METHODOLOGY

WEDGE DIAGRAM TOOL

SEPTEMBER 2017

MINNESOTA
LoGo
PEP

Prepared by:
LHB and the University of Minnesota, Center for Science, Technology, and Environmental Policy

This work is supported by the Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), under Award Number DE-DE-EE0007229. This project was made possible by a grant from the U.S. Department of Energy and the Minnesota Department of Commerce.

CONTENTS

Introduction 3

Baseline Data 3

Business-As-Usual (BAU) Forecast 3

Goals 5

Strategic Plan 5

Strategy Interactions 5
Definitions 6
Persistence of Strategies 8

1. Commercial/Industrial Efficiency
1.1. Energy Code Enforcement 8
1.2. Stretch Energy Code 9
1.3. Building Retrofits 11
1.4. Appliance, Equipment, and Fixture Efficiency 13
1.5. Efficient Building Operations 14
1.6. Behavior Change 15

2. Residential Efficiency
2.1. Energy Code Enforcement 16
2.2. Stretch Energy Code 17
2.3. Retrofit/Weatherization 19
2.4. Appliance, Equipment, and Fixture Efficiency 20
2.5. Behavior Change 22

3. Electric Grid Mix
3.1. Planned Portfolio Mix Changes 24
3.2. Increased Renewable Energy Standard (RES) 25

4. Renewable Energy
4.1. On-Site Photovoltaics 27
4.2. Green Power Purchase – Commercial/Industrial 28
4.3. Green Power Purchase – Residential 29

5. End-use Fuel Switching (coming soon)
5.1. Commercial/Industrial Fuel Switching (coming soon) 31
5.2. Residential Fuel Switching (coming soon) 32

Appendix 34

Default Values for User Inputs

Assumptions

Planned Portfolio Mixes

Bibliography 38

INTRODUCTION

Minnesota’s Local Government Project for Energy Planning (LoGoPEP) aims to engage local governments in committing to actionable strategies for energy and greenhouse gas emission reductions by providing communities with planning tools that will help them prioritize impactful strategies, understand implementation pathways, outline a plan for action, and measure progress toward their goals.

The wedge diagram tool allows users to explore a city’s potential energy futures through a web-based interactive diagram that shows forecasted city-wide greenhouse gas emissions from building energy consumption. The diagram includes historic baseline data, a business-as-usual forecast to 2040, reduction goals, and reduction “wedges” that can be achieved through actions such as implementing neighborhood outreach programs, developing new citywide regulations, and supporting statewide policies. By inputting levels of commitment to each building-energy reduction strategy, users can visualize the predicted impacts in real-time and prioritize high-impact strategies. The wedge diagram is intended to be a living tool that can be adapted each year as communities learn more about the impacts of their actions.

The wedge diagram tool is currently exclusive to non-travel energy, which comprises 55% of statewide emissions. To comprehensively address citywide emissions, local governments should also consider vehicle travel, air travel, waste, wastewater, and agricultural emissions.

BASELINE DATA

Baseline energy emissions data is reported through the Regional Indicators Initiative for 2007-2013 based on information provided by energy utilities and in compliance with the *U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions* produced by ICLEI.[1]

BUSINESS-AS-USUAL (BAU) FORECAST

The business-as-usual forecast for energy emissions is based upon the premise that the average person/building/job will use the same amount of energy in the future as they do today, and that the carbon-intensity of the energy used stays constant. This approach enables strategies such as efficiency improvements, updated building codes, and clean energy to be accounted for in the reduction wedges, whether these improvements are legislatively mandated, market-driven, or voluntary.

---

[1] For more information on the baseline emissions methodology, refer to the Regional Indicators Initiative website: www.regionalindicatorsmn.com.

Business-as-usual energy emissions in the year 2040 are estimated by:

1. Calculating the 5-year moving average residential energy consumption per person and commercial/industrial energy consumption per job from the baseline data for natural gas and electricity.
2. Multiplying the normalized energy consumption from Step 1 by population and jobs estimates for 2040, respectively, to get the total expected energy consumption.
3. Multiplying the total expected energy consumption by the most recent emissions factors for electricity and natural gas, respectively, to get the total expected energy emissions.

The baseline energy consumption, demographic data, and emissions factors are from the Regional Indicators Initiative data. Population and job forecasts are from the Metropolitan Council for communities within their jurisdiction.[2] Demographic forecasts for cities outside of the Twin Cities metropolitan region are from the Minnesota State Demographic Center.[3] Since projections are not available at the city scale, the Demographic Center recommended extrapolating city estimates by applying each city's 2015 share of its county's population to the county-level forecasts.

Since different portfolios of reduction strategies are available to new buildings versus existing buildings, the business-as-usual energy use needs to be divided between new and existing buildings to effectively calculate the reduction wedges. This is done by applying a new construction rate of 1.53% per year for commercial buildings and 1.35% per year for residential buildings, which reflects the average regional growth since 2000.[4] The remaining energy consumption is allocated to existing buildings.

Since this methodology does not account for city-specific building stock or growth projections, it likely results in an underestimate of new construction for rapidly growing communities.

---

[2] Metropolitan Council, "Population, Households and Employment Forecasts to 2040, Twin Cities Metropolitan Area (January 1, 2017)," 2017, https://metrocouncil.org/Data-and-Maps/Data/CouncilResearchProducts/Council-Forecasts.aspx.

[3] Minnesota State Demographic Center, "County Population Projections (March 2017)," 2017, "Minnesota County Labor Force Projections, 2015-2030," 2017. Since job projections are only available through 2030, a linear forecast is used to estimate later years.

[4] Survey results from the 2012 Commercial Building Energy Consumption Survey (CBECS) and the 2015 Residential Energy Consumption Survey (RECS) show the number of buildings and the year built for a statistical sample of buildings. This information can be used to estimate the historic new construction rate. The new construction rate of 1.53% per year for commercial buildings was calculated based on building area for the Midwest - West North Central region for the years 2000-2012. The new construction rate of 1.35% per year for residential buildings was calculated based on the number of housing units in the Midwest - West North Central region for the years 2000-2015. This time period was selected to moderate the effects of economic conditions. Since demolished buildings are not included in the survey data, the new construction rates may be slightly overestimated.

GOALS

While local governments are encouraged to develop their own emissions reduction goals, the wedge diagram tool also includes Minnesota's statewide goals from the Next Generation Energy Act of 2007: 30 percent below 2005 levels by 2025 and 80 percent below 2005 levels by 2050. Since the earliest available year of baseline data is 2007, this is used instead of 2005 to calculate the goal milestones.[5]

Note that the statewide goals are intended to address Minnesota's total emissions, not just those from building energy. Although here they have been applied directly to the building energy sector, it may be necessary to beat these goals to offset sectors that are more difficult to reduce, such as air travel.

STRATEGIC PLAN

The strategic plan shows the anticipated outcomes of committing to a set of emission reduction strategies selected by the user. The strategic plan is calculated by adjusting the business-as-usual forecast based on the sum of the reductions achieved through each of the selected strategies. The reduction strategies are categorized into five broad categories that reduce emissions through efficiency (using less energy) and decarbonization (using energy that results in fewer emissions). These categories include: Commercial/Industrial Efficiency, Residential Efficiency, Electric Grid Mix, Renewable Energy, and Fuel Switching.

Strategy Interactions

Energy planning should be approached through a combination of efficiency and decarbonization, targeting both the source of the energy and the end use. However, if the savings from efficiency and decarbonization are both calculated based on the business-as-usual energy use and emissions factors, the savings would be double-counted. To avoid this, savings are applied first to efficiency strategies, then to electric grid mix strategies, and finally to renewable energy and fuel switching strategies. In essence, efficiency savings are based on business-as-usual energy use and business-as-usual emissions factors. Electric grid mix strategies are based on planned energy use and business-as-usual emissions factors. Renewable energy and fuel switching strategies are based on planned energy use and planned emissions factors.

In addition to these big picture strategy interactions, there are also several overlaps between strategies within a single category. These interactions are described in the respective category sections.

---

[5] The assumption that 2005 emissions are comparable to 2007 emissions is supported at the statewide scale, where the two years were within 1% of each other. Anne Claflin, "Greenhouse Gas Emissions: 1990-2014," 2017, doi:10.1007/978-1-4419-7991-9.

Example

In 2030, Community A has a business-as-usual energy use of 1000 MMBtu and a business-as-usual emissions factor of 0.10 tCO2e/MMBtu. Community A commits to efficiency strategies that reduce energy use by 25% by 2030 and plans to install enough on-site photovoltaics to generate 100 MMBtu per year. The energy utility that serves Community A plans to reduce their emissions factor by 30% by 2030.

Energy Efficiency Reduction: 1000 MMBtu x 25% x 0.10 tCO2e/MMBtu = 25 tCO2e
Electric Grid Mix Reduction: 750 MMBtu x 0.10 tCO2e/MMBtu x 30% = 22.5 tCO2e
On-Site Photovoltaics Reduction: 100 MMBtu x 0.07 tCO2e/MMBtu = 7 tCO2e

Definitions

The following terms are used in the calculation of the savings potential associated with each strategy.

- **Emission reduction**
  For each strategy, the emission reduction represents the reduction in tonnes of carbon dioxide equivalents (tCO_2e) from the business-as-usual based on changes in energy intensity and emission intensity for each strategy.

- **Building energy use**
  Building energy use refers to the amount of energy used in buildings, in million British thermal units (MMBtu). This is the first data point needed for the energy efficiency strategies, and is typically separated into commercial and industrial buildings versus residential buildings, as well as existing versus new buildings. For strategies that have different savings rates based on fuel type, building energy use may also be separated between electricity and natural gas.

  While *BAU* building energy use is used as the starting point for all efficiency strategies, *planned* building energy use is the starting point for decarbonization strategies. Planned building energy use is defined as the amount of energy anticipated after all efficiency and fuel switching strategies are applied.

- **Implementation period**
  The implementation period is the time period during which each strategy is implemented. Some strategies result in savings that persist beyond their implementation period while others do not.

- **Participation rate**
  Participation rates are defined as the percentage of people or buildings adopting the given strategy, assuming all households operate at the same energy intensity, and all jobs have equivalent energy intensities. Since this is not true (especially for commercial/industrial buildings), the participation rate is more accurately described as the percentage of energy use that will be affected by the strategy. For example, if large commercial buildings comprise 25% of the

building stock, but use 50% of the energy, a strategy that targets all large commercial buildings would use a participation rate of 50%.

For one-time strategies such as equipment replacement or retrofits, participation rates are distributed equally across the implementation period selected for strategy adoption. For example, a participation rate of 15% for building retrofits from 2025-2040 would result in a 1% annual participation rate. For ongoing strategies such as behavior change or green power purchase, participation rates are assigned to each year of the designated implementation period. For example, a participation rate of 15% for behavior change from 2025-2040 would result in a 15% annual participation rate.

- **Energy savings rate**
  Energy savings rates are defined as the reduction in energy use from the BAU based upon the given strategy. Depending on the strategy, there may be separate energy savings rates for electricity versus natural gas.

- **Emissions factor**
  Emissions factors refer to the emissions intensity of each unit of energy consumed, in tonnes of carbon dioxide equivalent per million British thermal unit (tCO_2e/MMBtu). Since natural gas emission factors do not vary substantially over time, the emissions factor for natural gas remains constant at 0.05 tCO_2e/MMBtu.[6] The emission intensity of electricity changes based on the primary energy used to generate the electricity. In this analysis, electricity supplied through the grid is assigned an emissions factor that changes over time based on the anticipated portfolio mix of each utility serving the community. In communities served by multiple utilities, their emissions factor is a weighted average and may be different for the commercial/industrial sector than it is for the residential sector based on the percentage of the total load met by each utility. Electricity supplied through renewable energy – whether from green power purchase or on-site renewables – are assigned an emissions factor of zero.[7]

  While the *BAU* emissions factor is used to determine emissions savings for all efficiency strategies, the *planned* emissions factor is the starting point for decarbonization strategies. The planned emissions factor is the anticipated emissions factor of the grid, after applying the electric grid mix strategies.

---

[6] Table G.1 and G3, Local Government Operations Protocol, for the Quantification and Reporting of Greenhouse Gas Emissions Inventories, Version 1.1, May 2010.

[7] There is a risk of double-counting savings from renewable electricity if these savings are accounted for both within the utility's emissions factor and as a separate strategy. The emissions factors reported by Xcel Energy, for example, include the impact of Windsource customers on their grid average.

Persistence of Strategies

Persistence is defined as the effectiveness and longevity of reduction strategies after the initial implementation period. Savings from one-time strategies that are based on installed technology (e.g. Stretch Energy Code and Appliance, Equipment, and Fixture Efficiency) are typically assumed to persist throughout the planning horizon, reflecting the lifetime of the energy-saving building component or device. Savings from strategies that rely on the continued engagement of the building operator or occupants (e.g. Energy-Efficient Operations and Behavior Change) are assumed to be contingent on continued participation. Assumptions regarding persistence are described for each strategy in the documentation below.

1. COMMERCIAL/INDUSTRIAL EFFICIENCY

Increased energy efficiency in commercial and industrial new construction, renovations, and existing buildings can be achieved by improving the building's thermal envelope, using more efficient equipment, appliances, and fixtures, and using these devices more efficiently.

Strategy Interactions:

- The savings from these efficiency strategies are based on the business-as-usual emissions factor rather than the planned emissions factor.
- Savings from Energy Code Enforcement are applied before the Stretch Energy Code, so that the savings from a Stretch Energy Code are compared to the planned energy code, rather than compared directly to the business-as-usual.
- Buildings constructed within the planning horizon are not eligible for strategies for existing buildings. For example, a building constructed in 2025 can achieve ongoing savings through compliance with the energy code, but cannot achieve additional savings through efficient building operations. While this may underestimate the total savings potential for a new building, it avoids double-counting.
- The remaining commercial/industrial efficiency strategies are defined in a way that avoids overlap. For example, Building Retrofits include actions related to the building's thermal envelope, but not mechanical or electrical systems and devices, which are covered in Appliance, Equipment, and Fixture Efficiency. Efficient Building Operations addresses operations and maintenance practices that are typically within the control of a building operator, while actions that are controlled by building occupants are included in Behavior Change.

1.1. Energy Code Enforcement

New construction and renovation projects in Minnesota are required to comply with the Minnesota Energy Code. In 2015, Minnesota adopted the 2012 *International Energy Conservation Code* (IECC), which identifies energy conservation requirements for building envelopes and systems and references ASHRAE 90.1-2010 as a compliance pathway. This strategy estimates the emissions savings from the increased energy efficiency of a new building that complies with the current energy code as compared to a baseline building. To avoid double-counting with other strategies, renovations are not included within this strategy.

Emission Reduction (tCO2e) = BAU New Commercial/Industrial Building Energy Use (MMBtu) x Compliance Rate (% of new building area complying with the energy code) x Energy Savings Rate (%) x BAU Emissions Factor (tCO2e/MMBtu)

Inputs:

- Compliance Rate
  This refers to the percentage of new building area complying with the energy code. In 2012-2013, the average rate of compliance with the State's Energy Code was determined to be 91.8% for commercial buildings.[8]

Assumptions:

- The methodology for predicting energy use from new construction is described in the "Business-As-Usual Forecast" section at the beginning of this document.
- New buildings that comply with the energy code achieve 34.5% energy savings in comparison with the average baseline building.[9] This assumes the energy performance of the average baseline building is comparable to the ASHRAE 90.1-1989 energy code – which was in effect from 1991 to 2009 – and that meeting Minnesota's current energy code is equivalent to meeting ASHRAE 90.1-2010.[10]
- Although new versions of the energy code typically go into effect in Minnesota every 6 years, future energy code improvements are not modeled as part of this strategy. Commercial building energy savings have historically ranged from 3.2-11.9% for each 3-year code update.[11]
- Energy savings rates are applied equally to natural gas and electricity.
- Energy savings associated with energy-efficient building design and construction are expected to persist over the lifetime of the building.

1.2. Stretch Energy Code

This strategy involves meeting more aggressive energy performance thresholds for new construction than required by the current Energy Code, with the goal of producing as much energy on-site as is used. This concept is called net-zero energy. Minnesota has implemented a unique example of a net-zero energy standard

---

[8] Minnesota Department of Labor & Industry Construction Codes and Licensing Division, "Energy Code Compliance in Minnesota Baseline for ARRA Compliance," no. September (2013), http://bcapcodes.org/wp-content/uploads/2015/12/Energy-Code-Compliance-in-Minnesota-2012-2013-Baseline-for-ARRA-Compliance.pdf.

[9] J Zhang et al., "Energy and Energy Cost Savings Analysis of the IECC for Commercial Buildings," *Pacific Northwest National Laboratory*, no. August (2013): 1–87.

[10] Zhang et al., "Energy and Energy Cost Savings Analysis of the IECC for Commercial Buildings," Table C.3. ASHRAE 90.1-2010 is one compliance pathway in IECC 2012. Energy savings from ASHRAE 90.1-2010 are within 10% of the alternative pathway – a set of requirements specific to IECC 2012.

[11] Eric O'Shaughnessy et al., "Estimating the National Carbon Abatement Potential of City Policies: A Data-Driven Approach," 2016.

through a program called Sustainable Buildings 2030 (SB 2030), which sets stepped energy performance targets for new and renovated buildings that lead to net-zero energy building design by 2030. To avoid double-counting with other strategies, renovations are not included within this strategy.

The SB 2030 Energy Standard is currently required on projects that receive general obligation bond funding from the State of Minnesota, and there are several ways to expand this strategy to include additional buildings. Individual projects can elect to pursue aggressive performance targets (which may be incentivized through utility programs). Cities can require compliance with a green building policy for their own buildings and other projects that receive financial support or regulatory approval from the city. At the statewide scale, the building code can be revised to either adopt a more aggressive energy code or to provide a stretch code as an option that can be adopted by local jurisdictions.

Emission Reduction (tCO2e) = [BAU New Commercial/Industrial Building Energy Use (MMBtu) x Compliance Rate (% of new building area complying with stretch energy code) x Energy Emissions Savings Rate (%) - On-Site Renewable Electricity (MMBtu)] x BAU Emissions Factor (tCO2e/MMBtu) + On-Site Renewable Electricity (MMBtu) x Planned Electricity Emissions Factor (tCO2e/MMBtu)

Inputs:

- Compliance Rate
  This refers to the percentage of new building area that complies with the stretch energy code. The SB 2030 Energy Standard is currently required on projects that receive general obligation bond funding from the State of Minnesota. The default compliance rate of 15% approximates the percentage of new commercial buildings that could be impacted by a citywide green building policy.[12] This rate could approach 100% through state-level action to adopt a stretch energy code within – or as an appendix to – the state building code.

Assumptions:

- The methodology for predicting energy use from new construction is described in the "Business-As-Usual Forecast" section at the beginning of this document.
- The energy emissions savings rate increases over time, mimicking the savings anticipated through complying with SB 2030 and assuming a lag time between building design and occupancy. For example, a building that starts schematic design in 2030 would be designed to be net-zero energy, but may not actually be built and operational until 2035. The savings values are slightly different than the stated SB 2030 savings of 70%, 80%, and 90% due to a different baseline being used. SB 2030 uses a 2003 building, which has been estimated to be 10%

---

[12] This typically includes all public buildings in addition to private buildings that receive something of value from the City (e.g. such as financial assistance or Planned Unit Development approval). The default rate used here is an intuitive estimate, and should be refined based on a city-specific breakdown of new buildings.

worse than a building meeting ASHRAE 90.1 1989. The baseline building used here is assumed to meet ASHRAE 90.1 1989.

	2020	2025	2030	2035	2040
Energy Emissions Savings Rate	67%	78%	89%	100%	100%

- To avoid double-counting, energy emissions savings are adjusted from the user input to remove savings associated with energy code enforcement (Strategy 1.1).
- On-site renewable electricity is calculated based on the assumption that energy emissions savings of 84% can be achieved through efficiency.[13] The remaining 16% required to achieve net zero energy will need to be fulfilled by renewable energy generation.
- Renewable energy generation savings are based on the planned electricity emissions factor, rather than the BAU emissions factor.
- Energy savings rates are applied equally to natural gas and electricity.
- Energy savings associated with energy-efficient building design and construction are expected to persist over the lifetime of the building.

1.3. Building Retrofits

Commercial building retrofits are defined here as building envelope improvements that decrease the energy required for space conditioning due to reduced thermal transfer between the building interior and exterior. Retrofits can include wall and roof insulation, energy-efficient windows, and air sealing.

Emission Reduction (tCO2e) = BAU Existing Commercial/Industrial Building Electricity Use (MMBtu) x Participation Rate (% of existing buildings undergoing retrofit) x Electricity Savings Rate (%) x BAU Electricity Emissions Factor (tCO2e/MMBtu) + BAU Existing Commercial/Industrial Building Natural Gas Use (MMBtu) x Participation Rate (% of existing buildings undergoing retrofit) x Natural Gas Savings Rate (%) x BAU Natural Gas Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This refers to the percentage of commercial buildings expected to undergo a retrofit during the specified implementation period. Although these efficiency improvements produce economic savings for most buildings, only 2% of net

---

[13] Ibid. Based on discussions with Minnesota agency staff, the CSEO analysis estimates the contribution of different technologies toward achieving net-zero energy in 2030. Energy efficiency is estimated to comprise 78% of the required commercial electricity savings and 90.9% of the required commercial natural gas savings. Since commercial buildings typically use relatively equal amounts of electricity and natural gas, an unweighted average is used to estimate the total energy savings achievable through efficiency.

present value has been achieved nation-wide.[14] The default participation rate is 30%, which is based on the ultimate net participation rate estimated in a national study for commercial building retrofits.[15] This is described as an "aggressive but reasonable level of participation."

Assumptions:

- The energy savings rate for natural gas is 17%. This is derived from the assumption that heating loads can be reduced by 22% through changes to the building envelope that reflect the use of ENERGY STAR technologies.[16] Since 76.5% of commercial natural gas in the West North Central region is used for space heating,[17] reducing this heating load by 22% results in overall natural gas savings of 17%. Using the best available technologies, this savings rate could increase to 37%.[18]
- The energy savings rate for electricity is 2%. Electricity is used for both space heating and cooling in Minnesota, with 4% of total commercial electricity used for heating and 12% used for cooling.[19] Heating loads can be reduced by 22% and cooling loads can be reduced by 9% through changes to the building envelope that reflect the use of ENERGY STAR technologies.[20] This results in an overall electricity reduction of 0.9% from heating and 1.1% from cooling,

---

[14] Iain Campbell and Koben Calhoun, "Old Buildings Are U.S. Cities' Biggest Sustainability Challenge," *Harvard Business Review*, 2016.

[15] Dan York et al., "Frontiers of Energy Efficiency: Next Generation Programs Reach for High Energy Savings," no. January (2013).

[16] This 22% was derived from a graphic analysis of the graphs presented in the DOE's "Quadrennial Technology Review." Figure 5.3 shows that using ENERGY STAR technologies would reduce residential heating energy consumption by 38% (which is a combination of envelope strategies and equipment, appliance, and fixture strategies). Figure 5.9 shows that 59% of heating energy savings can be achieved through envelope strategies. 59% of 38% is 22%.

[17] U.S. EIA, "Table E7 . Natural Gas Consumption and Conditional Energy Intensities (Btu) by End Use, 2012 (CBECS)," 2016, https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e7.pdf.

[18] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities," no. September (2015): 1–505.

[19] U.S. EIA, "Table E5. Electricity Consumption (kWh) by End Use, 2012 (CBECS)," 2016, https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e5.pdf.

[20] The 9% cooling savings was derived from a graphic analysis of the graphs presented in the DOE's "Quadrennial Technology Review." Figure 5.3 shows that using ENERGY STAR technologies would reduce residential cooling energy consumption by 40% (which is a combination of envelope strategies and equipment, appliance, and fixture strategies). Figure 5.8 shows that 22% of the total possible cooling energy savings can be achieved through envelope strategies. 22% of 40% is 9%.

totaling 2%. Using the best available technologies, this savings rate could increase to 4%.[21]

- Energy savings from thermal envelope improvements are assumed to persist over the lifetime of the building since these savings are not dependent on occupant behavior.

1.4. Appliance, Equipment, and Fixture Efficiency

Existing commercial buildings can improve their energy efficiency by replacing mechanical equipment, lighting fixtures, and appliances.

Emission Reduction (tCO2e) = BAU Existing Commercial/Industrial Building Energy Use (MMBtu) x Participation Rate (% of existing buildings replacing appliances, equipment, and fixtures) x Energy Savings Rate (%) x BAU Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This refers to the percentage of existing commercial buildings expected to replace appliances, equipment, and fixtures with higher efficiency models during the specified implementation period. The default participation rate is 70%, which is based on the ultimate net participation rate estimated in a national study for commercial HVAC replacement.[22] This is described as an "aggressive but reasonable level of participation." With lower upfront cost and shorter payback periods, lighting fixture replacement is expected to achieve higher levels of participation (80%).[23]

Assumptions:

- The energy savings rate is 17%. This is derived from the U.S. Department of Energy's estimates of the national average savings of 21% for commercial buildings using ENERGY STAR technologies.[24] The envelope-driven portion of these savings is 4%, which is already accounted for in the Building Retrofits strategy. The remaining 17% is therefore attributed to Appliance, Equipment, and Fixture Efficiency. Nationally, annual reductions of 7% electricity and 8% natural gas are achieved in commercial buildings based on current appliance

---

[21] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities."

[22] York et al., "Frontiers of Energy Efficiency: Next Generation Programs Reach for High Energy Savings."

[23] Ibid.

[24] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities."

standards.[25] Savings up to 37% are achievable for commercial buildings using the best available technologies.[26]

- The energy savings are distributed equally between electricity and natural gas, with savings possible for lighting, ventilation, water heating, refrigeration, and equipment, along with some heating and cooling (some of which is included in the Building Retrofits strategy).
- The savings associated with appliance, equipment, and fixture replacement are assumed to persist over time.

1.5. Efficient Building Operations

Low to no-cost improvements in energy efficiency can be achieved through building operations by optimizing temperature setpoints and setback schedules and conducting equipment maintenance and diagnostics. In addition to regular diagnostic tasks conducted by the building operator, efficient building operations may also include periodic re-commissioning, during which a certified professional will systematically identify and remedy energy wasting malfunctions.

Emission Reduction (tCO2e) = BAU Existing Commercial/Industrial Building Energy Use (MMBtu) x Participation Rate (% of existing buildings undergoing efficient building operations) x Energy Savings Rate (%) x BAU Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This represents the percentage of commercial buildings practicing energy-efficient operations during each year of the specified implementation period. The default participation rate is 85%, which is based on the ultimate net participation rate estimated in a national study for commercial building operations and performance programs.[27] This is described as an "aggressive but reasonable level of participation."

Assumptions:

- The Energy Savings Rate is 23%. This reflects the savings potential simulated by the New Buildings Institute for implementing best practices for commissioning, operations, and maintenance in a mid-size office building in Minneapolis and

---

[25] Amanda Lowenberger et al., "The Efficiency Boom: Cashing In on the Savings from Appliance Standards" 20045, no. 202 (2012): 1–87.

[26] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities."

[27] York et al., "Frontiers of Energy Efficiency: Next Generation Programs Reach for High Energy Savings."

Duluth.[28] This is on the conservative end of the savings potential of 23-30% modeled on a national scale by the Pacific Northwest National Laboratory.[29]

- The persistence of savings for this strategy relies on the continued implementation of energy-efficient operation practices. If the participation rate drops, savings achieved in previous years will not persist. This may slightly underestimate the continued savings from this strategy; the average persistence for retrocommissioning programs range from 5-7 years, and a 3-year life is assumed for programs like strategic energy management.[30]

1.6. Behavior Change

Businesses and industries can reduce their energy consumption through actions such as using smart power strips and power management strategies to reduce plug loads, turning off lights and computers, using operable windows and blinds to control heat gain, and adjusting temperature setpoints. These actions can be supported through behavior change programs that are based on information, education, and/or social interaction.[31] Examples of behavior change programs include real-time feedback, competitions, and strategic energy management led by an energy champion.

Emission Reduction (tCO2e) = BAU Existing Commercial/Industrial Building Energy Use (MMBtu) x Participation Rate (% of buildings participating in behavior change program) x Energy Savings Rate (%) x BAU Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This represents the percentage of commercial buildings engaged in behavior change strategies during each year of the specified implementation period. The default participation rate is 33%, which is the projected adoption rate of strategic energy management in 2030.[32]

---

[28] Mark Frankel, Morgan Heater, and Jonathan Heller, "Sensitivity Analysis: Relative Impact of Design, Commissioning, Maintenance and Operational Variables on the Energy Performance of Office Buildings," *ACEEE Summer Study on Energy Efficiency in Buildings, August 12-17*, 2012, 52–64, https://newbuildings.org/wp-content/uploads/2015/11/SensitivityAnalysis_ACEEE20122.pdf.

[29] N Fernandez et al., "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction," 2017, http://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf. The cited range of savings reflects seven of the nine commercial building types studied, excluding secondary schools (49%) and stand-alone retail/dealership (41%).

[30] York et al., "Frontiers of Energy Efficiency: Next Generation Programs Reach for High Energy Savings."

[31] Reuven Sussman and Maxine Chikumbo, "Behavior Change Programs: Status and Impact," *ACEEE Report*, no. October (2016).

[32] Ibid.

Assumptions:

- The average percentage reduction in energy consumption for businesses engaged in behavior change activities is 5%. This is within the range of savings typically achieved through real-time feedback (1%-15%), persuasive messaging (1.2%-8%), competitions (1.8%-21%), and in-person strategies (4.4%-27%).[33]
- The energy savings rate is applied equally to natural gas and electricity. In practice, commercial behavior change programs often achieve higher savings in electricity than natural gas – whether due to being targeted at electricity only, or due to the types of actions taken.[34]
- The energy savings rate is assumed to be constant over time. This does not account for variations in savings as programs ramp-up or as the participants' engagement level changes.[35]
- Long-term persistence rates for behavior change strategies are currently unknown, but are likely to depend on the duration of user exposure to the program.[36,37] Here, the persistence of savings for this strategy is assumed to rely on the continued implementation of behavior-based energy management.

2. RESIDENTIAL EFFICIENCY

2.1. Energy Code Enforcement

New construction and renovation projects in Minnesota are required to comply with the Minnesota Energy Code. In 2015, Minnesota adopted the 2012 *International Energy Conservation Code* (IECC), which identifies energy conservation requirements for building envelopes and systems. This strategy estimates the emissions savings from the increased energy efficiency of a residential building that complies with the current energy code as compared to a baseline building. To avoid double-counting with other strategies, renovations are not included within this strategy.

Emission Reduction (tCO2e) = BAU New Residential Building Energy Use (MMBtu) x Compliance Rate (% of new building area complying with the energy code) x Energy Savings Rate (%) x BAU Emissions Factor (tCO2e/MMBtu)

---

[33] Ibid.

[34] Ibid.

[35] Ibid.

[36] Heidi Ochsner, Alden Jones, and Rita Siong, "Persistence of Behavioral Energy Management Activities and Savings in Commercial Office Buildings," in *Behavior, Energy & Climate Change Conference* (Washington, 2014), doi:10.5811/westjem.2011.5.6700.

[37] Peter Therkelsen and Prakash Rao, "Organizational Change in Industry Through Strategic Energy Management : Results and Barriers to Success," in *Behavior, Energy & Climate Change Conference* (Sacramento, 2015).

Inputs:

- Compliance Rate
  This refers to the percentage of new building area complying with the current energy code. In 2012-2013, the average rate of compliance with the State's Energy Code was determined to be 76.8% for residential buildings.[38]

Assumptions:

- New buildings that comply with the energy code achieve 38.5% energy savings in comparison with the average baseline building.[39] This assumes the energy performance of the average baseline building is comparable to the 1989 Model Energy Code (MEC) – which was in effect during the 1990s – and that meeting Minnesota's current energy code is equivalent to meeting 2012 IECC.[40]
- Although new versions of the energy code typically go into effect in Minnesota every 6 years, future energy code improvements are not modeled as part of this strategy.
- Energy savings rates are applied equally to natural gas and electricity.
- Energy savings associated with energy-efficient building design and construction are expected to persist over the lifetime of the building.

2.2. Stretch Energy Code

This strategy involves meeting more aggressive energy performance thresholds for new construction than required by the current Energy Code, with the goal of producing as much energy on-site as is used. This concept is called net-zero energy. Minnesota has implemented a unique example of a net-zero energy standard through a program called Sustainable Buildings 2030 (SB 2030), which sets stepped energy performance targets for new and renovated buildings that lead to net-zero energy building design by 2030. To avoid double-counting with other strategies, renovations are not included within this strategy.

The SB 2030 Energy Standard is currently required on projects that receive general obligation bond funding from the State of Minnesota, and there are several ways to expand this strategy to include additional buildings. Individual projects can elect to pursue aggressive performance targets (which may be incentivized through utility programs). Cities can require compliance with a green building policy for their own buildings and other projects that receive financial support or regulatory approval from the city. At the statewide scale, the building code can be revised to either

---

[38] Minnesota, Department of Labor & Industry Construction Codes and Licensing Division. 2013. "Energy Code Compliance in Minnesota Baseline for AARA Compliance," no. September. http://bcapcodes.org/wp-content/uploads/2015/12/Energy-Code-Compliance-in-Minnesota-2012-2013-Baseline-for-ARRA-Compliance.pdf.

[39] Jeremy Williams, "Presentation Overview : Introduction Statutory Requirements Program Structure Recent Accomplishments" (U.S. Department of Energy, 2014).

[40] ASHRAE 90.1-2010 is one compliance pathway in IECC 2012. Energy savings from ASHRAE 90.1-2010 are within 10% of the alternative pathway – a set of requirements specific to IECC 2012. Zhang et al., "Energy and Energy Cost Savings Analysis of the IECC for Commercial Buildings," Table C.3.

adopt a more aggressive energy code or to provide a stretch code as an option that can be adopted by local jurisdictions.

Emission Reduction (tCO2e) = [BAU New Residential Building Energy Use (MMBtu) x Compliance Rate (% of new building area complying with stretch energy code) x Energy Emissions Savings Rate (%) - On-Site Renewable Electricity (MMBtu)] x BAU Emissions Factor (tCO2e/MMBtu) + On-Site Renewable Electricity (MMBtu) x Planned Electricity Emissions Factor (tCO2e/MMBtu)

Inputs:

- Compliance Rate
  This refers to the percentage of new building area that complies with the stretch energy code. The SB 2030 Energy Standard is currently required on projects that receive general obligation bond funding from the State of Minnesota. The default compliance rate of 15% approximates the percentage of new residential buildings that could be impacted by a citywide green building policy.[41] This rate could approach 100% through state-level action to adopt a stretch energy code within – or as an appendix to – the state building code.

Assumptions:

- The methodology for predicting energy use from new construction is described in the “Business-As-Usual Forecast” section at the beginning of this document.
- The energy emissions savings rate increases over time, mimicking the savings anticipated through complying with SB 2030 and assuming a lag time between building design and occupancy. For example, a building that starts schematic design in 2030 would be designed to be net-zero energy, but may not actually be built and operational until 2035. The savings values are slightly different than the stated SB 2030 savings of 70%, 80%, and 90% due to a different baseline being used. SB 2030 uses a 2003 building, which has been estimated to be 10% worse than a building meeting 1989 MEC. The baseline building used here is assumed to meet 1989 MEC.

	2020	2025	2030	2035	2040
Energy Emissions Savings Rate	67%	78%	89%	100%	100%

- To avoid double-counting, energy emissions savings are adjusted from the user input to remove savings associated with energy code enforcement (Strategy 1.1).

---

[41] This typically includes all public buildings in addition to private buildings that receive something of value from the City (e.g. such as financial assistance or Planned Unit Development approval). The default rate used here is an intuitive estimate, and should be refined based on a city-specific breakdown of new buildings.

- On-site renewable electricity is calculated based on the assumption that energy emissions savings of 80% can be achieved through efficiency.[42] The remaining 20% required to achieve net zero energy will need to be fulfilled by renewable energy generation.
- Renewable energy generation savings are based on the planned electricity emissions factor, rather than the BAU emissions factor.
- Energy savings rates are applied equally to natural gas and electricity.
- Energy savings associated with energy-efficient building design and construction are expected to persist over the lifetime of the building.

2.3. Retrofit/Weatherization

Home weatherization is defined here as building envelope improvements that decrease the energy required for space conditioning due to reduced heat transfer between the building interior and exterior. Weatherization methods can include wall and roof insulation, energy-efficient windows, and air sealing. Programs such as home energy audits can help homeowners identify and prioritize impactful envelope upgrades. This strategy applies to existing homes and does not include improvements to mechanical or electrical systems.

Emission Reduction (tCO2e) = BAU Existing Residential Building Electricity Use (MMBtu) x Participation Rate (% of existing buildings undergoing retrofit) x Electricity Savings Rate (%) x BAU Electricity Emissions Factor (tCO2e/MMBtu) + BAU Existing Residential Building Natural Gas Use (MMBtu) x Participation Rate (% of existing buildings undergoing retrofit) x Natural Gas Savings Rate (%) x BAU Natural Gas Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This refers to the percentage of residential buildings expected to undergo a retrofit during the implementation period specified. A study of eight utility-led programs found that participation rates for building energy efficiency programs range from 0.6% to 16.1%, with an average of 4%.[43] However, improving program design could increase participation rates to above 50%.[44]

---

[42] Ibid. Based on discussions with Minnesota agency staff, the CSEO analysis estimates the contribution of different technologies toward achieving net-zero energy in 2030. Energy efficiency is estimated to comprise 78.5-79.5% of the required residential electricity savings and 76.5-85.2% of the required residential natural gas savings.

[43] O'Shaughnessy et al., "Estimating the National Carbon Abatement Potential of City Policies: A Data-Driven Approach."

[44] Ibid.

Assumptions:

- The energy savings rate for natural gas is 37%. This is derived from the assumption that heating loads can be reduced by 52% through changes to the building envelope that reflect the use of ENERGY STAR technologies.[45] Since 72% of residential natural gas in the West North Central region is used for space heating,[46] reducing this heating load by 52% results in overall natural gas savings of 37%. Using the best available technologies, this savings rate could increase to 71%, practically eliminating the need for space heating.[47]
- The energy savings rate for electricity is 6%. Electricity is used for both space heating and cooling in Minnesota, with 10% of total electricity used for heating and 5% used for cooling.[48] Heating loads can be reduced by 52% and cooling loads can be reduced by 24% through changes to the building envelope that reflect the use of ENERGY STAR technologies.[49] This results in an overall electricity reduction of 5% from heating and 1% from cooling, totaling 6%. Using the best available technologies, this savings rate could increase to 12%.[50]
- Energy savings from thermal envelope improvements are assumed to persist over the lifetime of the building since these savings are not dependent on occupant behavior.

2.4. Appliance, Equipment, and Fixture Efficiency

Existing residential buildings can improve their energy efficiency by replacing inefficient mechanical equipment, lighting fixtures, and appliances. There are currently federal appliance and equipment efficiency standards for over 60 product

---

[45] This 52% was derived from a graphic analysis of the graphs presented in the DOE's "Quadrennial Technology Review." Figure 5.2 shows that using ENERGY STAR technologies would reduce residential heating energy consumption by 53% (which is a combination of envelope strategies and equipment, appliance, and fixture strategies). Figure 5.7 shows that 98% of heating energy savings can be achieved through envelope strategies, with the other 2% coming from equipment. 98% of 53% is 52%.

[46] U.S. EIA, "Table CE4.3. Household Site End-Use Consumption by Fuel in the Midwest Region, Totals, 2009 (RECS)," 2013, https://www.eia.gov/consumption/residential/data/2009/index.php?view=consumption#end-use-by-fuel.

[47] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities."

[48] U.S. EIA, "Table CE4.3. Household Site End-Use Consumption by Fuel in the Midwest Region, Totals, 2009 (RECS)."

[49] The 24% cooling savings was derived from a graphic analysis of the graphs presented in the DOE's "Quadrennial Technology Review." Figure 5.2 shows that using ENERGY STAR technologies would reduce residential cooling energy consumption by 33% (which is a combination of envelope strategies and equipment, appliance, and fixture strategies). Figure 5.6 shows that 74% of the total possible cooling energy savings can be achieved through envelope strategies. 74% of 33% is 24%. See earlier footnote for description of the 52% heating savings.

[50] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities."

types, representing about 90% of home energy use.[51] Higher efficiency can be promoted through voluntary product certification through programs such as ENERGY STAR, which use 10-50% less energy than standard models.[52]

Emission Reduction (tCO2e) = BAU Existing Residential Building Energy Use (MMBtu) x Participation Rate (% of existing households replacing appliances, equipment, and fixtures) x Energy Savings Rate (%) x Ratio of Electricity to Natural Gas Savings x BAU Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This refers to the percentage of existing residential buildings replacing appliances, equipment, and fixtures during the implementation period specified. The default rate of 50% is based on the ultimate net participation rate estimated in a national estimate of savings potential for the replacement of residential lighting, appliances, and mechanical systems.[53] This is described as an "aggressive but reasonable level of participation."

Assumptions:

- The energy savings rate is 13%. This is derived from the U.S. Department of Energy's estimates of the national average savings of 30% for residential buildings using ENERGY STAR technologies.[54] The envelope-driven portion of these savings is 17%, which is already accounted for in the Retrofit/Weatherization strategy. The remaining 13% is therefore attributed to Appliance, Equipment, and Fixture Efficiency. A portion of these savings can be achieved through federal appliance standards, which in 2015 were estimated to save 23% for electricity and 6% for natural gas.[55] Savings up to 18% are achievable for households using the best available technologies.[56]

---

[51] U.S. DOE Building Technologies Office, "Saving Energy and Money with Appliance and Equipment Standards in the United States," Updated January 2017, https://energy.gov/sites/prod/files/2017/01/f34/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet-011917_0.pdf

[52] U.S. Environmental Protection Agency, "ENERGY STAR Qualified Appliances," https://www.energystar.gov/ia/new_homes/features/Appliances_062906.pdf

[53] York et al., "Frontiers of Energy Efficiency: Next Generation Programs Reach for High Energy Savings."

[54] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities."

[55] Joanna Mauer, "Energy-Saving States of America : How Every State Benefits from National Appliance Standards," *Appliance Standards Awareness Project and American Council for an Energy-Efficient Economy*, no. February (2017).

[56] U.S. DOE, "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities."

- The energy savings are distributed equally between electricity and natural gas, with savings possible for lighting, water heating, refrigeration, and drying, along with minimal HVAC (most of which is included in the Retrofit/Weatherization strategy).
- The savings associated with appliance, equipment, and fixture replacement are assumed to persist over time.

2.5. Behavior Change

Residents can reduce their household energy consumption through actions such as turning off lights and computers, using operable windows and blinds to control heat gain, and adjusting temperature setpoints. These actions can be supported through behavior change programs that are based on information, education, and/or social interaction.[57] Examples of behavior change programs include home energy reports that encourage conformation to social norms by comparing a household's energy use to that of its neighbors, real-time feedback, and competitions.

Emission Reduction (tCO2e) = BAU Residential Energy Use (MMBtu) x Participation Rate (% of households participating in behavior change program) x Energy Savings Rate (%) x BAU Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This represents the percentage of households engaged in behavior change strategies during each year of the specified implementation period. Participation rates can be increased through behavior change programs, which may be implemented as "opt-out" programs – in which all residents participate unless they request to be excluded – or "opt-in" programs in which residents actively choose to participate. Opt-in programs typically have lower participation rates (~20%), but result in higher per-customer savings than opt-out programs.[58] The default participation rate used here is 98%, which is modeled upon an opt-out home energy report program.[59]

Assumptions:

- The average percentage reduction in energy consumption for households engaged in behavior change activities is 1.6%. Energy savings for behavior change programs vary based on program design, with higher per-customer savings achieved through opt-in programs than through opt-out programs. While savings from opt-in home energy report programs can reach as high as 16%, opt-out program savings range from 1.2-2.2% for electricity and 0.3-1.6%

---

[57] Sussman and Chikumbo, "Behavior Change Programs: Status and Impact."

[58] Ibid.

[59] Ibid.

for natural gas.[60] This is similar to the savings seen from real-time feedback, with demonstrated savings of 1% and a theoretical maximum potential of up to 17%.[61] Savings from residential competitions range from 0.7-14% for electricity and 0.4-10% for natural gas, with most achieving savings of 5% or less.[62]

- The energy savings rate is applied equally to natural gas and electricity. In practice, residential behavior change programs often achieve higher savings in electricity than natural gas – whether due to being targeted at electricity only, or due to the types of actions taken.[63]
- The energy savings rate is assumed to be constant over time. This does not account for variations in savings as programs ramp-up or as the participants' engagement level changes.[64]
- The persistence of savings for this strategy relies on the continued implementation of behavioral practices.[65] If the participation rate drops, savings achieved in previous years will not persist.[66]

3. ELECTRIC GRID MIX

With the majority of non-travel energy emissions attributed to electricity consumption, strategies that impact the electric generation sector have the potential to result in significant savings. This wedge includes strategies that shift the primary energy used to generate electricity for the grid to less carbon-intensive sources.

Strategy Interactions:

- The savings from these strategies are based on planned – not business-as-usual – electricity use. Increasing energy efficiency will decrease the savings from these strategies.
- If both strategies are selected, the Planned Portfolio Mix Changes are applied before the Accelerated Portfolio Mix Changes, so that the Accelerated Changes represent only the savings that are above and beyond the Planned Changes.
- Electric grid mix strategies are treated independently from the renewable energy strategies. It is assumed that the renewable energy strategies occur in addition to electric grid mix changes, rather than counting local renewable energy generation toward system-wide emissions reduction goals. This reflects current practice for green power purchase programs in which the renewable

---

[60] Ibid.

[61] Ibid.

[62] Ibid.

[63] Ibid.

[64] Ibid.

[65] Ibid.

[66] A study has shown that suspending a home energy report program after two years of ongoing participation resulted in energy savings declining at a rate of 20% per year for two years. This gradual decline is not reflected in this tool. Ibid.

energy credit (REC) is owned by the end customer, but may result in an overestimate of savings when RECs are owned by the utility, which is often the case for community solar projects.
- To avoid double-counting, the emissions savings from any displaced electricity achieved through the Renewable Energy strategies are based on the planned emissions intensity of the grid, which is selected in this section. For example, if the grid mix is less clean, the savings from an on-site photovoltaic system will be greater.

3.1. Planned Portfolio Mix Changes

Minnesota's Renewable Energy Standard requires electric utilities to procure at least 25% of their portfolio from renewable sources by 2025. This has resulted in a reduction in the electricity emissions factor during the baseline time period, and will continue to achieve reductions through 2025. In addition to these legislated savings, electric utilities impact their emissions factor through other portfolio management decisions, such as switching from coal-fired power plants to natural gas. This strategy is based on the projected emissions factors identified by electric utilities in their Integrated Resource Plans (IRPs).[67]

Emission Reduction (tCO2e) = Planned Electricity Use (MMBtu) x Difference between BAU Electricity Emissions Factor and Planned Portfolio Mix Emissions Factor (tCO2e/MMBtu)

Assumptions:
- The savings from planned portfolio mix changes are estimated by calculating a weighted emissions factor based on the breakdown of primary fuels forecasted by electricity suppliers (e.g. 15% coal, 22% natural gas, etc.) in conjunction with the emissions factors by fuel type provided by the U.S. Energy Information Administration.[68] Utility-specific values were calculated for the electricity providers serving the greatest number of Minnesota customers. All other electricity providers are using the regional average for Midwest Reliability Organization West (MRO West).

---

[67] Every two years, electric utilities submit IRPs to the Public Utilities Commission that for the next 15 years, indicating the resource options they might use to meet the service needs of their customers.

[68] U.S. EIA, “Table A.3. Carbon Dioxide Uncontrolled Emission Factors,” n.d., https://www.eia.gov/electricity/annual/html/epa_a_03.html. See Appendix for planned portfolio mix by fuel type for each electricity provider, which is derived from their Integrated Resource Plans (IRPs).

Planned Emissions Factor Savings Rates:

	2020	2025	2030
Xcel Energy	19%	29%	35%
SMMPA	7%	14%	14%
Great River Energy	5%	9%	14%
Minnesota Power	8%	16%	16%
Ottertail Power	7%	14%	21%
MRO West[69]	0%	0%	0%

3.2. Increased Renewable Energy Standard (RES)

Emissions rate savings beyond those currently planned by electric utilities could be achieved through a more ambitious transition to renewable sources. This strategy is based on procuring 50% of the grid portfolio from renewable sources by 2030.

Emission Reduction (tCO2e) = Planned Electricity Use (MMBtu) x Difference between Planned Electricity Emissions Factor (before applying the RES) and Increased Renewable Energy Standard Emissions Factor (tCO2e/MMBtu)

Increased Renewable Energy Standard Emissions Factor (tCO2e/MMBtu) = Planned Electricity Emissions Factor (before applying the RES) (tCO2e/MMBtu) / % of Planned Electricity Generated from Non-Renewable Sources (before applying the RES) x % of Planned Electricity Generated from Non-Renewable Sources (after applying the RES)

Assumptions:

- Renewable electricity sources will be added to the grid mix until a total of 50% is achieved in 2030. If the Planned Portfolio Mix already exceeds 50% renewables, this strategy will not have an impact.
- The percentage of planned electricity generated from non-renewable sources before applying the RES is based on the Planned Portfolio Mix. Utility-specific values were calculated for the five electricity providers serving the greatest number of Minnesota customers.[70] For all other electricity providers, the regional average for Midwest Reliability Organization West (MRO West) is used. If the Planned Portfolio Mix is not selected, the baseline portfolio mix is assumed.

---

[69] Since there is not an integrated resource plan for the region as a whole, the planned portfolio mix changes are here assumed to only include what is required to meet state and federal mandates. The only mandate currently in place is to meet Minnesota's 25% Renewable Energy Standard. Since the baseline grid mix already meets this requirement, the grid mix is assumed to remain constant for the purposes of the Planned Portfolio Mix Changes strategy.

[70] See Appendix for planned portfolio mix by fuel type for each electricity provider, which is derived from their Integrated Resource Plans (IRPs).

Planned Electricity Generated from Non-Renewable Sources (before RES):

	2015	2020	2025	2030
Xcel Energy	75%	65%	63%	65%
SMMPA	86%	79%	72%	72%
Great River Energy	79%	75%	72%	68%
Minnesota Power	75%	70%	65%	65%
Ottertail Power	84%	80%	75%	71%
MRO West	75%	75%	75%	75%

- The percentage of planned electricity generated from non-renewable sources after applying the RES is 50% in 2030, matching the proposed increase in the RES. Years prior to 2030 are estimated based on a linear increase in the percentage of renewables from the planned portfolio mix in 2020 to 50% in 2030. Years after 2030 are assumed to remain constant at 50%.
- Renewables replace non-renewable sources in equal proportions, rather than targeting specific energy sources. In practice, this would be determined through integrated resource planning. This method will therefore underestimate savings from utilities that replace carbon-intensive energy sources (e.g. coal) and overestimate savings from utilities that replace carbon-neutral energy sources (e.g. nuclear) with renewables.

4. RENEWABLE ENERGY

In addition to the energy transition occurring at the scale of the electric grid, local commitment to renewable energy can contribute to emissions reductions. This wedge includes strategies such as green power purchase by residents and businesses as well as on-site renewable installations.

Strategy Interactions:

- The savings from these strategies are based on planned – not business-as-usual – electricity use. Increasing energy efficiency will decrease the savings from these strategies.
- Renewable energy strategies are limited to meet a maximum of 100% of the community’s energy demand, meaning that excess energy production cannot be used to offset other sources. This does not reflect current practice – in which a household with solar panels could be a net-positive energy prosumer – and may not reflect the community’s approach to carbon accounting.
- It is assumed that the renewable energy strategies occur in addition to electric grid mix changes, rather than counting local renewable energy generation toward system-wide emissions reduction goals. This reflects current practice for green power purchase programs in which the renewable energy credit (REC) is owned by the end customer, but may result in an overestimate of savings when RECs are owned by the utility, which is often the case for community solar projects.
- The savings from renewable energy strategies are based on the planned emissions intensity of the grid, which is specified in the electric grid mix wedge.

If the grid mix is less carbon-intensive, the savings from additional renewable energy will be reduced.

- The selected renewable energy strategies are combined with the selected electric grid mix strategy to determine the planned carbon intensity of energy used within the community. This planned carbon intensity is used to calculate savings from the fuel switching strategies. For example, if residents switched from natural gas water heaters to electric water heaters, the resulting electricity use is assigned an emissions factor that accounts for both green power purchase and a cleaner grid.

4.1. On-Site Photovoltaics

Minnesota has a goal of meeting 1.5% of its annual electricity consumption through solar energy by 2020 and 10% by 2030.[71] Building owners may elect to install photovoltaic panels on their roofs to reduce their electricity costs and carbon footprint. The generated electricity can either be used on site, which may require energy storage, or sold back to the grid. This strategy is dependent on the amount of viable rooftop area within the community that receives adequate solar energy.

Emission Reduction (tCO2e) = Rooftop Solar Resource (MWh) x Electricity Conversion Factor (MMBtu/MWh) x Rooftop Utilization Rate (%) x Planned Emissions Factor (tCO2e/MMBtu)

Inputs:

- Rooftop Solar Resource (MWh)
  This is the total viable rooftop solar generation potential within the community. This can be estimated using a solar suitability tool that considers the amount of solar energy reaching a rooftop as well as practical installation sizes that work around rooftop obstacles. See LoGoPEP's Solar Energy Calculator for resources, including the Minnesota Solar Suitability App and Google Project Sunroof. [72,73] As a state, Minnesota has the technical potential to meet 38.5% of its annual electricity consumption through rooftop photovoltaics.[74] Therefore the default number used for this input is equal to 38.5% of the community's baseline electricity consumption.

- Rooftop Utilization Rate
  This is the percentage of the total viable rooftop solar resource that will be utilized for photovoltaic panels. LoGoPEP's Solar Energy Calculator can be used to determine a target utilization rate based on statewide solar goals. The

---

[71] State of Minnesota, "M.S. 216B.1692" (2016).

[72] National Renewable Energy Laboratory, "NSRDB Data Viewer," n.d.

[73] University of Minnesota, "Minnesota Solar Suitability Analysis: Methods," n.d.

[74] Pieter Gagnon et al., "Rooftop Solar Photovolatic Technical Potential in the United States: A Detailed Assessment," 2016.

current rooftop utilization rate for solar panels in cities across the U.S. is less than 1%.[75] An analysis by the National Renewable Energy Laboratory suggests that adoption rates would increase 8.2% if the payback period was less than 15 years. Since solar installations typically utilize about 56% of their rooftop's potential, a default utilization rate of 4.6% is used (56% of 8.2%).[76]

Assumptions:

- At the community scale, the electricity generated by on-site photovoltaics cannot exceed the total planned electricity consumption. This does not apply to the building scale; individual buildings can produce more electricity than they use.
- To distribute emissions savings between sectors, it is assumed that the ratio of commercial/industrial solar to residential solar is equal to the ratio of commercial/industrial electricity usage to residential electricity usage. This does not impact the overall size of the wedge, but does impact the amount of grid-based electricity remaining in each sector that is eligible for green power purchase.

4.2. Green Power Purchase – Commercial/Industrial

Commercial and industrial customers that purchase electricity from a utility company can participate in voluntary programs that allow them to purchase a portion of their electricity from renewable energy sources. In Minnesota, utility green tariff programs and community solar gardens (CSGs) are two options for consumers seeking to purchase renewable electricity.[77]

Emission Reduction (tCO2e) = Planned Commercial/Industrial Electricity Use (MMBtu) x Participation Rate (% of commercial/industrial electricity loads met through green power purchase) x Planned Electricity Emissions Factor (tCO2e/MMBtu)

Inputs:

- Participation Rate
  This indicates the percentage of commercial and industrial electricity provided through green power purchase each year of the specified implementation period. The default participation rate for commercial electricity is 1%, which is significantly higher than the percentage of Xcel's statewide non-residential

---

[75] O'Shaughnessy et al., "Estimating the National Carbon Abatement Potential of City Policies: A Data-Driven Approach."

[76] Ibid.

[77] Eric O' Shaughnessy, Chang Liu, and Jenny Heeter, "Status and Trends in the U.S. Voluntary Green Power Market (2015 Data)," 2015.

electricity sales provided through their Windsource program in 2016 of 0.1%.[78] Utility companies may be able to provide community-specific baseline information.

Assumptions:

- The sum of carbon-neutral electricity achieved through on-site photovoltaics and green power purchase cannot exceed the total planned electricity. On-site solar is applied first. For example:
    - If a community meets 25% of its electricity load through on-site solar, and specifies green power purchase participation and subscription rates of 100%, 25% of the community's electricity load will be met through on-site solar and the remaining 75% will be met through green power purchase.
    - If a community meets 25% of its electricity load through on-site solar, and specifies a green power purchase participation rate of 75% and a subscription rate of 100%, 25% of the community's electricity load will be met through on-site solar, and the remaining 75% will be met through green power purchase.
    - If a community meets 25% of their electricity load through on-site solar, and specifies a green power purchase participation rate of 50% and a subscription rate of 100%, 25% of the community's electricity load will be met through on-site solar, 50% will be met through green power purchase, and the remaining 25% will be met through the electric grid.

4.3. Green Power Purchase – Residential

Residential customers that purchase electricity from a utility company can participate in voluntary programs that allow them to purchase a portion of their electricity from renewable energy sources. In Minnesota, utility green tariff programs and community solar gardens (CSGs) are two options for consumers seeking to purchase renewable electricity.[79]

Emission Reduction (tCO2e) = Planned Residential Electricity Use (MMBtu) x Participation Rate (% of residential electricity loads met through green power purchase) x Planned Electricity Emissions Factor (tCO2e/MMBtu)

---

[78] Xcel's Community Energy Reports include the Minnesota – Business Total Subscribed Energy for Windsource. Dividing this by the total non-residential energy reported in Form 7610 results in the participation rate identified above. Xcel Energy, "Annual Community Energy Report - City of Roseville, 2016," 2017; Xcel Energy, "Minnesota Electric Utility Annual Report (Form 7610), 2016," 2017.

[79] Shaughnessy, Liu, and Heeter, "Status and Trends in the U.S. Voluntary Green Power Market (2015 Data)."

Inputs:

- Participation Rate
  This indicates the percentage of residential electricity provided through green power purchase each year of the specified implementation period. The default participation rate is 3%, which is higher than the percentage of Xcel's statewide residential electricity sales provided through their Windsource program in 2016 of 1.3%.[80] Utility companies may be able to provide community-specific baseline information.

Assumptions:

- The sum of carbon-neutral electricity achieved through on-site photovoltaics and green power purchase cannot exceed the total planned electricity. On-site solar is applied first. See Green Power Purchase – Commercial/Industrial Assumptions for example calculations.

5. END-USE FUEL SWITCHING (COMING SOON)

With over a fifth of the state's energy emissions coming from fuel combustion in homes, businesses, and industries, to achieve aggressive greenhouse gas reduction targets these emissions must be addressed.[81] In addition to efficiency strategies to reduce the amount of energy need for space heating, water heating, cooking, and industrial processes, the energy for these needs can be met through less carbon-intensive sources. Natural gas is currently less carbon-intensive than electricity in Minnesota. However, as the electricity grid transitions to renewable energy sources, it will become less carbon-intensive than natural gas. This wedge includes strategies that shift from on-site combustion to electricity use.

Strategy Interactions:

- Both efficiency and other decarbonization strategies are applied before fuel switching strategies. The savings from these strategies are based on planned – not business-as-usual – energy use and emissions factors.
- If selected, the On-Site Solar Thermal strategy is applied before fuel switching. For water heating, fuel switching is only applied to the percentage of natural gas that is not being met by solar thermal.
- Green power purchase rates are applied to the additional electricity load from fuel switching.
- These strategies account for the on-site efficiency savings inherent in switching from combustion to electricity use, but do not include additional efficiency savings from technologies such as heat pumps, which are typically powered by

---

[80] Xcel's Community Energy Reports include the Minnesota – Residential Total Subscribed Energy for Windsource. Dividing this by the total non-residential energy reported in Form 7610 results in the participation rate identified above. Xcel Energy, "Annual Community Energy Report - City of Roseville, 2016"; Xcel Energy, "Minnesota Electric Utility Annual Report (Form 7610), 2016."

[81] Claflin, "Greenhouse Gas Emissions: 1990-2014."

electricity. Therefore, these strategies should be applied in conjunction with the Appliance, Equipment, and Fixture Efficiency strategies to fully account for savings associated with electric heat pump heating systems.

5.1. Commercial/Industrial Fuel Switching (coming soon)

This strategy models the impact of switching from natural gas space and water heating to electric heating systems in commercial buildings. The savings depend on the planned electricity emissions factor; if the electricity emissions factor is higher than the natural gas emissions factor, this strategy will result in added emissions. Since switching from natural gas to electric heating often involves switching to heat pumps – which are much more efficient than gas-fired boilers – this strategy should be considered in conjunction with the Appliance, Equipment, and Fixture strategy.

Emission Reduction (tCO2e) = Commercial/Industrial Electricity Use Increase (MMBtu) x Planned Electricity Emissions Factor (tCO2e/MMBtu) - Commercial/Industrial Natural Gas Reduction (MMBtu) x Planned Natural Gas Emissions Factor (tCO2e/MMBtu)

Commercial/Industrial Electricity Use Increase (MMBtu) = Commercial/Industrial Natural Gas Reduction (MMBtu) x [1 - Energy Savings Rate (% savings from fuel switching)]

Commercial/Industrial Natural Gas Reduction (MMBtu) = Planned Commercial/Industrial Natural Gas Use (MMBtu) x Percentage of Commercial/Industrial Natural Gas Used for Space and Water Heating x Participation Rate (% of commercial/industrial buildings served by natural gas that switch to electricity)

Inputs:

- Participation Rate
  The participation rate is the percentage of commercial/industrial buildings served by natural gas for space and water heating that have switched to electricity by the end of the specified implementation period. The default participation rate is 5%.[82]

---

[82] The percentage of commercial building area in the West North Central region of the Midwest using electricity as the primary space heating source has decreased over the past decade, from 20% in 2003 to 14% in 2012. The percentage using electricity as the water heating source has increased, from 51% in 2003 to 55% in 2012. U.S. EIA, “Table B29. Primary Space-Heating Energy Sources, Total Floorspace for Non-Mall Buildings, 2003 (CBECS),” 2006; U.S. EIA, “Table B29. Primary Space-Heating Energy Sources, Floorspace, 2012 (CBECS),” 2016; U.S. EIA, “Table B32. Water-Heating Energy Sources, Floorspace for Non-Mall Buildings, 2003 (CBECS),” 2006; U.S. EIA, “Table B32. Water-Heating Energy Sources, Floorspace, 2012 (CBECS),” 2016.

Assumptions:

- The energy savings rate from switching from natural gas to electric heating is 20%. This is based on a thermal efficiency of 80% for natural gas-fired equipment and 100% for electric.[83] The actual energy savings will vary based on the baseline and replacement technologies (electric heat pumps can achieve efficiencies of over 400%). However, this strategy accounts only for the inherent efficiency differences between on-site combustion and electricity, and not for specific technologies.
- The percentage of natural gas used for space and water heating is 89%, which is average for commercial buildings in the West North Central region of the Midwest.[84]

5.2. Residential Fuel Switching (coming soon)

This strategy models the impact of switching from natural gas space and water heating to electric heating systems in residential buildings. The savings depend on the planned electricity emissions factor; if the electricity emissions factor is higher than the natural gas emissions factor, this strategy will result in added emissions. Since switching from natural gas to electric heating often involves switching to heat pumps – which are much more efficient than gas-fired furnaces – this strategy should be considered in conjunction with the Appliance, Equipment, and Fixture strategy.

Emission Reduction (tCO2e) = Residential Electricity Use Increase (MMBtu) x Planned Electricity Emissions Factor (tCO2e/MMBtu) - Residential Natural Gas Reduction (MMBtu) x Planned Natural Gas Emissions Factor (tCO2e/MMBtu)

Residential Electricity Use Increase (MMBtu) = Residential Natural Gas Reduction (MMBtu) x [1 - Energy Savings Rate (% savings from fuel switching)]

Residential Natural Gas Reduction (MMBtu) = Planned Residential Natural Gas Use (MMBtu) x Percentage of Residential Natural Gas Used for Space and Water Heating x Participation Rate (% of residential buildings served by natural gas that switch to electricity)

Inputs:

- Participation Rate
  The participation rate is the percentage of residential buildings served by natural gas for space and water heating that have switched to electricity by the

---

[83] *Code of Federal Regulations*, Energy Efficiency Program for Certain Commercial and Industrial Equipment, title 10, sec. 431.87.

[84] U.S. EIA, "Table E7 . Natural Gas Consumption and Conditional Energy Intensities (Btu) by End Use, 2012 (CBECS)." Space heating accounts for 76.5% and water heating accounts for 12.8% of total natural gas consumption.

end of the specified implementation period. Based on the regional growth rate of electric heating over the past ten years, the default participation rate is 20% by 2040.[85]

Assumptions:

- The energy savings rate from switching from natural gas to electric heating is 20%. This is based on a thermal efficiency of 80% for natural gas-fired equipment and 100% for electric.[86] The actual energy savings will vary based on the baseline and replacement technologies (electric heat pumps can achieve efficiencies of over 400%). However, this strategy accounts only for the inherent efficiency differences between on-site combustion and electricity, and not for specific technologies.
- The percentage of natural gas used for space and water heating is 93%, which is the average for residential buildings in Iowa, Minnesota, North Dakota, and South Dakota.[87] This percentage is adjusted if the On-Site Solar Thermal strategy is selected in order to avoid double-counting savings from water heating strategies.

---

[85] The percentage of housing units in the West North Central region of the Midwest using electricity as the primary space and water heating source has increased by 10% over the past ten years. Electric space heating increased from 18% in 2005 to 27% in 2015 and water heating increased from 28% to 38%. U.S. EIA, "Table HC12.4 Space Heating Characteristics by Midwest Census Region, 2005 (RECS)," n.d.; U.S. EIA, "Table HC6.7 Space Heating in Homes in the Northeast and Midwest Regions, 2015 (RECS)," 2017; U.S. EIA, "Table HC12.8 Water Heating Characteristics by Midwest Census Region, 2005 (RECS)," n.d.; U.S. EIA, "Table HC8.7 Water Heating in Homes in the Northeast and Midwest Regions, 2015 (RECS)," 2017.

[86] *Code of Federal Regulations*, Energy Efficiency Program for Certain Commercial and Industrial Equipment, title 10, sec. 431.87.

[87] U.S. EIA, "Table E7 . Natural Gas Consumption and Conditional Energy Intensities (Btu) by End Use, 2012 (CBECS)." Space heating accounts for 71.8% and water heating accounts for 21.4% of residential natural gas consumption.

APPENDIX

DEFAULT VALUES FOR USER INPUTS

Strategy	User Input	Default
Commercial/Industrial Efficiency		
Energy Code Enforcement	Compliance Rate	91.8%
Stretch Energy Code	Compliance Rate	15%
Building Retrofit	Participation Rate	30%
Appliance, Equipment, and Fixture Efficiency	Participation Rate	70%
Efficient Building Operations	Participation Rate	85%
Behavior Change	Participation Rate	33%
Residential Efficiency		
Energy Code Enforcement	Compliance Rate	76.8%
Stretch Energy Code	Compliance Rate	15%
Retrofit/Weatherization	Participation Rate	4%
Appliance, Equipment, and Fixture Efficiency	Participation Rate	50%
Behavior Change	Participation Rate	98%
Renewable Energy		
On-Site Photovoltaics	Rooftop Solar Resource (MWh)	38.5% of baseline electricity
On-Site Photovoltaics	Rooftop Utilization Rate	4.6%
Green Power Purchase – C/I	Participation Rate	1%
Green Power Purchase – Res.	Participation Rate	3%
Fuel Switching		
Commercial/Industrial Fuel Switching	Participation Rate	5%
Residential Fuel Switching	Participation Rate	20%

ASSUMPTIONS

Strategy	Assumption	Value
Commercial/Industrial Efficiency		
Energy Code Enforcement	New Construction Energy Savings Rate	34.5%
Stretch Energy Code	Energy Emissions Savings Rate	67-100%
Stretch Energy Code	Maximum Energy Efficiency Savings	84%
Building Retrofit	Electricity Savings Rate	2%
Building Retrofit	Natural Gas Savings Rate	17%
Appliance, Equipment, and Fixture Efficiency	Energy Savings Rate	17%
Efficient Building Operations	Energy Savings Rate	23%
Behavior Change	Energy Savings Rate	5%
Residential Efficiency		
Energy Code Enforcement	New Construction Energy Savings Rate	38.5%
Stretch Energy Code	Energy Emissions Savings Rate	67-100%
Stretch Energy Code	Maximum Energy Efficiency Savings	80%
Retrofit/Weatherization	Electricity Savings Rate	6%
Retrofit/Weatherization	Natural Gas Savings Rate	37%
Appliance, Equipment, and Fixture Efficiency	Energy Savings Rate	13%
Behavior Change	Energy Savings Rate	1.6%
Electric Grid Mix		
See Planned Portfolio Mixes		
Fuel Switching		
C/I Fuel Switching	% Natural Gas Used for Space Heating	76.5%
C/I Fuel Switching	% Natural Gas Used for Water Heating	12.8%
C/I Fuel Switching	Energy Savings Rate	20%
Residential Fuel Switching	% Natural Gas Used for Space Heating	71.8%
Residential Fuel Switching	% Natural Gas Used for Water Heating	21.4%
Residential Fuel Switching	Energy Savings Rate	20%

PLANNED PORTFOLIO MIXES

Xcel Energy[88]:

	2015	2020	2025	2030
Coal	34%	31%	24%	15%
Natural Gas	15%	6%	11%	22%
Nuclear	27%	29%	28%	28%
Refuse	4%	3%	2%	-
Wind/Solar/Hydro	21%	32%	35%	35%
Purchases	-	-	-	-

Southern Minnesota Municipal Power Agency[89]:

	2015	2025
Coal	55%	49%
Natural Gas	1%	1%
Nuclear	-	-
Refuse	-	-
Wind/Solar/Hydro	14%	28%
Purchases	30%	23%

Great River Energy (GRE) [90]:

	2013	2029
Coal	67%	58%
Natural Gas	3%	2%
Nuclear	-	-
Refuse	-	-
Wind/Solar/Hydro	21%	32%
Purchases	9%	8%

---

[88] Xcel Energy, "E002/RP-15-21 Response to MN Public Utilities Commission Information Request No. 31," 2016. Although portfolio mix for 2031 and 2032 are also included in this document, it is noted that the scenarios for these years have not been fully developed since they are beyond the planning period for the Resource Plan. Therefore, the 2030 portfolio mix is applied to all subsequent years.

[89] Southern Minnesota Municipal Power Agency, "In the Matter of SMMPA's 2014-2028 Integrated Resource Plan Docket No. ET9/RP-13-1104 Response IR8: Greenhouse Gas Reduction Goal," 2014.

[90] Great River Energy's 2014 Integrated Resource Plan includes a historic fuel type breakdown for 2013 and a forecasted breakdown for 2029 based on their Preferred Plan. Great River Energy, "Great River Energy Resource Plan 2015-2029, Docket No. ET2/RP-14-813," 2014, http://greatriverenergy.com/wp-content/uploads/2016/02/2014_irp.pdf.

Minnesota Power [91]**:**

	2016	2025
Coal	54%	45%
Natural Gas	1%	20%
Nuclear	-	-
Refuse	-	-
Wind/Solar/Hydro	25%	35%
Purchases	20%	-

Ottertail Power [92]**:**

	2017	2031
Coal	55%	37%
Natural Gas	-	2%
Nuclear	-	-
Refuse	-	-
Wind/Solar/Hydro	16%	29%
Purchases	29%	32%

Midwest Reliability Organization West (MRO West)[93]**:**

	2014
Coal	58%
Natural Gas	3%
Nuclear	13%
Refuse	1%
Wind/Solar/Hydro	24%
Purchases	-

---

[91] Minnesota Power, "2015 Integrated Resource Plan," 2015, https://www.mnpower.com/Content/Documents/Environment/2015-resource-plan.pdf. The 2015 breakdown is based on a graphic analysis of Figure 7: Base Case Energy Position for 2016. The 2025 breakdown reflects the Preferred Plan Power Supply Mix shown in Figure 23.

[92] Ottertail Power Company, "Application for Resource Plan Approval 2017-2031," 2016. The savings above reflect the preferred plan with externalities applied. This results in higher savings than if externalities were not applied.

[93] U.S. EPA, "Subregion Resource Mix (eGRID2014v2)," 2017, https://www.epa.gov/sites/production/files/2017-02/documents/egrid2014_summarytables_v2.pdf.

BIBLIOGRAPHY

Campbell, Iain, and Koben Calhoun. “Old Buildings Are U.S. Cities’ Biggest Sustainability Challenge.” *Harvard Business Review*, 2016.

Claflin, Anne. “Greenhouse Gas Emissions: 1990-2014,” 2017. doi:10.1007/978-1-4419-7991-9.

Construction, McGraw-Hill. *Smart Market Report: Business Case for Energy Efficient Building Retrofit and Renovation*, 2011.

Fernandez, N, S Katipamula, W Wang, Y Xie, M Zhao, and C Corbin. “Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction,” 2017. http://buildingretuning.pnnl.gov/publications/PNNL-25985.pdf.

Frankel, Mark, Morgan Heater, and Jonathan Heller. “Sensitivity Analysis: Relative Impact of Design, Commissioning, Maintenance and Operational Variables on the Energy Performance of Office Buildings.” *ACEEE Summer Study on Energy Efficiency in Buildings, August 12-17*, 2012, 52–64. https://newbuildings.org/wp-content/uploads/2015/11/SensitivityAnalysis_ACEEE20122.pdf.

Gagnon, Pieter, Robert Margolis, Jennifer Melius, Caleb Phillips, and Ryan Elmore. “Rooftop Solar Photovolatic Technical Potential in the United States: A Detailed Assessment,” 2016.

Great River Energy. “Great River Energy Resource Plan 2015-2029, Docket No. ET2/RP-14-813,” 2014. http://greatriverenergy.com/wp-content/uploads/2016/02/2014_irp.pdf.

Lowenberger, Amanda, Joanna Mauer, Marianne Dimascio, Jennifer Amann, and Steven Nadel. “The Efficiency Boom: Cashing In on the Savings from Appliance Standards” 20045, no. 202 (2012): 1–87.

Mauer, Joanna. “Energy-Saving States of America : How Every State Benefits from National Appliance Standards.” *Appliance Standards Awareness Project and American Council for an Energy-Efficient Economy*, no. February (2017).

Metropolitan Council. “Population, Households and Employment Forecasts to 2040, Twin Cities Metropolitan Area (January 1, 2017),” 2017. https://metrocouncil.org/Data-and-Maps/Data/CouncilResearchProducts/Council-Forecasts.aspx.

Minnesota Department of Labor & Industry Construction Codes and Licensing Division. “Energy Code Compliance in Minnesota Baseline for ARRA Compliance,” no. September (2013). http://bcapcodes.org/wp-content/uploads/2015/12/Energy-Code-Compliance-in-Minnesota-2012-2013-Baseline-for-ARRA-Compliance.pdf.

Minnesota Power. “2015 Integrated Resource Plan,” 2015. https://www.mnpower.com/Content/Documents/Environment/2015-resource-plan.pdf.

Minnesota State Demographic Center. “County Population Projections (March 2017),” 2017. https://mn.gov/admin/demography/data-by-topic/population-data/our-projections/.

———. “Minnesota County Labor Force Projections, 2015-2030,” 2017. https://mn.gov/admin/demography/data-by-topic/population-data/our-projections/.

National Renewable Energy Laboratory. “NSRDB Data Viewer,” n.d.

O’Shaughnessy, Eric, Jenny Heeter, David Keyser, and Pieter Gagnon. “Estimating the National Carbon Abatement Potential of City Policies: A Data-Driven Approach,” 2016.

Ochsner, Heidi, Alden Jones, and Rita Siong. “Persistence of Behavioral Energy Management Activities and Savings in Commercial Office Buildings.” In *Behavior, Energy & Climate Change Conference*. Washington, 2014. doi:10.5811/westjem.2011.5.6700.

Ottertail Power Company. “Application for Resource Plan Approval 2017-2031,” 2016.

Shaughnessy, Eric O’, Chang Liu, and Jenny Heeter. “Status and Trends in the U.S. Voluntary Green Power Market (2015 Data),” 2015.

Southern Minnesota Municipal Power Agency. “In the Matter of SMMPA’s 2014-2028 Integrated Resource Plan Docket No. ET9/RP-13-1104 Response IR8: Greenhouse Gas Reduction Goal,” 2014.

State of Minnesota. M.S. 216B.1692 (2016).

Strategies, Center for Climate. “Minnesota Climate Strategies and Economic Opportunities,” 2016.

Sussman, Reuven, and Maxine Chikumbo. “Behavior Change Programs: Status and Impact.” *ACEEE Report*, no. October (2016).

Therkelsen, Peter, and Prakash Rao. “Organizational Change in Industry Through Strategic Energy Management : Results and Barriers to Success.” In *Behavior, Energy & Climate Change Conference*. Sacramento, 2015.

U.S. DOE. “Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities,” no. September (2015): 1–505.

U.S. EIA. “Table A.3. Carbon Dioxide Uncontrolled Emission Factors,” n.d. https://www.eia.gov/electricity/annual/html/epa_a_03.html.

———. “Table B29. Primary Space-Heating Energy Sources, Floorspace, 2012 (CBECS),” 2016.

———. “Table B29. Primary Space-Heating Energy Sources, Total Floorspace for Non-Mall Buildings, 2003 (CBECS),” 2006.

———. “Table B32. Water-Heating Energy Sources, Floorspace, 2012 (CBECS),” 2016.

———. “Table B32. Water-Heating Energy Sources, Floorspace for Non-Mall Buildings, 2003 (CBECS),” 2006.

———. “Table CE4.3. Household Site End-Use Consumption by Fuel in the Midwest Region, Totals, 2009 (RECS),” 2013. https://www.eia.gov/consumption/residential/data/2009/index.php?view=consumption#end-use-by-fuel.

———. “Table E5. Electricity Consumption (kWh) by End Use, 2012 (CBECS),” 2016. https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e5.pdf.

———. “Table E7 . Natural Gas Consumption and Conditional Energy Intensities (Btu) by End Use, 2012 (CBECS),” 2016. https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e7.pdf.

———. “Table HC12.4 Space Heating Characteristics by Midwest Census Region, 2005 (RECS),” n.d.

———. “Table HC12.8 Water Heating Characteristics by Midwest Census Region, 2005 (RECS),” n.d.

———. “Table HC6.7 Space Heating in Homes in the Northeast and Midwest Regions, 2015 (RECS),” 2017.

———. “Table HC8.7 Water Heating in Homes in the Northeast and Midwest Regions, 2015 (RECS),” 2017.

U.S. EPA. “Subregion Resource Mix (eGRID2014v2),” 2017. https://www.epa.gov/sites/production/files/2017-02/documents/egrid2014_summarytables_v2.pdf.

U.S. National Archives and Records Administration. Code of Federal Regulations, Energy Efficiency Program for Certain Commercial and Industrial Equipment, title 10, sec. 431.87 (2016).

University of Minnesota. “Minnesota Solar Suitability Analysis: Methods,” n.d.

Williams, Jeremy. “Presentation Overview : Introduction Statutory Requirements Program Structure Recent Accomplishments.” U.S. Department of Energy, 2014.

Xcel Energy. “Annual Community Energy Report - City of Roseville, 2016,” 2017.

———. “E002/RP-15-21 Response to MN Public Utilities Commission Information Request No. 31,” 2016.

———. “Minnesota Electric Utility Annual Report (Form 7610), 2016,” 2017.

York, Dan, Maggie Molina, Max Neubauer, Seth Nowak, Steven Nadel, Anna Chittum, Neal Elliott, et al. “Frontiers of Energy Efficiency: Next Generation Programs Reach for High Energy Savings,” no. January (2013).

Zhang, J, R Athalye, R Hart, M Rosenberg, Y Xie, S Goel, V Mendon, and B Liu. “Energy and Energy Cost Savings Analysis of the IECC for Commercial Buildings.” *Pacific Northwest National Laboratory*, no. August (2013): 1–87.