 % clean electricity goal depend on the costs and benefits included. The benefit-cost ratio for the 1**00% Clean Electricity** scenario is 0.74, meaning that the direct costs of energy system upgrades outweigh the benefits. However, the costs and benefits are less in this scenario than in the **Net Zero Economy-Wide** scenario. Additionally, adding in the health benefits and the carbon dioxide emissions benefits results in ratios above 2, meaning that the benefits are more than double the costs. The economic modeling also shows economic benefits in the **100% Clean Electricity** scenario, with the economy growing by 0.5% and about 7,320 new jobs in the state.

Both the **100% Clean Electricity** and **Net Zero Economy-Wide** scenarios yield net benefits compared to the **Baseline** scenario when all benefits are included in the analysis. Meeting the **100% Clean Electricity** scenario has the highest benefit-cost ratios, as the benefits outweigh the costs by the most significant magnitude when considering all benefits. This is due to a relatively low energy system cost compared to the health benefits of coal unit retirements to reach the goal. However, meeting the **Net Zero Economy-Wide** scenario, which requires a higher magnitude of economy-wide investments, has larger net benefits both directly (including avoided fossil fuels, health benefits, and carbon dioxide benefits) and indirectly (increasing gross state product and additional jobs).

The **Net Zero Economy-Wide** scenario has larger net benefits both directly (including avoided fossil fuels, health benefits, and avoided carbon dioxide impacts) and indirectly (increasing gross state product and additional jobs).

APPENDIX A: ANALYSIS OF ADDITIONAL SCENARIOS

DESCRIPTION OF ADDITIONAL SCENARIOS

ACCELERATED CLEAN ELECTRICITY

This scenario includes a target to reach net-zero emissions by 2050 in all economic sectors, with an accelerated target for reaching 100% clean electricity by 2040.

DELAYED ACTION

This scenario includes a target to reach net-zero emissions by 2050 in all economic sectors, but the adoption of end-use technologies, such as electric vehicles and heat pumps, is delayed by 10-15 years.

LIMITED COAL AND GAS

This scenario includes a target to reach net-zero emissions by 2050 in all economic sectors with no new gas plants in the time frame and accelerated coal retirements. Limiting new gas and accelerating coal retirement reduces environmental and environmental justice costs of new fossil fuel construction and operation.

NO NEW TRANSMISSION EXPANSION

This scenario includes a target to reach net-zero emissions by 2050 in all economic sectors (including electricity) without expanding interstate transmission. This scenario is not included in the benefit-cost analysis because all data needed for the calculations are not included.

SUMMARY

When all benefits are included (system benefits, avoided health costs, and avoided CO2 costs), the **Net Zero Economy-Wide** scenario has higher net benefits ($111 billion dollars) and a higher benefit-cost ratio (2.0) than any of the three sub-scenarios.

The scenario with the highest net benefits of the three scenarios is the **Limited Coal and Gas** scenario, with a net benefit of $103.5 billion dollars. This scenario involves the highest costs but also the highest benefits. The ratio of benefits to costs is the lowest of the three at 1.83.

SCENARIO	BENEFITS INCLUDED	PRESENT VALUE BENEFITS (billion $)	PRESENT VALUE COSTS (billion $)[10]	RATIO
Accelerated Clean Electricity	System Benefits	113.91	120.05	0.95
	System Benefits + Avoided Health Costs [11]	181.54	120.05	1.51
	System Benefits + Avoided Health Costs + Avoided CO2 Costs	220.45	120.05	1.84
Delayed Action	System Benefits	75.89	97.17	0.78
	System Benefits + Avoided Health Costs	140.13	97.17	1.44
	System Benefits + Avoided Health Costs + Avoided CO2 Costs	183.22	97.17	1.89
Limited Coal and Gas	System Benefits	117.67	124.23	0.95
	System Benefits + Avoided Health Costs	180.87	124.23	1.46
	System Benefits + Avoided Health Costs + Avoided CO2 Costs	227.75	124.23	1.83

Table 5: Summary of Benefit-Cost Ratios for Key Decarbonization Scenarios

[10 Net present value of the costs includes only the costs of system investments.
[11] The estimate of avoided health costs in this table are the high estimates of the range detailed in this report.

ACCELERATED CLEAN ELECTRICITY

The **Accelerated Clean Electricity** scenario includes a target of meeting 100% clean electricity goals by 2040, rather than 2050, on top of a goal for economy-wide net-zero emissions by 2050. This accelerated timeline causes higher costs for energy system upgrades than the net-zero economy-wide by 2050 scenarios. The **Accelerated Clean Electricity** scenario costs $120 billion, whereas the **Net Zero Economy-Wide** scenario without the accelerated timeline energy system costs $111 billion. The direct benefits are also slightly higher in the **Accelerated Clean Electricity** scenario from avoided fossil fuel costs in the energy sector. In the **Accelerated Clean Electricity** scenario, these benefits are about $114 billion, whereas in the **Net Zero Economy-Wide** scenario, the benefits are about $110 billion.

The benefit-cost ratio of this scenario is 0.95 from 2023–2050. This is close to the benefit-cost ratio of the **Net Zero Economy-Wide** scenario (0.996). The net benefits are -$6 billion, meaning that the energy system costs outweigh the benefits of the energy system by $6 billion.

ACCELERATED CLEAN ELECTRICITY: ENERGY SYSTEM COSTS BY CATEGORY	
Cost of Clean Fuels	$4,966,150,003
Cost of Demand Side Investments	$42,362,035,001
Cost of Electric Sector	$71,932,942,957
Other Costs	$787,753,245
TOTAL	**$120,048,881,206**

Table 6.1. Energy System Costs by category in the **Accelerated Clean Electricity** scenario from 2023–2050, compared to baseline costs.

ACCELERATED CLEAN ELECTRICITY: ENERGY SYSTEM COSTS AND AVOIDED FOSSIL FUEL COSTS

ACCELERATED CLEAN ELECTRICITY: COSTS AND BENEFITS		
Cost	Energy System Upgrade Costs	$120,048,881,206
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$113,914,992,502

Table 6.2. Total costs and benefits from 2023–2050 in the **Accelerated Clean Electricity** scenario compared to baseline.

ACCELERATED CLEAN ELECTRICITY: SUMMARY			
TYPE OF CALCULATION	**CALCULATION**	**VALUE**	**ROUNDED VALUE**
Benefit : Cost Ratio	$113,914,992,502 / $120,048,881,206	0.95	1
Benefits - Costs	$113,914,992,502 - $120,048,881,206	-$6,133,888,704	-$6 billion

Table 6.3. Comparison of costs and benefits from 2023–2050 in the **Accelerated Clean Electricity** scenario compared to the baseline, only including energy system costs and benefits.

ACCELERATED CLEAN ELECTRICITY: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, AND HEALTH BENEFITS

The health benefits associated with the accelerated clean electricity scenario are similar to those in the net-zero economy-wide scenario - between $30 billion and $68 billion. These benefits are similar due to the coal plants retiring on similar timelines in both scenarios. Coal combustion for electricity production has considerable health impacts. Combining health impacts with energy system costs and benefits results in ratios between 1.12 and 1.51. This means that the benefits outweigh the costs between 2023 and 2050. When including health benefits, the net benefits over time are between $24 billion and $61 billion.

ACCELERATED CLEAN ELECTRICITY: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$120,048,881,206	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$113,914,992,502	
Benefit	Avoided health impacts	$30,061,478,091	$67,627,366,996

Table 6.4. Total costs and benefits from 2023–2050 in the **Accelerated Clean Electricity** scenario compared to baseline.

ACCELERATED CLEAN ELECTRICITY: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$143,976,470,593 / $120,048,881,206	1.12	1
	Benefits - Costs	$143,976,470,593 - $120,048,881,206	$23,927,589,387	$24 billion
High	Benefit:Cost Ratio	$181,542,359,498 / $120,048,881,206	1.51	2
	Benefits - Costs	$181,542,359,498 - $120,048,881,206	$61,493,478,292	$61 billion

Table 6.5. Comparison of costs and benefits from 2023–2050 in the **Accelerated Clean Electricity** scenario compared to the baseline, including energy system costs and benefits, and health benefits.

ACCELERATED CLEAN ELECTRICITY: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, HEALTH BENEFITS, AND AVOIDED CO2 EMISSIONS

Adding the avoided costs of carbon dioxide emissions to the accelerated clean electricity scenario is the last step of the benefit cost analysis of this scenario. These impacts are between $11 billion (using an estimate of $15 per ton) and $39 billion (using an estimate of $51 per ton).

The resulting ratio of benefits to costs is between 1.3 and 1.84, meaning the benefits outweigh the costs of the accelerated clean electricity scenario when including energy system costs, avoided fossil fuel costs, health benefits, and avoided carbon dioxide emissions. The net benefits are between $35 billion and $100 billion (table 6.7).

ACCELERATED CLEAN ELECTRICITY: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$120,048,881,206	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$113,914,992,502	
Benefit	Avoided health impacts	$30,061,478,091	$67,627,366,996
Benefit	Avoided CO2 impacts	$11,443,842,400	$38,909,064,160

Table 6.6. Total costs and benefits from 2023–2050 in the **Accelerated Clean Electricity** scenario compared to baseline.

ACCELERATED CLEAN ELECTRICITY: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$155,420,312,993 / $120,048,881,206	1.30	1
	Benefits - Costs	$155,420,312,993 - $120,048,881,206	$35,371,431,787	$35 billion
High	Benefit:Cost Ratio	$220,451,423,658 / $120,048,881,206	1.84	2
	Benefits - Costs	$220,451,423,658 - $120,048,881,206	$100,402,542,452	$100 billion

Table 6.7. Comparison of costs and benefits from 2023–2050 in the **Accelerated Clean Electricity** scenario compared to the baseline, including energy system costs and benefits, health benefits, and avoided CO2 impacts.

DELAYED ACTION

The **Delayed Action** scenario involves meeting net-zero emissions economy-wide by 2050, with a delay in the adoption of end-use technologies by 10-15 years. In this scenario, the costs of energy system changes are about $97 billion from 2023–2050, with the majority of these costs in the generation of electricity ($63 billion) and significant costs in demand side investments ($18 billion) and clean fuels ($14 billion). This cost breakdown is shown in Table 6.1.

The avoided costs of fossil fuels, counted as benefits in this study, are about $76 billion from 2023–2050 (Table 7.2). The costs, therefore, outweigh the benefits when exclusively considering direct economic costs and benefits of energy system changes. The ratio of benefits to costs is 0.78, with the costs about $21 billion more than the benefits. The net costs are higher than the **Net Zero Economy-Wide** scenario because the efficiency gains of electrified transportation and heat pumps are delayed, therefore more energy is being used for a longer period of time. More fossil fuels are also used for longer in non-electricity sectors, so the avoided fossil fuel costs (counted as benefits) are also less than in the **Net Zero Economy-Wide** scenario.

DELAYED ACTION: ENERGY SYSTEM COSTS BY CATEGORY	
Cost of Clean Fuels	$13,681,661,504
Cost of Demand Side Investments	$18,421,818,545
Cost of Electric Sector	$62,584,237,339
Other Costs	$2,482,968,418
TOTAL	**$97,170,685,805**

Table 7.1. Energy System Costs by category in the **Delayed Action** scenario from 2023–2050, compared to baseline costs.

DELAYED ACTION: ENERGY SYSTEM COSTS AND AVOIDED FOSSIL FUEL COSTS

DELAYED ACTION: COSTS AND BENEFITS		
Cost	Energy System Upgrade Costs	$97,170,685,805
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$75,890,581,918

Table 7.2. Total costs and benefits from 2023–2050 in the **Delayed Action** scenario compared to the baseline.

ACCELERATED CLEAN ELECTRICITY: SUMMARY			
TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Benefit : Cost Ratio	$75,890,581,918 / $97,170,685,805	0.78	1
Benefits - Costs	$75,890,581,918 - $97,170,685,805	-$21,280,103,888	-$21 billion

Table 7.3. Comparison of costs and benefits from 2023–2050 in the **Delayed Action** scenario compared to the baseline, only including energy system costs and benefits.

DELAYED ACTION: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, AND HEALTH BENEFITS

Adding health benefits to this analysis results in additional benefits. The health benefits in the D**elayed Action** scenario are between $29 billion and $64 billion (Table 7.4). These benefits come from a reduction in fossil fuel use compared to the baseline, which results in fewer emissions and fewer health impacts from those emissions. However, the health benefits ($29 billion - $64 billion) are slightly lower than in the **Net Zero Economy-Wide** scenario. This lower health benefit is associated with more fossil fuel use for longer in non-electricity sectors due to the delayed adoption of technologies like electric vehicles and heat pumps.

Adding the health benefits to the benefit-cost ratios results in a ratio of 1.08–1.44. Regardless of using the low or high estimate, the benefits outweigh the costs in the **Delayed Action** scenario when health impacts are added. The net benefits are between $7 billion and $43 billion (Table 7.5).

DELAYED ACTION: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$97,170,685,805	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$75,890,581,918	
Benefit	Avoided health impacts	$28,552,839,858	$64,239,852,472

Table 7.4. Total costs and benefits from 2023–2050 in the **Delayed Action** scenario compared to the baseline.

DELAYED ACTION: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$104,443,421,776 / $97,170,685,805	1.08	1
	Benefits - Costs	$104,443,421,776 - $97,170,685,805	$7,272,735,971	$7 billion
High	Benefit:Cost Ratio	$140,130,434,390 / $97,170,685,805	1.44	1
	Benefits - Costs	$140,130,434,390 - $97,170,685,805	$42,959,748,585	$43 billion

Table 7.5. Comparison of costs and benefits from 2023–2050 in the **Delayed Action** scenario compared to the baseline, including energy system costs and benefits, and health benefits.

DELAYED ACTION: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, HEALTH BENEFITS, AND AVOIDED CO2 EMISSIONS

The last step of the analysis for the **Delayed Action** scenario is adding the avoided carbon dioxide benefits. In this scenario, the monetized benefit of avoided carbon dioxide emissions is between $12 billion and $43 billion (Table 7.6). This is similar to, but slightly less than, the benefits of avoided carbon dioxide emissions in the **Net Zero Economy-Wide** scenario. Natural gas is used less in this scenario than in the **Net Zero Economy-Wide** scenario to generate electricity, while natural gas consumption in other sectors remains.

Adding carbon dioxide emission reductions also changes the benefit-cost ratios to 1.2–1.89, meaning that the benefits outweigh the costs by between $19 billion and $86 billion (Table 7.7).

DELAYED ACTION: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$97,170,685,805	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$75,890,581,918	
Benefit	Avoided health impacts	$28,552,839,858	$64,239,852,472
Benefit	Avoided CO2 impacts	$11,846,983,054	$43,088,873,339

Table 7.6. Total costs and benefits from 2023–2050 in the **Delayed Action** scenario compared to baseline.

DELAYED ACTION: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$116,290,404,830 / $97,170,685,805\	1.20	1
	Benefits - Costs	$116,290,404,830 - $97,170,685,805	$19,119,719,025	$19 billion
High	Benefit:Cost Ratio	$183,219,307,729 / $97,170,685,805	1.89	2
	Benefits - Costs	$183,219,307,729 - $97,170,685,805	$86,048,621,924	$86 billion

Table 7.7. Comparison of costs and benefits from 2023–2050 in the **Delayed Action** scenario compared to the baseline, including energy system costs and benefits, health benefits, and avoided CO2 impacts.

LIMITED COAL AND GAS

The **Limited Coal and Gas** scenario includes a target to reach net-zero emissions by 2050 in all economic sectors with no new gas plants in that time frame and accelerated coal retirements by 2030. Gas plants can be extended beyond their retirement dates, but no new gas plants can be built. While this is a faster retirement of coal, other scenarios have coal retiring at a similar trajectory, so coal retirements are only slightly faster. The limit of new gas is more impactful: since coal cannot be replaced by new gas, it is replaced by a large amount of renewable energy, and the lifetime of gas generation that already exists is extended. These gas facilities are less efficient than newer gas facilities, using more energy and more air pollution than new gas facilities.

The cost of energy system changes for the **Limited Coal and Gas** scenario is $124 billion, almost half of which ($76 billion) comes from electric sector costs (Table 8.1). This is primarily new renewable energy and storage built to replace coal and new gas. This is about $13 billion more than the **Net Zero Economy-Wide** scenario. The avoided costs of fossil fuels are also higher in this scenario ($118 billion) than in the **Net Zero Economy-Wide** scenario ($111 billion).

The costs in the **Limited Coal and Gas** scenario outweigh the benefits by about $7 billion, with a benefit-cost ratio of 0.95 (table 8.3). This is a lower ratio than the **Net Zero Economy-Wide** scenario, meaning that the costs more heavily outweigh the benefits in this scenario, but the two ratios are similar (0.95 and 0.996).

LIMITED COAL AND GAS: ENERGY SYSTEM COSTS BY CATEGORY	
Cost of Clean Fuels	$4,835,783,921
Cost of Demand Side Investments	$42,362,035,001
Cost of Electric Sector	$76,191,331,620
Other Costs	$845,275,219
TOTAL	**$124,234,425,761**

Table 8.1. Energy System Costs by category in the **Limited Coal and Gas** scenario from 2023–2050, compared to the baseline costs.

LIMITED COAL AND GAS: ENERGY SYSTEM COSTS AND AVOIDED FOSSIL FUEL COSTS

LIMITED COAL AND GAS: COSTS AND BENEFITS		
Cost	Energy System Upgrade Costs	$124,234,425,761
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$117,666,345,028

Table 8.2. Total costs and benefits from 2023–2050 in the **Limited Coal and Gas** scenario compared to the baseline.

LIMITED COAL AND GAS: SUMMARY			
TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Benefit : Cost Ratio	$117,666,345,028 / $124,234,425,761	0.95	1
Benefits - Costs	$117,666,345,028 - $124,234,425,761	-$6,568,080,733	-$7 billion

Table 8.3. Comparison of costs and benefits from 2023–2050 in the **Limited Coal and Gas** scenario compared to the baseline, only including energy system costs and benefits.

LIMITED COAL AND GAS: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, AND HEALTH BENEFITS

The health benefits associated with **Limited Coal and Gas** are between $28 billion and $63 billion (Table 8.4). This is less than the health benefits associated with the **Net Zero Economy-Wide** scenario. While coal is retired earlier in this scenario (associated with health benefits), the timeline for retiring coal in the baseline scenario is similar. The health benefits of retiring coal are large, but because coal is retired in all other scenarios by 2035, the health benefits in this scenario after 2030 are similar to the **Net Zero Economy-Wide** scenario. The inability in this scenario to replace retiring coal with more efficient natural gas in the near future results in lower-efficiency gas being used to replace coal, which is associated with adverse health impacts.

These health benefits are still impactful, however. Adding the health benefits to the **Limited Coal and Gas** scenario results in the benefits outweighing the costs by between $22 billion and $57 billion for a benefit-cost ratio of between 1.17 and 1.46 (Table 8.5).

DELAYED ACTION: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$124,234,425,761	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$117,666,345,028	
Benefit	Avoided health impacts	$28,092,431,501	$63,201,490,730

Table 8.4. Total costs and benefits from 2023–2050 in the **Limited Coal and Gas** scenario compared to the baseline.

DELAYED ACTION: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$145,758,776,529 / $124,234,425,761	1.17	1
	Benefits - Costs	$145,758,776,529 - $124,234,425,761	$21,524,350,768	$22 billion
High	Benefit:Cost Ratio	$180,867,835,758 / $124,234,425,761	1.46	1
	Benefits - Costs	$180,867,835,758 - $124,234,425,761	$56,633,409,997	$57 billion

Table 8.5. Comparison of costs and benefits from 2023–2050 in the **Limited Coal and Gas** scenario compared to the baseline, including energy system costs and benefits, and health benefits.

LIMITED COAL AND GAS: ENERGY SYSTEM COSTS, AVOIDED FOSSIL FUEL COSTS, HEALTH BENEFITS, AND AVOIDED CO2 EMISSIONS

The last step of the analysis of **Limited Coal and Gas** is to measure the benefits of avoided carbon dioxide emissions. The result is an additional benefit of between $13 billion and $46 billion. It also increases the net benefits to between $35 billion and $103 billion for benefit-cost ratios of between 1.28 and 1.83.

LIMITED COAL AND GAS: COSTS AND BENEFITS			
		LOW ESTIMATE	HIGH ESTIMATE
Cost	Energy System Upgrade Costs	$124,234,425,761	
Benefit	Avoided Costs of Fossil Fuels in Energy Systems	$117,666,345,028	
Benefit	Avoided health impacts	$28,092,431,501	$63,201,490,730
Benefit	Avoided CO2 impacts	$13,042,960,710	$46,880,571,714

Table 8.6. Total costs and benefits from 2023–2050 in the **Limited Coal and Gas** scenario compared to the baseline.

LIMITED COAL AND GAS: SUMMARY				
	TYPE OF CALCULATION	CALCULATION	VALUE	ROUNDED VALUE
Low	Benefit:Cost Ratio	$158,801,737,239 / $124,234,425,761	1.28	1
	Benefits - Costs	$158,801,737,239 - $124,234,425,761	$34,567,311,478	$35 billion
High	Benefit:Cost Ratio	$227,748,407,472 / $124,234,425,761	1.83	2
	Benefits - Costs	$227,748,407,472 - $124,234,425,761	$103,513,981,711	$104 billion

Table 8.7. Comparison of costs and benefits from 2023–2050 in the **Limited Coal and Gas** scenario compared to the baseline, including energy system costs and benefits, health benefits, and avoided CO2 impacts.

APPENDIX B: CARBON COST ANALYSIS

In this section, we compare the benefits of avoided CO2 emissions to the baseline using a wider range of social costs of carbon. This analysis is focused on the two main scenarios: **100% Clean Electricity** and **Net Zero Economy-Wide**.

In this analysis, we use the $190 social cost of carbon calculated by the United States Environmental Protection Agency as an additional carbon cost estimate.[12] In Table 9, we present the avoided carbon costs of two scenarios using the three CO2 cost estimates. In Table 10, we apply the medium and high CO2 costs to the net benefits and benefit-cost ratios of each scenario.

BENEFIT OF AVOIDED CARBON DIOXIDE EMISSIONS			
SCENARIO	LOW ($15 PER TON)	MEDIUM ($51 PER TON)	HIGH ($190 PER TON)
Net Zero Economy-wide	$12,782,584,067.52	$43,460,785,829.56	$161,912,731,521.89
100% Clean Electricity	$2,691,784,097.10	$9,152,065,930.13	$34,095,931,896.58

Table 9. Comparison of the value of avoided carbon dioxide emissions across cost of carbon metrics.

[12] The $190 social cost of carbon value from the Environmental Protection Agency includes changes in net agricultural productivity, human health effects, property damage from increased flood risk, changes in the frequency and severity natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The $190 estimate is based on a 2% discount rate using 2020 dollars.

SCENARIO	CO2 COST USED	PRESENT VALUE BENEFITS[13] (billion $)	PRESENT VALUE COSTS (billion $)	NET BENEFITS (billion $)	RATIO
Net Zero Economy-Wide	Low ($15 per ton)	191.48	111.12	80.36	1.72
	Medium ($51 per ton)	178.69	111.12	111.03	2.0
	High ($190 per ton)	222.15	111.12	229.49	3.06
100% Clean Electricity	Low ($15 per ton)	51.08	11.88	39.2	4.3
	Medium ($51 per ton)	57.54	11.88	45.66	4.84
	High ($190 per ton)	82.49	11.88	70.61	6.94

Table 10. Comparison of net benefits and benefit-cost ratios across values of avoided CO2 emissions.

This analysis shows that the value used to monetize avoided CO2 emissions is important to the total net benefits and benefit-cost ratio of each scenario. However, including avoided cost of fossil fuel investment, health benefits, and carbon benefits results in positive net benefits and benefit-cost ratios over 1 for each scenario regardless of carbon cost. This means that regardless of the monetization that we use, the magnitude of benefits changes, but we will see benefits regardless. The difference in magnitude of the benefit-cost ratio using the low CO2 cost versus the high CO2 cost is bigger for the **Net Zero Economy-Wide** scenario than the **100% Clean Electricity** scenario.

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[13] This includes avoided fossil fuel investment costs, avoided health costs, and avoided carbon costs. This includes the high estimate for health benefits.