APPENDIX F4 – HIGH ELECTRIFICATION SCENARIO DESCRIPTION

We worked with Energy and Environmental Economics (E3) to develop a High Electrification load forecast sensitivity, derived from the E3 statewide decarbonization analysis using PATHWAYS.[1] The objective of this sensitivity was to create a "bookend," examining the possible impacts on load growth and peak demand growth on our Upper Midwest NSP System service area, under a scenario with electrification sufficiently aggressive to achieve Minnesota's economy-wide goal of an 80 percent reduction in greenhouse gas (GHG) emissions below 2005 levels by 2050.[2] The Company does not suggest this amount of electrification is likely to occur, absent additional policy measures. We note that an 80 percent economy-wide reduction could theoretically be achieved with less electrification and more of other measures.

Without suggesting this much electrification will or should occur, the sensitivity asks: if there were very aggressive electrification of transportation, buildings, and other end uses, what are the potential impacts on energy consumption and peak demand during the planning period?

I. METHODS

E3 details its methodology in Attachment A to this Appendix. In summary, E3 began with the High Electrification scenario developed in its Minnesota PATHWAYS analysis.[3] In that analysis, E3 created two scenarios, High Electrification and High Biofuels, both targeting the 80 percent by 2050 economy-wide goal. The High Electrification scenario assumes low-carbon electricity (48 percent zero-carbon generation by 2025, 90 percent by 2050) and a high amount of energy efficiency – including high-efficiency appliances and building shell weatherization. All light, medium, and heavy-duty vehicle sales are electric by 2050; sales of electric heat pump equipment reach 95 percent by 2050, replacing electric, natural gas and LPG alternatives; and 50 percent of liquid fuels used in agriculture are electrified by 2050. As a result, statewide total electricity demand grows 60 percent by 2050, relative to 2015. Load growth is especially pronounced in the latter years (2035-2050).

E3 then developed hourly load shapes for each electrified end use, using simulated

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[1] In summary, for the PATHWAYS study, E3 developed a set of long-term economy-wide, deep decarbonization scenarios for the state of Minnesota. These scenarios provide an exploration of the cross-sectoral implications of meeting economy-wide carbon reduction goals, and highlight the role of Xcel Energy, and the electric sector as a whole, in meeting the state's economy-wide carbon goal. For details, see the E3 Minnesota PATHWAYS Report as Appendix P3.

[2] Minn. Stat. 216H.02, Subd. 1. *See* https://www.pca.state.mn.us/air/state-and-regional-initiatives.

[3] This analysis is summarized in E3 presentations from September 24 and October 23, 2018. *See* https://www.xcelenergy.com/company/rates_and_regulations/resource_plan_overview/midwest_energy_plan and, under Current Status, the 9/24/18 and 10/23/18 Workshop Materials.

demand by year based on a 2009 weather year. Water heating, which becomes dominated by heat pump water heaters, is assumed to be a "managed" load capable of being limited largely to off-peak hours. Passenger EVs are assumed to be mostly (90 percent) managed to avoid peak demand impacts. This is based on the experience of Xcel Energy and other utilities, that most charging happens at home and that it will likely be feasible, with a combination of technological controls and time-sensitive rates, to incentivize EV owners to mostly avoid on-peak charging. Heavier EVs and agricultural electrification are conservatively assumed to be flat across hours, i.e. an unmanaged load.

Electrified space heating, however, has a significant potential impact on total energy and peak demand, and is less amenable to being managed to off-peak hours. E3 assumed an increasing share of space heating is served by electric air-source heat pumps (ASHPs), which face special challenges in cold climates. Because efficiency of ASHPs decreases as outdoor air temperature drops, ASHPs are paired with backup electric resistance and thermal heating in this scenario. Below 0° Fahrenheit, there is a non-linear increase in input energy needs as an increasing share of heat is provided by electric resistance backup. See Attachment A to this Appendix for greater detail.

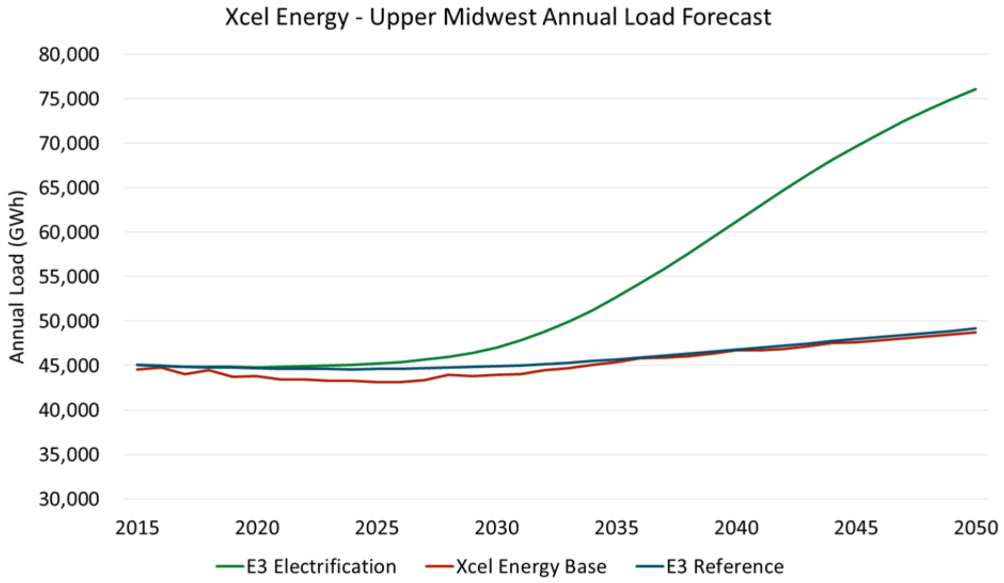
Finally, E3 scaled the Minnesota-wide results to the NSP System, i.e. Xcel Energy's service territory across five Upper Midwest states. Based on historical energy data, in recent years Xcel Energy's retail sales in those five states have been on average 67 percent of total retail sales in Minnesota, so E3's forecast of load and peak demand Minnesota-wide is multiplied by 67 percent to derive load and peak demand for the NSP System under this High Electrification sensitivity. This approach assumes that the scaling of Minnesota loads to the NSP System stays constant over the forecast period. If electrification of transportation, water, and space heating has a different growth rate in our Upper Midwest service territories than in Minnesota as a whole, then both energy and demand impacts could be significantly different for Xcel Energy.

II. RESULTS

Even with aggressive electrification of transportation, water heating and space heating, impacts on incremental energy and peak demand needs are relatively slight during the 2020-2034 Resource Plan planning period – but much more significant by 2050. This is primarily because adoption of EVs and electrified appliances reaches its "hockey stick" phase only near the end of the planning period. Further, even once electric alternatives dominate new sales, the stock of vehicles and appliances takes time to turn over.

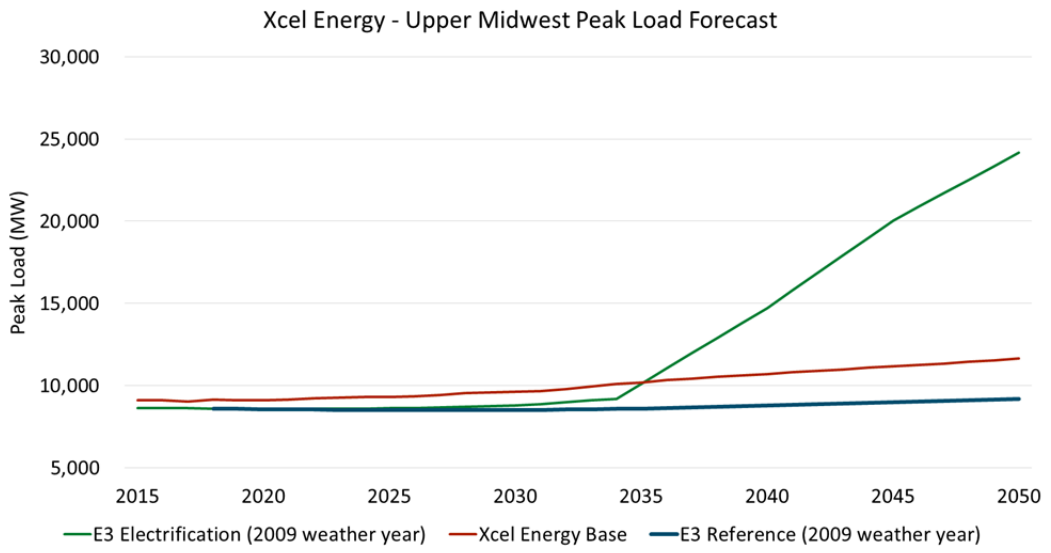
Load Impacts. When compared to E3's reference scenario, the high electrification scenario requires incremental energy on our Upper Midwest system of about 2,000 GWh in 2030 and 5,700 GWh by 2034. Incremental energy requirements increase dramatically thereafter, reaching 14,000 GWh in 2040 and almost 27,000 GWh by 2050. See Figure 1 below.

Figure 1: Incremental Annual Load under a High Electrification Scenario



Peak Demand Impacts. Impacts on peak demand under a high electrification scenario likewise come primarily after the planning period. For example, incremental peak demand requirements due to electrified loads are only 430 MW by 2034, but escalate dramatically thereafter, reaching over 5 GW of incremental peak demand by 2040 and almost 15 GW by 2050. See Figure 2 below.

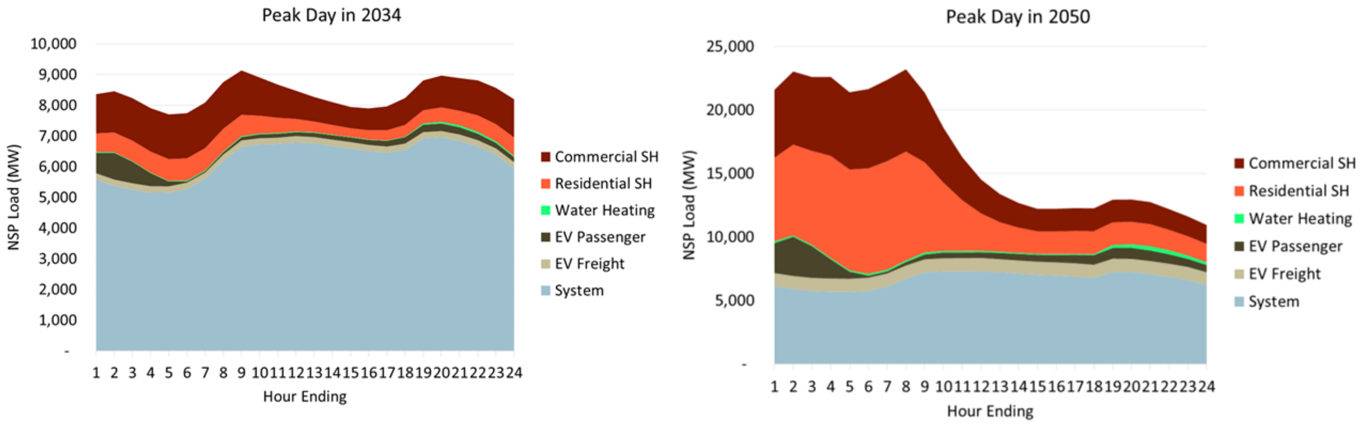
Figure 2: Incremental Peak Demand under a High Electrification Scenario



While some electrified loads, such as passenger EVs and water heating, are able to be managed mostly to off-peak hours, space heating has a significant peak demand impact since heating is needed round-the-clock. Figure 3 below shows peak demand in 2034 and 2050, illustrating both that the bulk of peak demand needs are from residential and commercial space heating – and, that space heating imposes incremental peak demand needs in all hours. After about 2034, our Upper Midwest NSP System becomes a winter peaking utility in this scenario.

Figure 3: Electricity Demand on a Peak Day in 2034 (Left) and 2050 (Right) under a High Electrification Sensitivity

Note difference in y-axis scale



III. IMPLICATIONS

Achieving Minnesota's goal of an 80 percent economy-wide GHG reduction will be challenging. Because of the progress the electricity sector has made to-date in reducing emissions, and its expected continued progress by 2050, there is significant potential to reduce emissions from other economic sectors using low-carbon electricity, which could help Minnesota achieve its statutory GHG goals. However, if electricity use by other sectors is to grow significantly, it is all the more important to maintain affordable and reliable electricity – highlighting the need to take advantage of economies of scale in pursuing low- and zero-carbon electricity options.

While most of the High Electrification sensitivity's impacts on load and peak demand come beyond the planning period, it is important to avoid a myopic view in planning the energy system to serve this potential demand beyond 2034. Firm capacity needs would increase dramatically just beyond the end of the planning period in this sensitivity. This strengthens the rationale for the Reliability Requirement – a minimum amount of firm, dispatchable resources to meet customers' energy needs whenever they peak, as discussed in Appendix J2: Reliability Requirement. Incremental peak capacity needs can be mitigated to some degree by putting in place time-sensitive rates and technological controls needed to manage electrified loads (EVs, water heating) to off-peak hours and match these flexible loads to hours of high renewable generation. However, as discussed in conjunction with the Reliability Requirement, renewable generation is not always available. Additionally, not all electrified loads are amenable to shifting off-peak, so it will be important to plan the system with a view beyond 2034.

Finally, a strategic electrification (or "beneficial electrification") approach may be preferable to an "electrify everything" approach. Considering cold climate challenges of some types of electrification, the difficulty of managing some electrified loads to off-peak hours, and the relative efficiency of the natural gas local distribution system in providing heat, it makes sense to focus electrification efforts on those end uses where electrification meets criteria such as:

- Reducing system costs for all utility customers;
- Reducing net CO_2 emissions; and
- Providing for a more efficient utilization of grid resources.[4]

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[4] As adopted in Colorado Senate Bill 19-236, and similar to the definition of beneficial electrification proposed by the Regulatory Assistance Project in https://www.raponline.org/knowledge-center/beneficial-electrification-ensuring-electrification-public-interest/.

Xcel NSP High Electrification Scenario

June 26, 2019

Prepared for Xcel Energy

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1 Background

This study investigates the potential future of Minnesota's energy economy. We model Minnesota's energy economy on an annual time scale, with key outputs including annual emissions, electric loads, and electric supply changes.

We model two evolutions: the evolution of energy demands and energy supply. To model energy demands we use LEAP, the Long-range Energy Alternatives Planning system. LEAP is an energy accounting framework that provides annual economy-wide energy and emissions results, including a stock roll-over component for major equipment categories (energy uses in buildings and transportation fleet). E3, in partnership with Xcel Energy - Upper Midwest, developed a LEAP model to represent the energy economy of Minnesota (Minnesota PATHWAYS). This model includes developing representation of the Minnesota economy as it exists today, and a series of transformations that reduce economy-wide emissions consistent with achieving the Next Generation Energy Act goal of 80% below 2005 emissions levels by 2050.

We take annual electricity loads from Minnesota PATHWAYS, downscale them to the Xcel Energy - Upper Midwest service territory, and pass them to RESOLVE, E3's electricity capacity expansion and operations model. We use RESOLVE to develop least-cost optimal expansion plans of the electricity grid. Together, the models allow us to track the change in composition of the Minnesota energy economy annually, as well as evaluate how the Xcel Energy - Upper Midwest electric supply could change in a decarbonized future. This document highlights the methods and data surrounding this modeling effort, with a focus on the High Electrification scenario.

The scope of our analysis does not focus on the full scope of greenhouse gas (GHG) emissions, which include agricultural and waste water emissions; we focus on direct energy consumption and energy supply.

Energy forecasting methodology

We begin by tracking the high level economic drivers: population, housing units, square footage, and total vehicle miles traveled (VMT). These data are sourced primarily from various federal and state data sources, including the Census and 2018 AEO. From these economic drivers, we forecast energy demands by using either a stock rollover approach, or a total energy approach.

When infrastructure data is available (such as the number of vehicles) we use a stock rollover approach to model the number of devices and track the improvements in efficiency or change in energy usage as newer, more efficient devices replace retiring devices.

A stock rollover approach allows us to track sales and retirements of devices by technology, track efficiency improvements explicitly, and see the physical lag in the energy system as devices are bought and consumed throughout their lifetimes before being replaced. Note shorter lived technologies, such as lighting and hot water heaters, might roll over multiple times during the study period whereas longer lived technologies, such as power plants and building shells, might roll over only once.

Using a stock rollover approach, the Minnesota PATHWAYS model tracks energy demand associated with existing devices from prior years that have not reached the end of their life. We establish the on-site energy demand associated with these devices by multiplying the number of devices from each vintage with the per-unit energy demand applicable to each vintage.

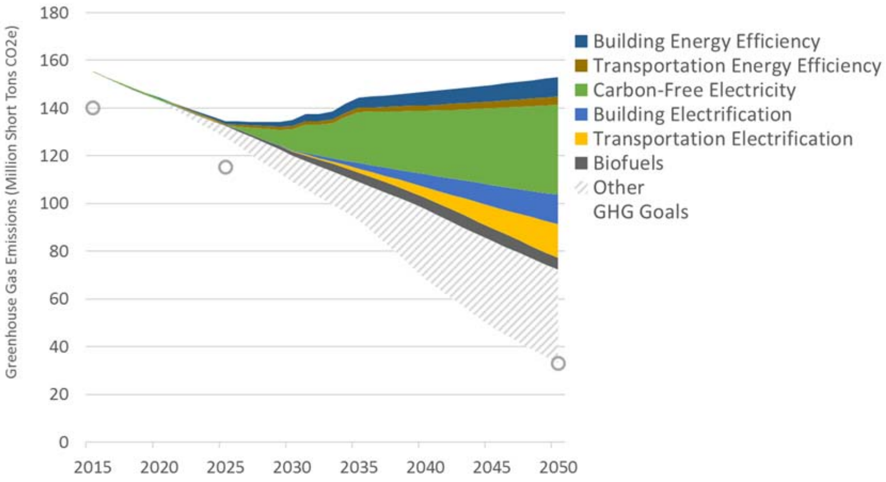
Secondly, we model the number of new devices that are added to each subsector every year. Every year sales of new devices are set to a quantity sufficient to replace retiring devices and meet the demand for new growth (new growth tracks the economic drivers such as housing units or population). Similar to the existing devices, we establish the on-site energy demand associated with new devices by multiplying the number of devices with the appropriate energy usage per device applicable to the new devices' vintage.

When data are limited or of poor quality (such as the industrial sector), we use a total energy approach in which we directly specify the energy demand by fuel, and forecast future energy demands benchmarking to fundamental economic drivers, such as population or AEO energy demand forecasts.

2 Summary of the "High Electrification" scenario:

The High Electrification scenario forecasts a pathway for Minnesota to achieve 80% decarbonization of the energy economy relative to a 2005 base year by 2050. This scenario leans heavily on electrification of end uses wherever practical. An electrification heavy pathway is dependent on carbon-free electricity that is used to displace fossil fuels in buildings and vehicles (Figure 1).

Figure 1. GHG Reductions by Measure: High Electrification Scenario



The high electrification scenario increases load by **60%** in 2050, relative to 2015. Load growth is especially pronounced in the latter years (2035-2050) as load growth from vehicle and space heating electrification exceed energy efficiency gains (Figure 2). For more details on key assumptions see Table 1, below.

Figure 2. Minnesota Load in the High Electrification Scenario

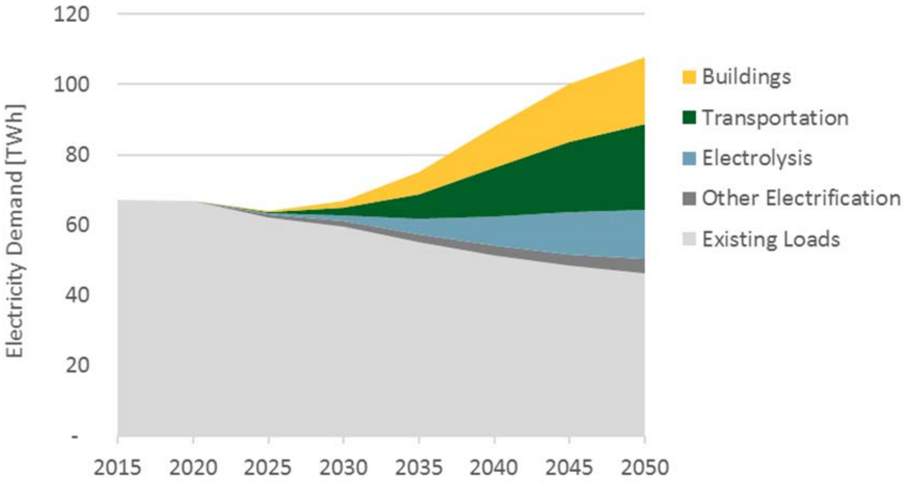


Table 1. Key scenario assumptions

	High Electrification (and low EE)
Electricity generation	
Zero-carbon generation	48% by 2025, 90% by 2050
Nuclear power	Assume nuclear is relicensed or replaced with other carbon-free generation
Buildings	
Energy Efficiency	50% of appliance sales are high-efficiency by 2030 No smart appliances and conservation by 2050 No reduction in demand in nonstock (Residential Other and Commercial Other) demand by 2030, and 30% reduction by 2050
Building Shell and Weatherization	100% adoption of efficient building shell/weatherization measures by 2030
Sales of Electric Heat Pump Equipment	50% by 2030, 95% by 2050, replacing electric, natural gas and LPG
Transportation	
Sales of Zero-Emission Vehicles	LDVs: 50% by 2030, 100% by 2050 MDVs: 50% by 2030, 100% by 2050 HDVs: 40% by 2030, 100% by 2050
Efficiency	Federal CAFÉ standards for LDVs through 2026
Other	50% of Residual Fuel Oil is electrified by 2050
Industry and Other	
Energy Efficiency	No efficiency improvements below baseline
Agriculture Electrification	50% of liquid fuels (Diesel, Gasoline, LPG) are electrified in Agriculture by 2050, at a 50% efficiency improvement due to electrification

3 Electrification load shapes

3.1 Load shapes for water heating and electric vehicles

In developing hourly electric load shapes, this study investigates the electric power system impacts of electrifying a variety of end uses including space heating, water heating, transportation electrification, and others. The next section discusses our space heating load shaping methodology in greater detail. Here we briefly cover the methodology used to create shapes for water heating, transportation electrification, and other electrification.

Water heating: In the High Electrification scenario there is a move towards increased heat pump water heater penetration. E3 used a set of managed heat pump and electric resistance water heating shapes from the Xcel Energy team. The managed resistance water heater shapes are controlled to have no demand from 7am through 6PM. Heat pump water heater shapes are sourced from a broader electricity and decarbonization study commissioned in part by Great River Energy and performed by Brattle in 2016[1]. To capture a representative split of years we use an 80%/20% split of heat pump water heaters / electric resistance water heaters and calculate a blended managed water heating profile. We calculate this profile for a single day that is applied to all the days in a year.

Passenger EV: In the High Electrification scenario there is a move towards increased vehicle electrification, of both passenger and freight. To calculate the load impact of electric passenger EV, E3 used a set of EV load profiles provided by Xcel Energy. These load profiles are sourced from the EV Project, and include both managed and unmanaged charging shapes[2]. For this analysis, we use a blended profile of 90% managed and 10% unmanaged charging. We again calculate this profile for a single day that is applied to all the days in a year.

Freight EV and Agriculture: The final major sources of incremental electrification in the High Electrification scenario are freight vehicles and agriculture. Public data on freight vehicle electric load shapes are sparse. Without accurate, publicly available charging data it is difficult to calculate a representative charging profile for these end uses, so E3 used a flat block across all hours – this indicates that charging demand is consistent across all hours. This is likely not to be accurate, especially if real-time electricity prices fluctuate strongly in future years as these vehicles might exhibit more sophisticated and price responsive charging behavior than the average residential passenger vehicle. Nevertheless, without more data we use a flat charging profile for this study.

In addition to the three categories mentioned above, space heating is the last significant source of electric load growth in the High Electrification scenario. Since space heating has the potential to create operational challenges due to its peaky nature in cold weather, we discuss space heating load shaping in more detail below.

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[1] https://greatriverenergy.com/wp-content/uploads/2015/10/Appendices-H-L.pdf
[2] https://www.energy.gov/sites/prod/files/2014/02/f8/nissan_leaf_driving_charging_2011.pdf

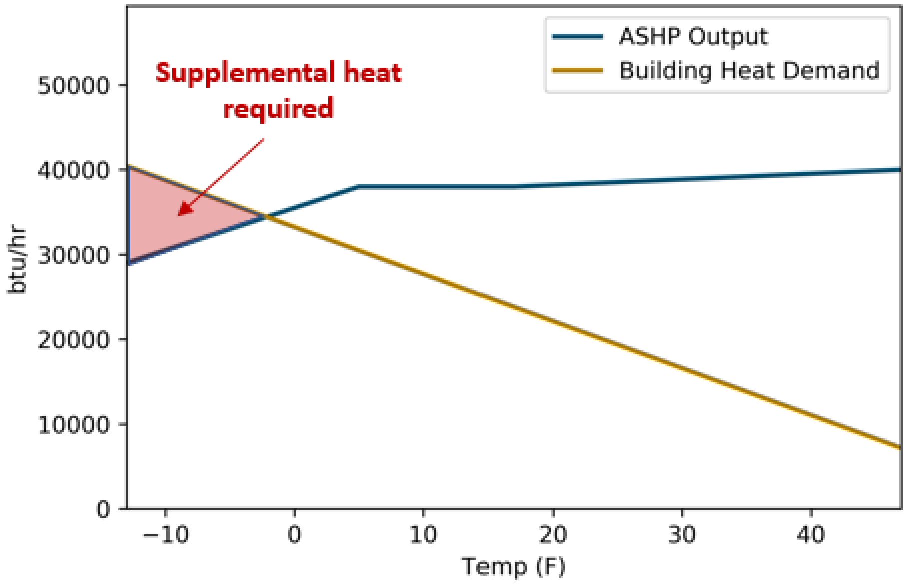
3.2 E3 space heating load shaping methodology

The E3 High Electrification scenario assumes that an increasing share of space-heating loads in Minnesota are served by electric air-source heat pumps (ASHP). ASHPs are relatively rare in Minnesota today, but in the High Electrification scenario adoption of ASHP technologies approaches 90% of state-wide floorspace by 2050. Such a large-scale adoption of ASHPs would add large new, and weather dependent, loads to the state's electricity system.

ASHPs and weather

The efficiency and output capacity of an ASHP decrease as outdoor air temperature drops. When an ASHP can no longer provide enough heat to maintain building comfort, supplemental sources of heat are required (Figure 3**Error! Reference source not found.**). There are two sources of supplemental heat typically used in combination with an ASHP: electric resistance and thermal. For the purposes of the High Electrification scenario we assume that all supplemental heat is served by electric resistance. Where a heat pump can have a coefficient of performance of higher than 2 cold temperatures, the COP of electric resistance heat is 1. The combination of decreasing heat pump efficiency and increasing reliance on electric resistance heat means that ASHPs require non-linear amounts of input power to keep buildings warm in cold weather.

Figure 3: Building Loads and Heat Pump Output

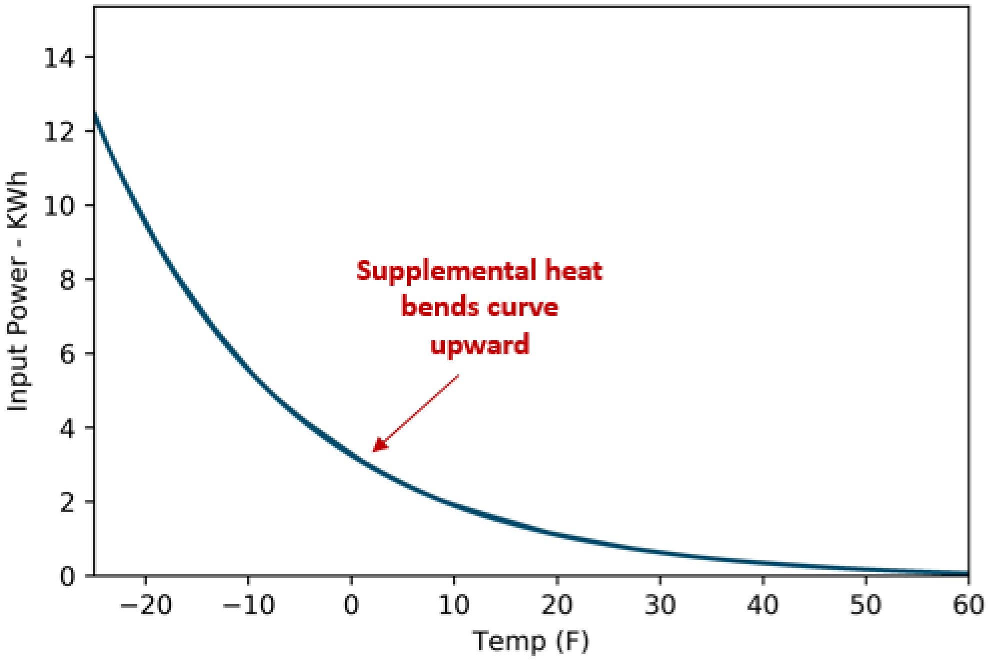


Building simulations and benchmarking

E3 developed relationships between temperature and ASHP loads for both residential and commercial buildings through simulations in the building science software EnergyPlus. E3 used a combination of Federal and local sources (EIA RECS 2015, EIA CBECS 2012, CEE 2018, CEE 2017, Edwards et al 2018) to benchmark the simulations to MN building heat demands.

Figure 4 shows the derived relationship between temperature and a cold climate ASHP load for a typical residential home in Minnesota[3]. The heat pump can cover all of the building's load until 0F, at which point an increasing share of heat is provided by the electric resistance element. By -25F, the ASHP has a COP of 1, the point at which buildings are assumed to be entirely heated by electric resistance.

Figure 4: Residential Heat Pump Load & Temperature



Weather matching

ASHP loads are weather dependent. On a very cold day outdoor air temperatures across Minnesota can vary by a wide margin (Figure 5). For instance, on January 16, 2009 the minimum outdoor air temperature was -5F in Cottonwood County but was -38F during the same hour in Koochinching County. This temperature gradient can lead to very different per-building loads across the state. For instance, a residential building in Cottonwood County with design load of 38 kbtu per hour requires 4 kW of input power to stay warm. That figure for an equivalent building in Koochinching County quadruples to over 16 kW because the heat pump is running entirely in electric resistance back-up mode.

In order to account for the diversity of weather impacts, E3 used a combination of NOAA historical weather data and Census county-level household data. E3 matched NOAA weather stations to their nearest county neighbor in order to develop a geographically explicit per-building load prediction (Figure 5). These shapes were then multiplied by the number of fuel-switching households per county and summed to develop a diversified ASHP shape for Minnesota as a whole. Figure 6 shows the cumulative 2050 loads from ASHP space heaters under a 2009 weather year on both an annual and peak week basis.

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[3] The performance of this heat pump is consistent with a top performing 48 kbtu/hr (4-ton) heat pump on the NEEP Cold Climate Heat Pump Product Specification listing.

Figure 5: Minimum Temperatures on January 16, 2009

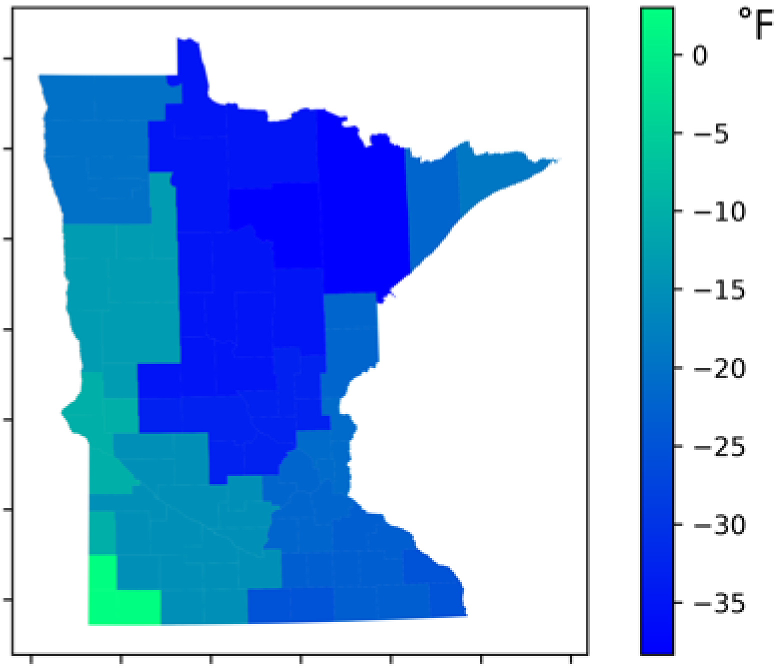
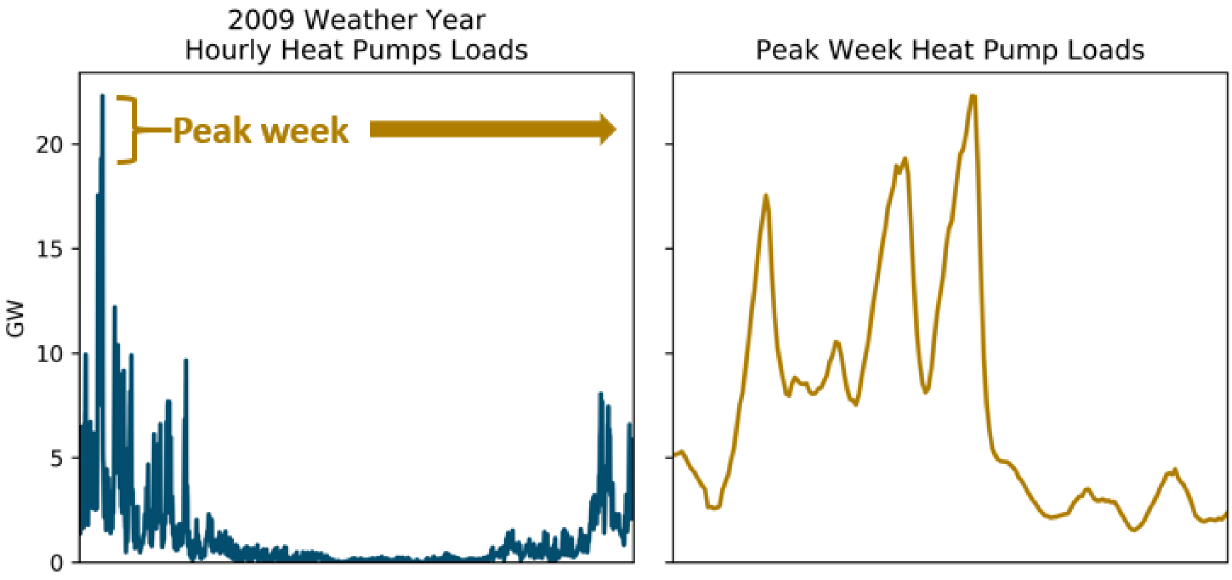


Figure 6: 2050 Residential Space Heat Load



Caveats and limitations

The load shapes developed through the above methodology offer an initial estimation of the scale of loads that follow from a near-complete electrification of space-heating in Minnesota. There are several factors that could make these loads higher or lower. Loads, particularly peak loads, could be higher if homes and businesses do not adopt cold-climate heat pump technologies. Loads could be lower if heat pump technologies continue to improve in cold-climate performance and if buildings heating loads are reduced through weatherization measures. Reduced heating loads decrease the amount of load in peak hours that must be covered by electric resistance back-up heat. Doing so pushes the non-linear portion of the load curve shown on Figure 4 to lower temperatures.

4 Simulating hourly loads

4.1 Forecasting hourly loads

In forecasting the Reference scenario, we project hourly loads by scaling up a historical year of Xcel Energy - Upper Midwest hourly loads according to the total energy in the forecast year. This methodology assumes that the load mix in the Reference scenario changes slowly enough that using a historical load shape will represent the Reference load shapes in the future. Although the Reference scenario has some changes in load across classes, the net load growth is small (0.24%/year) especially in comparison to the High Electrification scenario. Thus, we project hourly loads for the Reference scenario by scaling up each hour according to the total energy in the forecast year. For example, in 2009 the Xcel Energy - Upper Midwest annual load was 44.9 TWh; if the forecast year had an Xcel Energy - Upper Midwest load of 60 TWh we would scale up each hour by 1.33 (60/44.9 = 1.33) to calculate the hourly load for the Reference scenario in the forecasted year.

High electrification load

In calculating the High Electrification scenario load shape, we forecast the annual shape by layering on the incremental amount of electrification we expect in each of the load shaping categories. See Table 2 for the annual incremental electric load in the High Electrification scenario. In earlier years there is some amount of negative load due to efficiency gains[4], but in most categories we see load growth due to electrification.

Table 2. High Electrification scenario incremental annual electric load over Reference scenario (TWh)

	2015	2020	2025	2030	2034	2040	2045	2050
Space Heating	0.0	0.0	0.0	0.2	1.2	3.8	6.1	7.8
Water Heating	0.0	0.0	-0.1	-0.3	-0.2	0.2	0.6	0.8
Passenger EV	0.0	0.0	0.0	0.5	1.6	4.1	5.8	6.5
Other (Freight EV, Agriculture)	0.0	0.1	0.7	1.7	3.1	6.3	9.2	11.8

4.2 Downscaling Minnesota loads for the Xcel Energy - Upper Midwest service territory

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[4] This is especially the case for water heaters. Transitioning to heat pump water heaters causes lower load growth than the Reference scenario through 2034

To calculate hourly load shapes for the Xcel Energy - Upper Midwest system, E3 scaled the Minnesota hourly load shapes to Xcel Energy's service territory across five Upper Midwest states. Based on historical energy data, in recent years Xcel Energy's retail sales in those five states have been on average 67% of total retail sales in Minnesota (Table 2). So E3's forecast of load and peak demand Minnesota-wide is multiplied by 67% to derive load and peak demand for the Xcel Energy - Upper Midwest system under this High Electrification sensitivity.

This approach assumes that the scaling of Minnesota loads to the Xcel Energy - Upper Midwest system stays constant over the forecast period. If electrification of transportation, water, and space heating has a different growth rate in our Upper Midwest service territories than in Minnesota as a whole, then both energy and demand impacts could be significantly different for Xcel Energy.

Space heating loads have a significant impact on the estimated peak load, especially in the 2040-2050 timeframe. Using this load shaping methodology for the Xcel Energy – Upper Midwest territory, the incremental peak impact of the High Electrification scenario over the Reference scenario grows from 430 MW in 2034 to over 14 GW in 2050, as the utility shifts from a summer peaking utility to a winter peaking utility due primarily to space heating demands. As noted in the load shaping section above, technology choice matters – foregoing building weatherization and cold climate heat pump technologies could make this peak demand even greater. Other peak mitigation options include non-electric thermal backup sources of heat, or managed load programs (like DR).

Table 2. Minnesota to Xcel Energy - Upper Midwest Scaling Factor[5]

	Xcel Energy - Upper Midwest Annual Load (MWh)	Minnesota Annual Retail Sales (MWh)	Load Share	
2009	44,923,739	64,004,463	70%	
2010	46,188,165	67,799,706	68%	
2011	46,133,452	68,532,708	67%	
2012	45,550,281	67,988,535	67%	
2013	45,177,181	68,644,103	66%	
2014	45,197,106	68,719,367	66%	
2015	44,565,009	66,579,234	67%	
2016	44,670,394	66,546,492	67%	
			67%	**Average**

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[5] Source for Minnesota load: EIA state profile on retail sales for 2009 to 2016