Minnesota Energy Efficiency Potential Study: 2020–2029

Appendix E: Load Management and Demand Response

Contract # 121430
Publication Date: March 27, 2019

Conservation Applied Research and Development (CARD) FINAL Report

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ACKNOWLEGEMENTS

This project was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources, through the Conservation Applied Research and Development (CARD) program, which is funded by Minnesota ratepayers.

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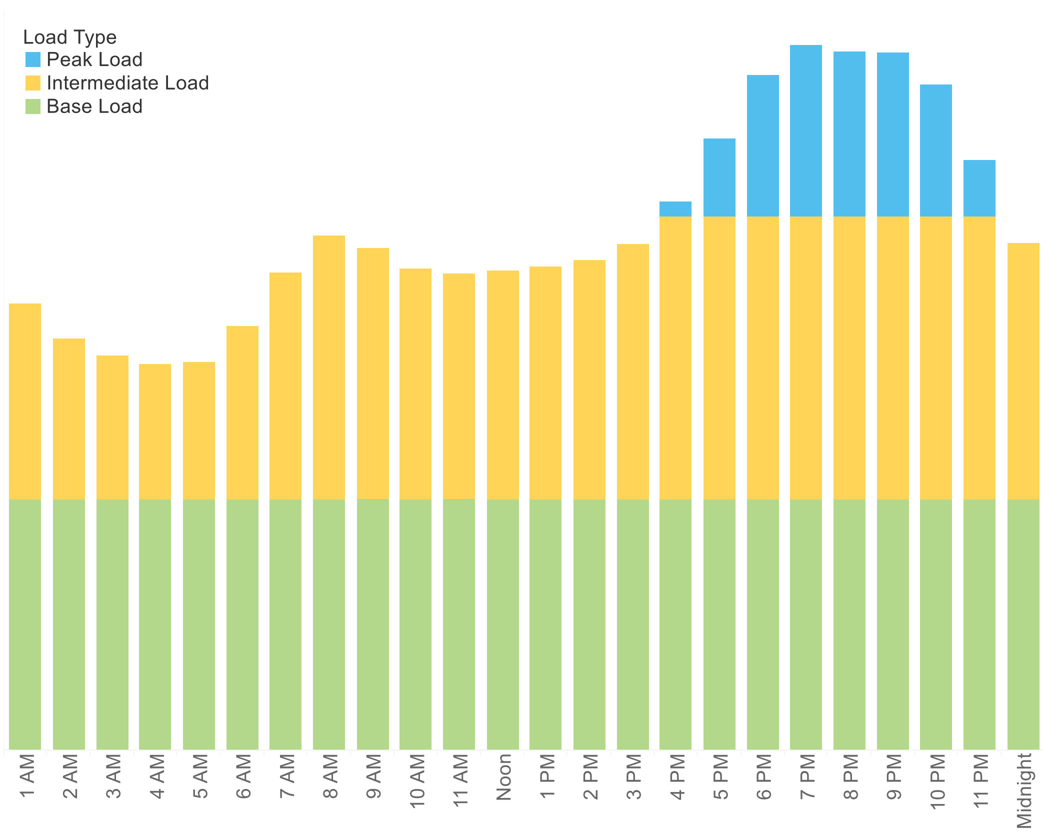
Introduction

Demand response is a load management strategy that reduces energy use during specific time intervals in order to reduce costs and minimize operational constraints associated with meeting peak electricity demand. The Federal Energy Regulatory Commission (FERC) defines demand response as "changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" (Lee et al. 2016). Demand response traditionally reduces peak energy usage only during the times of highest local or regional capacity constraint. In Minnesota, this typically occurs in the summer, but certain utilities do have winter peaking systems (MN PUC 2016). Demand response allows grid operators to reduce strain on the grid, lower costs, and avoid building peak load power generation facilities (Siano 2014; US EPA 2015). An example peak load period is shown in blue in Figure 1 below.

Figure 1 Example Daily Load Curve

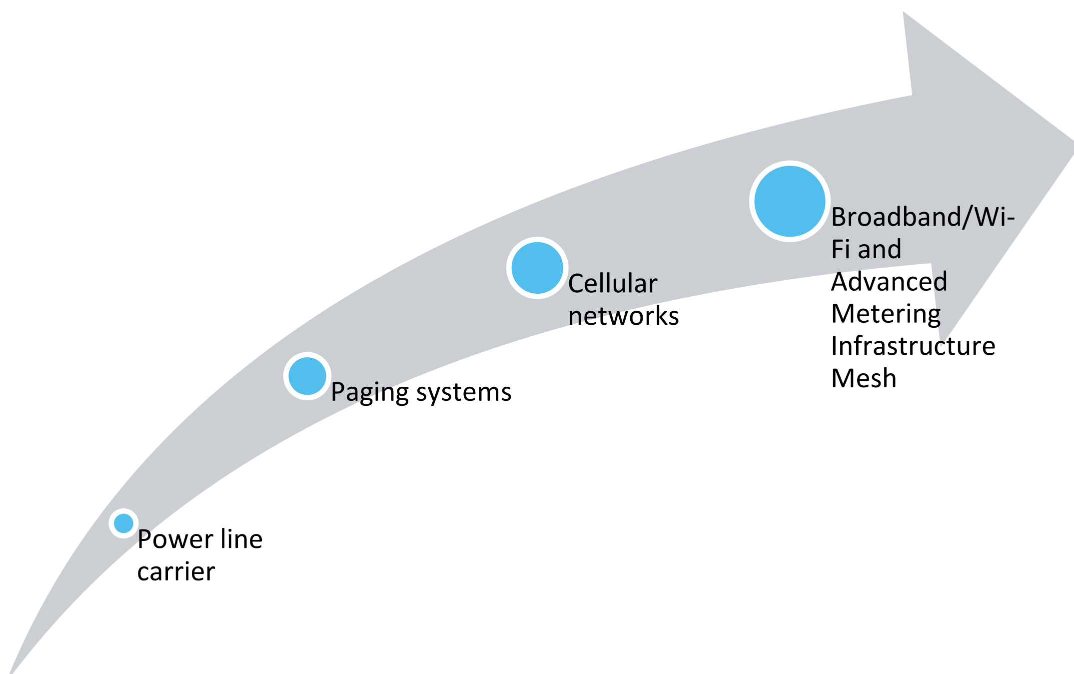


This Appendix provides an overview of demand response trends, results from other potential studies, and summarizes the technical potential of select demand response measures identified for this Statewide Natural Gas and Electric Energy-Efficiency and Carbon-Saving Potential Study. As an energy efficiency standard, Minnesota's Conservation Improvement Program (CIP) only considers demand response measures that reduce overall energy use. (Office of the Revisor of Statutes 2017). Our technical analysis remained within these parameters, though we provide a more general overview of demand response outside of energy efficiency programs to set a broad framework for further discussion.

Types of Demand Response

Research literature characterizes demand response in many different ways. This is partly a reflection of the changing characteristics of the resource, especially as smart devices and advanced meters come online and enable additional functionality (Bartholomew et al. 2009; Potter and Cappers 2017), and also as the communication technology used to call a demand response event evolves (PLMA 2017). As Figure 2 shows, demand response was historically implemented through one-way paging or radio signals to a single type of equipment such as an air conditioner to cycle a compressor on and off, or a phone call or a fax to a large commercial or industrial customer who may respond to a demand response event by physically turning off equipment. Demand response is shifting from these legacy systems to communication that is two-way, digital, automated, and able to simultaneously signal to a larger set of end uses.

Figure 2 Evolution of Demand Response Communication Technology



There are multiple ways to differentiate between types of demand response. Several studies characterize demand response as dispatchable versus non-dispatchable. Dispatchable resources refer to a direct customer response to a call for demand response. Dispatchable demand response includes powering down customer loads when an event is called, or direct load control of customer appliances such as air conditioners (FERC 2010). Non-dispatchable demand response programs create an incentive structure to reduce peak demand but are not tied to specific events called by a utility. These include programs such as time-of-use rates, further described below, where a customer is incentivized not to use energy during a certain time period (Bartholomew et al. 2009).

A different characterization is offered by Jennifer Potter and Peter Cappers, who give a thorough overview of the types of demand response in their publication, *Demand Response Advanced Controls Framework and Assessment of Enabling Technology Costs* (Potter and Cappers 2017). The authors divide demand response into two categories: incentive-based (i.e. payments) and time-based (i.e. rates).

Potter and Cappers (2017) outline *incentive-based demand response* as including controllable, configurable, manual, and behavioral resources.

- **Controllable demand response** has the ability to manage a customer's end-use device to increase or decrease load or to disconnect the load entirely from the grid. Energy management options under this framework are viable on a very short timescale, often without notifying the customer. An example of a controllable demand response program in Minnesota is air conditioner cycling, discussed in further detail below.
- **Configurable demand response** programs are similar to controllable programs by allowing centralized control of an end-use device. However, configurable demand response allows a customer to override a setting sent to the device by the central system. For example, a utility or demand response aggregator could send a signal to a connected thermostat during a peak event to increase the temperature setting. Under a configurable program, the customer would be allowed to override this setting.
- **Manual demand response** lets a customer curtail energy use in exchange for a predetermined incentive, in response to a call for the resource. It is not tied to a specific end use but rather allows a customer to adjust loads manually as appropriate.
- **Behavioral demand response** sends messages to customers to drive behavior change reductions in energy use, and is currently used on a very small scale.

Incentive-based demand response, specifically controllable and configurable resources, has the closest relationship with the scope of this study and its focus on energy efficiency measures.

Potter and Cappers use *time-based demand response* to encompass programs where customers respond to energy and capacity pricing signals that vary by time. They include the following programs:

- **Time-of-use** demand response is a tariff that charges different energy and capacity rates during fixed on and off-peak times of the day and season (Bartholomew et al. 2009).

- **Critical peak pricing** provides a discounted rate over the majority of the year with a significantly higher rate during a limited number of peak events. These peak events are called due to reliability or price constraints on the grid (Faruqui, Hledik, and Lineweber 2014).
- **Real Time Pricing** bills customers at hourly rates that reflect market prices. These are typically day-ahead price signals and do not include specific peak events (Bartholomew et al. 2009).
- **Variable peak pricing** is a combination of both time-of-use and critical peak pricing. Variable peak pricing breaks a billing cycle into smaller, hourly components such as on and off peak, but will match market prices for its on-peak periods (Potter and Cappers 2017).

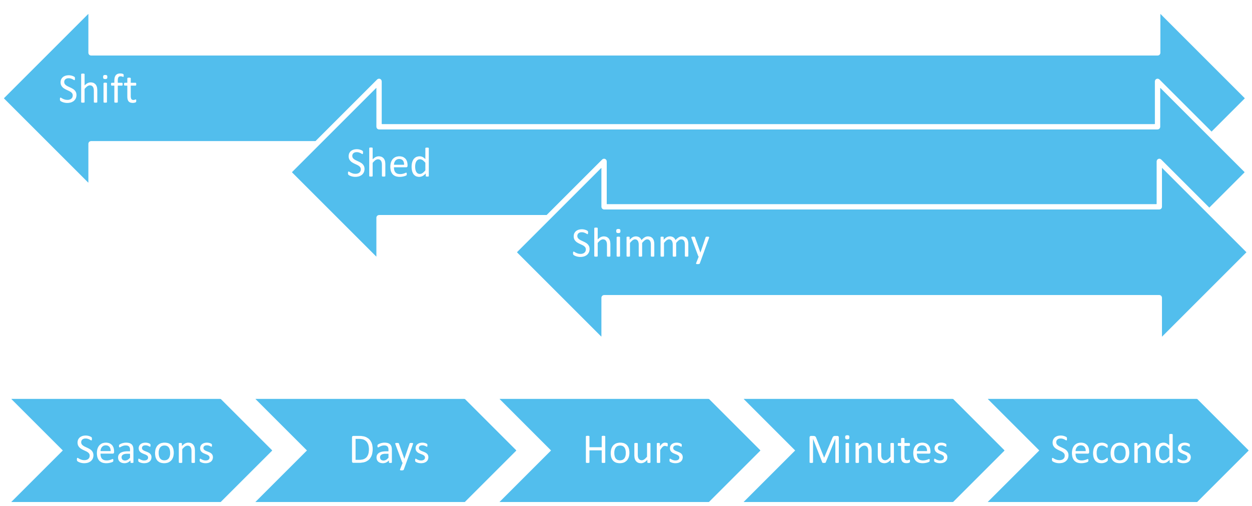
While time-based demand response programs are effective ways to reduce system capacity needs, there are limitations. First, all of the above time-based demand response programs require a customer to have some sort of interval or advanced meter to record verifiable energy use over time. As of 2016, Minnesota had an advanced meter infrastructure penetration of 17% (US DOE 2016). For these reasons, as well as the scope of this project mentioned above, this study focuses on incentive-based demand response measures. A more complete demand response potential study should focus on all of the applicable types of demand response listed above.

Timescales of Demand Response

A simple terminology for characterizing demand response programs is "shift, shed, and shimmy," discussed by Alstone et al. (2017) and by Potter and Cappers (2017). Each of these three terms covers a different timescale for the demand reduction, and offers distinct grid benefits. The

Figure 3 below shows this continuum, from seasons to seconds.

Figure 3 Shift, Shed, and Shimmy (adapted from Potter and Cappers 2017 and Alstone et al. 2017)



Shift encompasses moving load from one period of the day to another and may include increasing energy usage during some periods of a day. Shifting energy usage can be beneficial to address ramp rates of renewable energy. However, this shift in energy use may result in an increase in net energy use (O'Connell et al. 2015; MN State Legislature 2007). Configurable and controllable loads are types of incentive-based demand response under the shift category (Potter and Cappers 2017).

As the concentration and penetration of renewable energy on the grid increases, the traditional value of peak shifting is converging with other needs (Mims, Eckman, and Goldman 2017). These include shifting energy use to avoid high ramp rates,[1] to accommodate over-generation during times when load is low, and to accommodate the variable output of renewable generation from effects such as clouds and wind changes (Lanzisera et al. 2015). Demand shifting has also recently been examined as a tool to stabilize market prices when renewable generation is high (Goldenberg, Dyson, and Masters 2018).

Shed is the most traditional type of demand response. It reduces customer load and includes configurable and controllable demand response. Potter and Cappers (2017) outline shed resources as accomplishing the following:

- Add capacity resources to accommodate peak load
- Support a contingency event or an emergency condition
- Provide energy supply in hour-ahead or day-ahead markets

Alstone et al. (2017) designates a term to classify fast responding demand response as a *shimmy* resource. Shimmy resources are deployed at timescales less than an hour. They provide regulation reserves and energy imbalance services. However, to be a reliable resource for these services, an end-use customer cannot have the option to opt-out, and so it only applies to controllable loads (Potter and Cappers 2017).

Demand Response Potential Studies and Literature

This section reviews recent demand response potential studies as well as other demand response related literature for program trends. We reviewed potential studies covering geographies in California, Michigan, the Pacific Northwest, Pennsylvania, and for Portland General Electric in Oregon. We also include findings from a recent Xcel Energy potential study, though the study itself is discussed in the section titled Demand Response Programs in Minnesota.

Demand response potential studies in other parts of the country offer insight into the current state of both incentive-based and time-based demand response potential. For example, many of these studies include programmable communicating thermostats and energy management systems, which have the capability of responding to price signals to minimize cost to the end user (Hledik et al. 2016). The caveat

[1] The concept of high ramp rates is illustrated by the California duck curve (California ISO 2013). For example, increasing the penetration of solar energy on the grid could potentially lead to high ramp rates from the afternoon to an evening peak load as the setting sun and decrease of solar energy coincides with peak load on the system.

is that these types of demand response systems are best utilized in concert with advanced metering infrastructure (Siano 2014). Therefore, these potential studies may not directly align with the utility infrastructure in Minnesota.

California

Lawrence Berkley National Laboratory, E3, and Nexant prepared a demand response potential study for the state of California in 2017 looking out to 2025 (Alstone et al. 2017). The authors examined the technical potential as well as the cost effectiveness of a number of demand response options. These options included both traditional as well as smart, fast-responding demand response.

One significant finding from the Alstone et al. (2017) analysis is California Independent System Operator (CAISO) is shifting from needing its historically higher levels of peak reduction due to the changing energy mix on the grid. The higher levels of renewable energy mandated by California's Renewable Portfolio Standard (RPS) require a higher degree of mixing energy efficiency, energy storage and demand response. "Shed" resources were found to have a relatively minimal impact potentially due to the availability of other options such as energy imports, natural gas ramping, and battery discharge. However, as renewable penetration increases, the value of "shimmy" resources' ancillary benefits was found to increase over time. Lastly, "shift" resources were found to have potentially positive benefits, depending on the current energy prices by generation type. The benefits of shift resources were predicted to vary by program type. For example, higher benefits were predicted where an automated pricing program was offered through an end-use such as a programmable controllable thermostat.

Michigan

In late 2017, Applied Energy Group released a report titled the State of Michigan Demand Response Potential Study (Applied Energy Group 2017). The study assessed potential in the years between 2018 and 2037. The study looked within broad program areas including "direct load control, storage, demand side rates or incentive programs, curtailment agreements, voltage optimization, and ancillary services." Similar to California, the study looked at both cost-effectiveness as well as the technical achievable potential of demand response. In the technical achievable potential category, battery storage and variable peak pricing were shown to be the leading solutions with the former taking the lead. Under the cost assumptions of the study, the areas with the highest potential included variable peak pricing and the residential sector. These leaders were followed by large commercial and industrial with small and medium commercial and industrial composing the smallest share of the groupings. The report identified programs that require advanced metering infrastructure as well as programs that prefer advanced metering infrastructure. This dichotomy of requirements, along with cost assumptions in the study, is useful for Minnesota in the interim until utilities transition to advanced metering infrastructure within their service territories.

Pacific Northwest

Navigant Consulting released a report in 2014 for the Northwest Power and Conservation Council (Navigant Consulting 2015). The report outlined demand response programs as part of the Seventh Power Plan, which addresses the future energy needs of the Pacific Northwest through 2035 (Northwest Power and Conservation Council 2016). In its report, Navigant outlines a number of both basic and smart control technologies. This study codified demand response into a dichotomy of basic and smart. *Basic contro*l technologies include an on/off switch such as central air conditioner load control or manual control such as a curtailable tariff program. *Smart control* includes programmable controllable thermostats or automated demand response, which can be operated through various communication mechanisms such as Wi-Fi or a smart meter.

By the year 2030, the Seventh Power Plan demand response study estimated a mix of both basic and smart demand response options will yield a peak winter reduction of 9%, and 8% in the summer for a unit-cost of roughly $70 per kilowatt (kW) per year. In terms of smart control systems, the study found residential space heating and curtailable/interruptible programs to yield the most savings. In addition, at a unit-cost of roughly $40 per kW per year, smart demand response would be able to offer balancing services for a total of nearly 300 MW in the winter and over 300 MW in the summer. Agricultural and industrial sectors resulted in the highest unit costs in terms of balancing services. Lastly, the authors of this study identified that balancing services may be underestimated due to the nascence of these types of programs.

Pennsylvania

Pennsylvania investor owned utilities underwent a demand response potential study, which was performed by GDS Associates, Inc. et al. (2015). The report was less focused on technical potential and instead looked at economic drivers to understand the correct levels of incentives to offer consumers for participating in demand response programs. The authors "determined that the concept of technical potential used for estimating EE [energy efficiency] potential does not have a counterpart for demand response. For enough money, homes and businesses will forego virtually all electric demand temporarily" (GDS Associates, Inc. et al. 2015). In its report, programs addressing summer demand response were detailed.

In the case of residential demand response programs and commercial cooling programs, the authors concluded a net negative present value among almost all utilities for these programs through 2021. The only instances with a positive net present value were those in the investor owned utility where the control equipment was already installed. The incentive-based commercial and industrial programs differed in terms of costs as control equipment does not need to be installed to participate in this type of demand response. Therefore, in almost all cases, these yielded cost-effective demand reductions.

Portland General Electric

The Brattle Group prepared a demand response potential study for Portland General Electric (PGE) that focused on the time period of 2016-2035 (Hledik et al. 2016). PGE's investment in advanced metering infrastructure allowed a wider range of analysis of demand response choices, which included both time-based and smart control systems for the incentive-based programs. However, their previous investment in advanced metering infrastructure excluded this infrastructure from their benefit-cost assessment of demand response programs.

The programs yielding the highest benefit-cost ratio were those in the residential and large commercial and industrial sectors. This economic-based finding offers a similar conclusion as above by Navigant Consulting (2015) that the highest available demand response potential is available in the residential sector and in curtailable/interruptible loads. Water heating was found to yield positive results when weighing benefits of demand response and peak reduction. These results were found to be even more favorable when considering ancillary services this end use can provide. Bring your own thermostat was found to be more cost effective than traditional direct load control air conditioner programs due to lower equipment costs. The comparative capacity reductions were mostly realized in the long-term by the bring your own thermostat program. Agricultural pumping as well as small commercial and industrial demand response was found to yield negative to minimal value, respectively. Similarly, EV charging demand response yielded uneconomic results due to charging profiles of EV owners being out of sync with peak.

Programs Featured in Other Potential Studies

The potential studies discussed above show differing results in different areas of the country. Cost effectiveness as well as technical achievable potential differs due to a number of criteria that change in different areas of the country. These depend on factors such as customer profiles, installation of meter types, regulatory structure, and electricity rates. Below are summary tables that identify programs covered in the potential studies above. These are separated into three different figures. Figure 4 below outlines programs that cover all sectors (residential, commercial, and industrial). Figure 5 shows programs in commercial and industrial sector and Figure 6 shows programs in the residential sector.

Figure 4 Demand Response Programs in Potential Studies – All Sectors

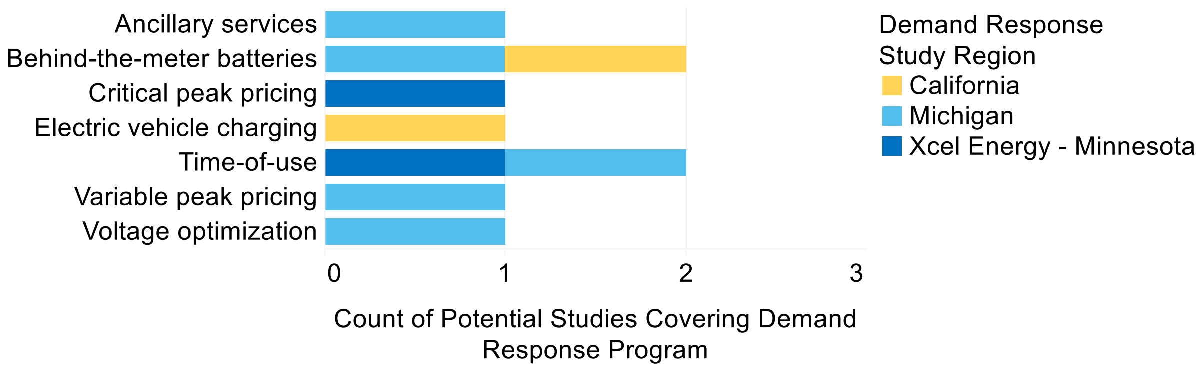


Figure 5 Commercial and Industrial Demand Response Programs in Potential Studies

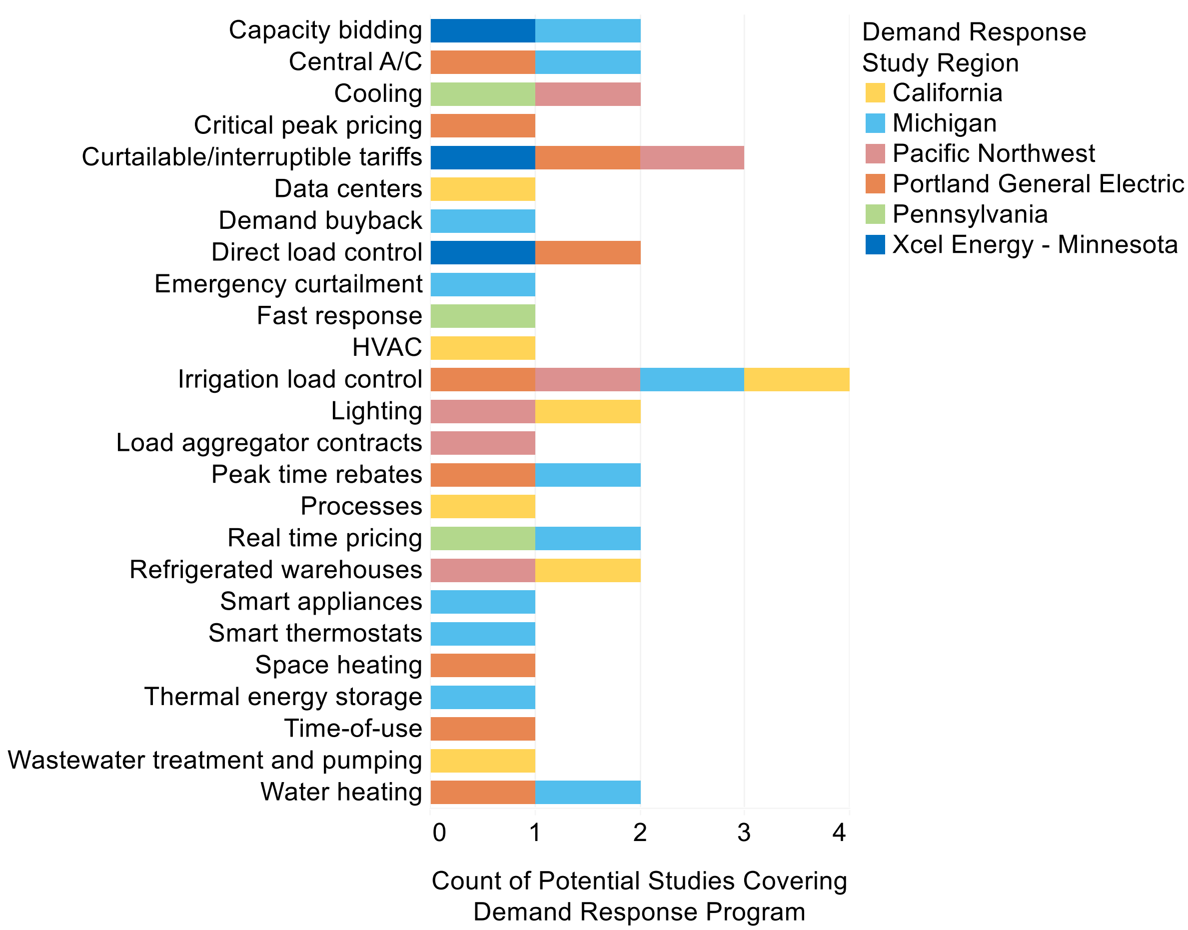
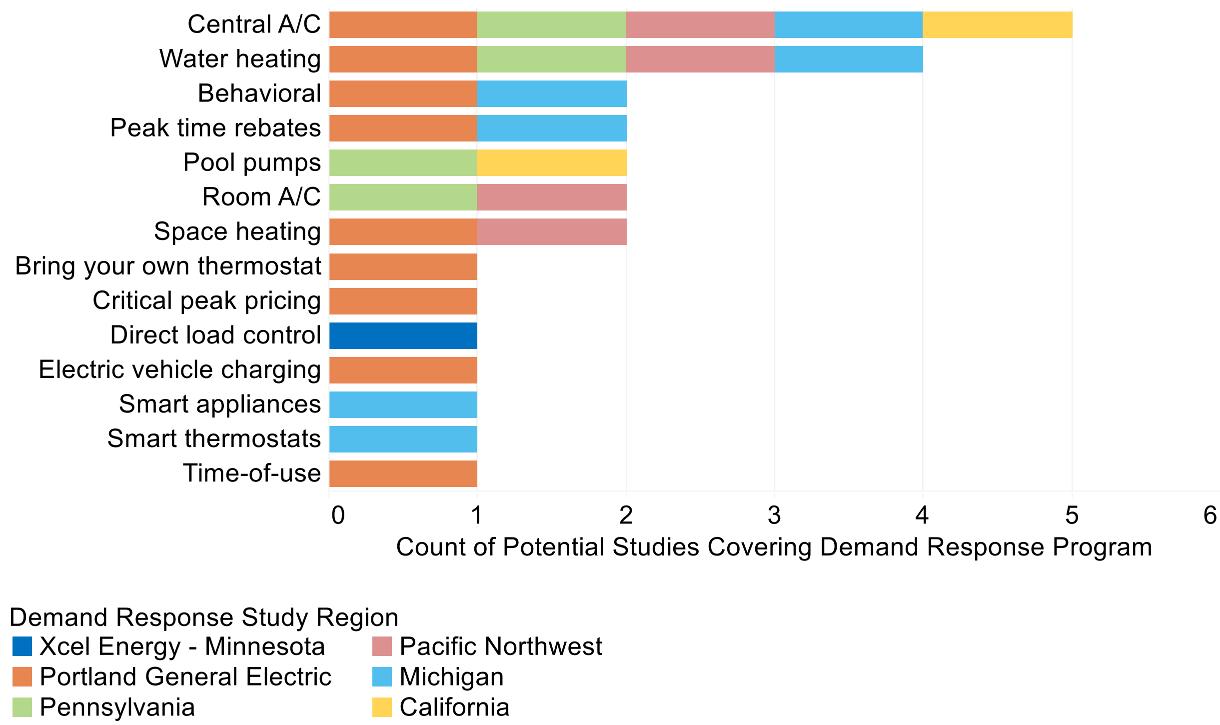


Figure 6 Residential Demand Response Programs in Potential Studies



As discussed in the studies above, advanced metering infrastructure can broaden the opportunity to incorporate demand response programs that are time-based as well as those that are automated. However, advanced metering infrastructure is not required for demand response options deployed using a customer's WiFi network such as programmable smart thermostats or smart appliances. The combination of quickly developing end-use technology along with emerging communication options allows learning to take place to determine the factors involved to reach the most cost-effective choices. Analyzing the above sources allowed us to narrow our list of possible demand response measures for this study. We determined options that are most feasible in Minnesota as well as those with the most potential for adoption using ubiquitous measures from these sources. These are discussed further below in our choice of measures.

Emerging Trends in Demand Response

Demand response programs will continue to evolve to take advantage of emerging technology trends. These technology drivers can offer more robust customer engagement, responsive feedback and monitoring, and increasingly elastic loads. Some leading trends are discussed below.

Internet of things and automated demand response

In the past decade, a significant trend in the consumer landscape is the rapid development and deployment of microprocessors in everyday devices, which has led to the internet of things. The internet of things pertains to a wide variety of connected devices in all sectors and energy end-uses. The list of internet of things connected energy loads includes equipment from televisions and cellular telephones to items such as home thermostats, electrical sockets, light bulbs, and energy management systems.

Along with the increasing penetration of internet of things devices is the development of newer forms of communication protocol and demand response without human interaction (Lanzisera et al. 2015). Predominant residential demand response programs such as those to control air conditioner cycling were called using radio signals or paging technology. In the air conditioner cycling example, a paging system sent a signal to a switch to turn off the air conditioner's compressor to offer peak savings and provide a shed service to the grid (Winch et al. 2009). This paging system is evolving into automated demand response, which consists of a communications protocol that can be used by a utility or demand response aggregator to communicate with end-use devices to automatically respond to demand response events (Lanzisera et al. 2015).The communications protocol used to send signals over this automated network is also evolving. Since 2002, Lawrence Berkley National Lab made efforts to release a standardized, automated communication framework referred to as Open Automated Demand Response 2.0 or shortened to OpenADR 2.0 (Piette et al. 2009).

OpenADR 2.0 is able to integrate communication with demand response resources along with distributed energy resources (DER) such as solar and wind energy, thereby enhancing the opportunity to create a cleaner grid (Yan et al. 2015). OpenADR 2.0 allows communication over the internet using web services to all end-use sectors including residential, commercial and industrial (OpenADR Alliance n.d.). In addition, the internet of things and enabling communication protocols such as OpenADR 2.0 allow costs for faster demand response to reach nearly zero when implementing energy efficient devices that already have connectivity built in. In this case, demand response becomes a secondary benefit from non-energy and energy efficiency benefits (Lanzisera et al. 2015).

Advanced metering infrastructure and demand response

Along with the internet of things, smart meters and advanced metering infrastructure are significant trends in demand response. Advanced metering infrastructure offers the potential to target and lower acquisition costs of new customers such as those in the residential sector (Patel et al. 2016). Advanced metering infrastructure also unlocks achievable potential in all areas of demand response based on time-varying rates (Applied Energy Group 2017; Faruqui, Hledik, and Lineweber 2014).

Advanced metering infrastructure is becoming widely used in combination with automated demand response. For example, OpenADR 2.0 interval level data is a requirement for demand response programs such as real time pricing that require validated consumption data coinciding with a particular time period (Siano 2014). In other cases, advanced metering infrastructure is able to utilize OpenADR 2.0 and a home area network for the purposes of telemetry as a feedback system. This allows utilities and load aggregators to provide fast load shed for a variety of prices depending on the end use being controlled (Lanzisera et al. 2015). Lastly, demand response signals may be sent through and managed alongside an existing network of advanced metering infrastructure through a meter data management system,[2] which may lower the cost of demand response and provide a broader use-case for an advanced metering infrastructure investment (Schleicher 2015).

Electric Vehicles

Electric vehicles are currently a small share of the total stock in the US, and there are roughly 6,000 electric vehicles in Minnesota (MN PUC 2018). Compared the total number of passenger vehicles at nearly 5,000,000, this is a small percentage (US DOT 2017). However, EV adoption is accelerating. In the 2020s, EVs are projected to reach cost parity with conventional vehicles (Randall 2016). EVs are already a lower cost for consumers per vehicle mile. For these reasons, EVs are expected to add significant load for utilities. EVs offer multiple options for demand response, as the typical vehicle is parked for the majority of its life. However, there are limitations with the amount of public or workplace charging in terms of grid connectivity while a vehicle may be at a user's workplace. Off-peak charging poses potential to lower costs and to offer lower emissions in parts of the country with high amounts of wind production (Weis, Jaramillo, and Michalek 2014). Off-peak charging may include delayed charging, where a customer is incentivized through a time-of-use rate or controlled charging, where a utility manages customer's charging, while allowing opt outs if needed. PG&E recently tested managed charging among a subset of its customers driving BMW i3 vehicles and found participation to range between 20 and 50 percent, depending on the time of day of the charging event (Kaluza, Almeida, and Mullen 2016). Another option for utilities is to use vehicles as storage or vehicle to grid (V2G) when generation is cheap and draw on the batteries when wholesale prices increase. However, there is mixed discussion surrounding the potential for negative impacts on batteries due to increased numbers of cycling on the battery and its potential accelerated decline from this type of use. Researchers have found that designing a program with these considerations in mind can prevent early battery decay. However, V2G has the potential to accelerate decay when recommendations are ignored (Uddin, Dubarry, and Glick 2018).

[2] A meter data management system is a software solution used by a utility to utilize on a long-term basis, large amounts of data provided by advanced metering infrastructure.

Demand Response Programs in Minnesota

Demand response programs are currently offered by utilities and electric associations throughout Minnesota. These programs may be part of an investor owned utility's CIP portfolio, provided they result in an overall reduction in energy use (Office of the Revisor of Statutes 2017). Under the purview of CIP, municipal utilities and cooperative electric associations are allowed to use load management to "meet 50 percent of the conservation investment and spending requirements" within the applicable subdivision of the statute (Office of the Revisor of Statutes 2017). In addition, a cooperative electric association subject to rate regulation can recover expenses from load management programs.

Demand response can also be implemented by a utility or electric association outside of CIP. In these cases it generally provides a cost hedging or grid reliability benefit. Cost-recovery for investor-owned utilities would occur through a rate case or a special rider recovery to try to recover costs faster. If an investor-owned utility were using equipment in the demand response program, it can earn a rate of return on the investment.

Two recent publicly available studies provide insight into demand response program performance in Minnesota. A 2013 report titled *Demand Response and Snapback Impact Study* analyzed residential and small commercial measures in three different climate zones in Minnesota (Parker and Dickinson 2013). "Snapback" refers to the jump in energy used when recovering from a demand response event. Programs determined to not produce snapback included ice storage, electric heating and thermal storage, and onsite generation. In the snapback category, programs included air conditioning cycling, water heating curtailment, and electric heating cycling. This study concluded a net energy savings could be achieved even when snapback occurred (Parker and Dickinson 2013).

In 2014, the Brattle Group released a report titled Demand Response Market Potential in Xcel Energy's Northern States Power Service Territory (Faruqui, Hledik, and Lineweber 2014). While this study was not specific solely to Minnesota, it provided a useful source of information such as discussion surrounding the deployment of advanced metering infrastructure and the subsequent demand response program options this would enable, such as critical peak pricing and a redesigned time-of-use rate. In addition, it provided capacity savings by program type, potential increased penetration rates by program, and explored options of program redesign.

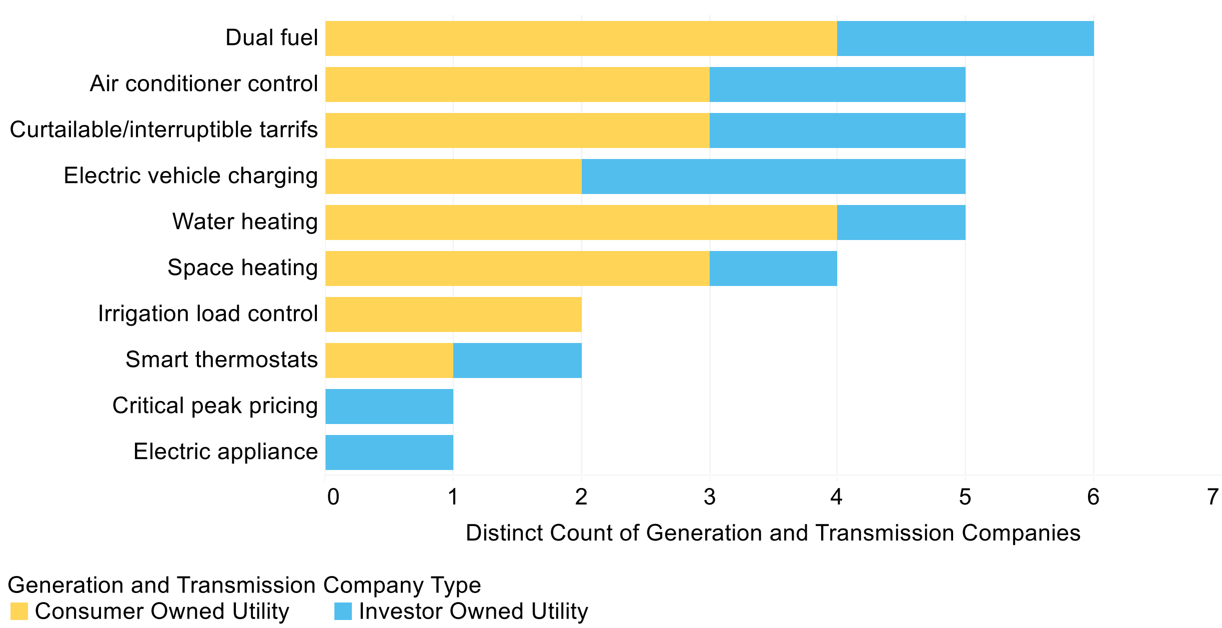
Figure 7 below illustrates the current demand response programs offered by Minnesota generation and transmission companies (Dairyland Power Cooperative; Great River Energy; Minnesota Power 2017; Minnkota Power Cooperative; Missouri River Energy Services 2017; Otter Tail Power Company 2017; Xcel Energy).[3] As shown in Figure 7, legacy programs such as dual fuel heating,[4] water heating, and air

[3] The programs represented in Figure 7 are sourced from a review of utility websites listed in the citation.

[4] Dual fuel programs consist of a customer switching from an electric heating system to an auxiliary non-electric fuel source such as propane or fuel oil during a demand response event.

conditioner direct load control still dominate the program type landscape. These program offerings agree with the potential studies mentioned above, which pinpoint the residential sector and curtailable large commercial and industrial customers as the lowest hanging fruit. However, this program landscape will change with the addition of new technologies. As the chart below shows, many utilities are integrating electric vehicle charging programs and smart thermostat demand response offerings into their program portfolios and their participating customers are expected to grow in the coming years. In addition to emerging program options, Missouri River Energy Services is working with its communities to roll out advanced metering infrastructure and coordinate with their demand response offerings (Missouri River Energy Services 2017). In addition, at the end of 2017, Xcel Energy proposed a residential time-of-use pilot with the Minnesota Public Utilities Commission that would leverage an advanced metering infrastructure installation in two areas of the Twin Cities Metro Area. If approved, this program would begin implementation in 2019 (Northern States Power Company 2017).

Figure 7 Minnesota Demand Response Programs

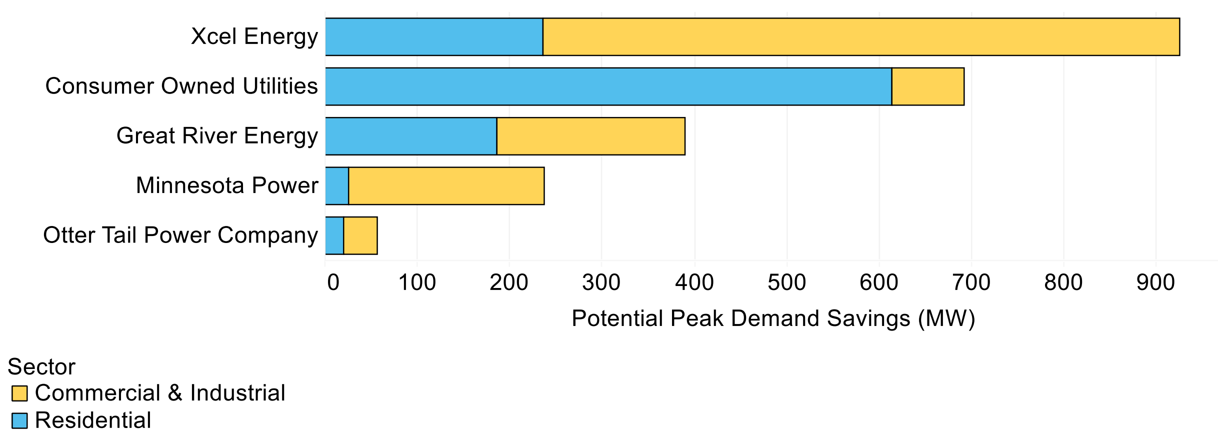


The utilities offering the programs above and the associated potential peak demand capacities are shown below in Figure 8. These values are reported annually by all utilities to the U.S. Energy Information Administration via Form EIA-861.[5] As part of this process, utilities report both potential and actual demand response capacity. The potential peak demand savings reported by each utility "refers to

[5] There are multiple sources for demand response enrolled capacity. For example, investor owned utilities report demand response savings through annual CIP Status Reports. Municipal utilities and cooperative electric associations self-report demand response to the state using Energy Savings Platform. These numbers varied from EIA data, and so the project team chose to use EIA because it provided a consistent source across all utility groups.

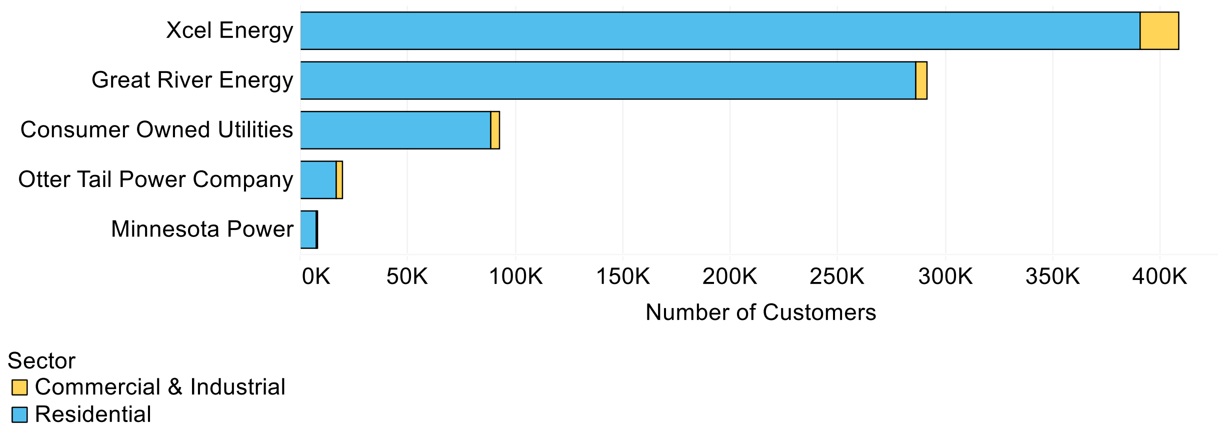
the total demand savings that could occur at the time of the system peak hour assuming all demand response is called" (US EIA 2017). In other words, although Xcel Energy has nearly one gigawatt of demand response, it does not call on the entirety of this resource each year. To consolidate the figure below, municipal utilities and electric cooperative utilities were grouped into "Consumer Owned Utilities." Due to a large enrollment of its member cooperatives, Great River Energy was reported separately.

Figure 8 Minnesota Demand Response Potential Capacity (MW) by Utility and Sector (Source: US EIA)



Each utility or utility group shows different reliance on customer sectors for its demand response capacity. Xcel Energy, for example, has a large capacity enrollment in its interruptible load program as well as its rooftop unit direct load control program, which makes up the bulk of its capacity. Its residential air conditioning direct load control program has far more customers enrolled as shown in Figure 9 below, but the savings associated with each home are much lower than those offered by its larger commercial and industrial customers. Consumer owned utilities such as municipal electric utilities and cooperative electric associations have a much larger capacity in the residential sector. Great River Energy, which is a generation and transmission provider for cooperative electric associations throughout Minnesota, offers a roughly equal mix of capacity in each sector. Great River Energy's residential offerings are composed in large part by water heater load management, which the organization has offered for the past three decades. In contrast, Minnesota Power's customer mix is heavily weighted, in terms of usage, toward large commercial and industrial customers and its demand response resource reflects this customer mix.

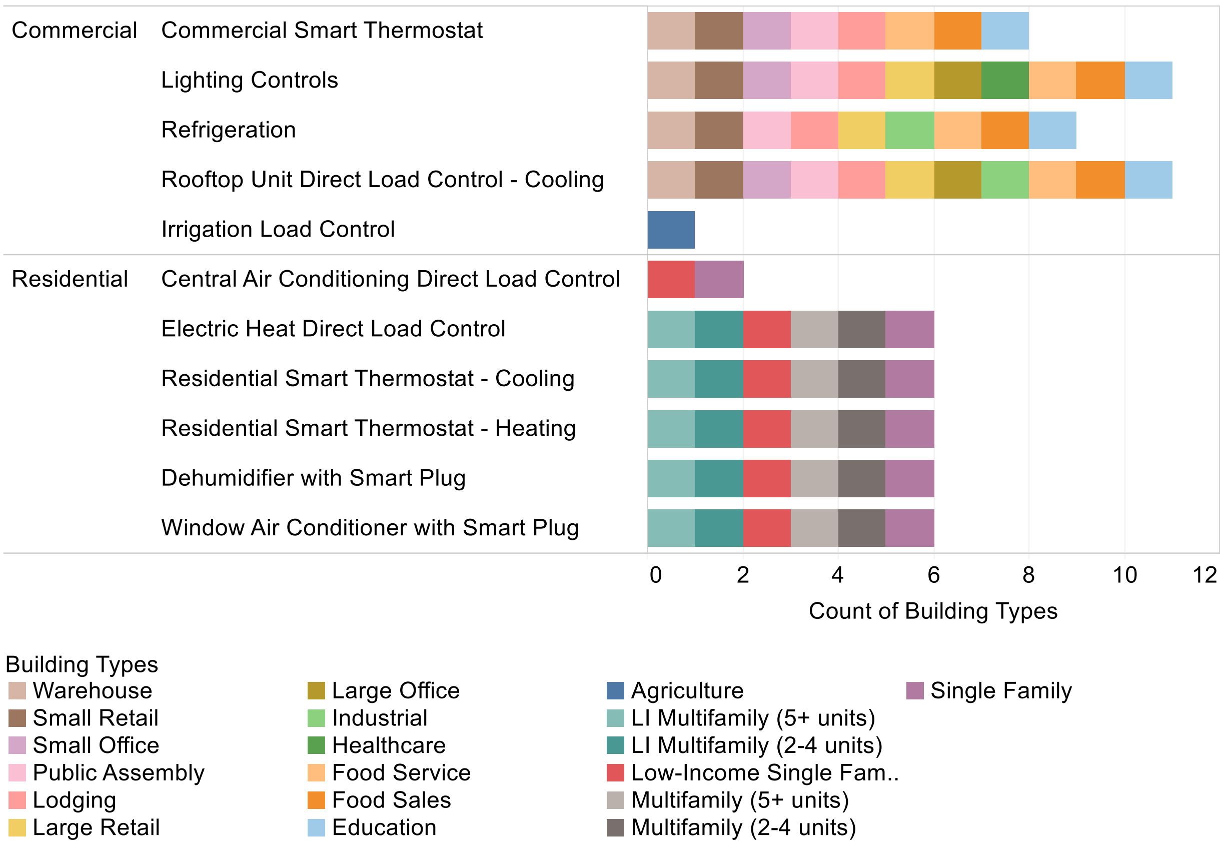
Figure 9 Number of Enrolled Customers in Demand Response Programs by Utility (Source: US EIA)



Demand Response Measures Included in This Study

This study evaluated the technical potential of select demand response measures determined to be widely applicable in Minnesota and allowable within the CIP framework. As is clear from the above review, numerous additional measures and programs exist for demand response, especially those that utilize time-varying rates, but full consideration was beyond the scope of this study. Figure 10 below displays each measure included as part of this study along with the associated building types for which it was evaluated.

Figure 10 Demand Responses Measures Included in this Study



Commercial and Industrial

Demand response in the commercial and industrial (C&I) sector, which includes agriculture, can range from manual to automated control. This includes the legacy method of notifying a customer of an event and requesting equipment to be manually turned off, to devices that can respond to an event automatically. This section covers a sample of these technologies.

In the agricultural sector, growers of crops as well as other sectors utilizing pumping equipment can enroll in irrigation load control (also called interruptible irrigation). In Minnesota's Dakota Electric Co-op utility territory, 98% of its agricultural customers enroll in the offered irrigation load control program (Jordan 2015). Great River Energy has the ability to control its distribution utility members enrolled in irrigation control up to four hours per day in the cooling season (GRE 2018). However, the impact of irrigation load control programs on a utility's overall portfolio may be minimal. For example, in Dakota Electric Co-op's territory, irrigation only accounts for 1% of all member charges. Residential and commercial customers account for the majority of the remainder (Jordan 2015). Each utility in Minnesota has a different mix of these customer classes and so the applicability of this type of load control may vary statewide. In addition, some crops may be sensitive to watering interruption, such as potatoes (Pacific Power 2017). This could impact different regions of the state where there may be predominance of these sensitive crops such as north central Minnesota which has a high concentration of potato production.

For HVAC, utilities have been offering air conditioning load control for a number of years. These programs in Minnesota will be covered in greater depth below. During an event, air conditioner load control typically consists of a customer's compressor being cycled on and off while the fan continues to operate. This reduces energy consumption while minimizing customer impact. This type of program was typically operated using radio frequency, one-way control to send a signal to a unit (Winch et al. 2009). These programs are now shifting to be operated by smart thermostats, which offer better tailored programs to a customer's needs, two-way communication, and advanced analytics (Robinson et al. 2016).

Smart thermostats offer opportunities that go beyond the legacy one-way demand response control of cooling systems. A smart thermostat can offer lower costs as opposed to a building automation system for customers such as schools and small offices and retail customers (Snell 2015). There are a wide range of smart thermostat programs including bring your own thermostat programs, self-install, and subsidizing the purchase and installation of a thermostat. There may also be an opportunity to lower marketing costs to enroll customers in demand response programs as smart thermostat adoption increases. For example, demand response events, such as through the Nest thermostat, can be pushed directly to the thermostat and phone app to notify the customer and request enrollment (Nest 2013).

Demand response is also applicable for some lighting end uses. Lighting can be more predictable than HVAC in some regards in terms of seasonal lighting changes and the infiltration of light into a building. Lighting also responds linearly as it is a direct function of current, and so can be easier to control than some other demand response end uses such as HVAC. Lighting could potentially interplay with HVAC through controllable shades and glazing during a demand response event (Ziegenfus 2012). In California, Target Corporation used its existing energy management system (EMS) to communication with Pacific Gas & Electric through OpenADR 2.0, a protocol discussed above. Target is able to control both its lighting and HVAC in its stores during an event in a matrix pattern so as to minimize customer impact while decreasing load. Combining these end uses with coincident rooftop solar production create additional reductions in coincident grid load (Johnson and Riker 2017).

Refrigeration has the ability to offer demand response services. This can occur at larger scales where an entire refrigerated warehouse may be available to a utility, or this may be at a more granular level such as an individual case in a grocery store or a bank of cases in a supermarket (Deru et al. 2016; Hirsch et al. 2015). Precooling these cases may increase the total energy savings during an event, which would be a consideration for alignment with CIP. In addition, medium temperature cases pose a barrier for enrollment due to strict guidelines surrounding allowable temperature, which may pose difficulties when trying to enroll customers (Hirsch et al. 2015).

Smart plugs may offer potential savings with short payback depending on the customer, the end use, and the run-time of the equipment. For example, vending machines could offer quick payback whereas a water fountain, which uses less energy, would require a longer amount of time (Boss Controls 2015). Smart plugs are also an option that will be discussed further in the residential sector below.

Larger C&I customers with servers could be a potential source of demand response with automated hardware management. This is a growing area of research, but initial results show that servers could provide “shimmy” demand response services such as frequency regulation. Servers have the ability to quickly respond to signals and are a major source of energy usage. This may pose opportunities in the future to pair with variable renewable generation such as wind and solar on the grid (Sweeney et al. 2016).

As discussed above in the Target example, building automation systems or energy management systems offer the opportunity to integrate multiple end uses to automatically respond to a demand response signal. This can include HVAC and lighting end uses as well as plug loads. Integration of demand response into an existing system means that energy use from “fans, pumps, HVAC equipment, dampers, mixing boxes, and thermostats” can be managed while an energy manager can control aspects such as temperature and humidity for building occupants (Rewey 2012). The need to tailor each system to respond differently to a demand response signal, however, could increase transaction costs, and so this would need to be weighed against the capacity reduction and the price to enroll this customer.

Residential

Depending on the utility territory, the residential sector may have a significant opportunity for demand response, which was discussed in the review of demand response potential studies above. For example, apart from its C&I curtailable load program, the next largest portion of Xcel Energy’s demand response capacity in the past has come from its air conditioner load control program called Saver’s Switch (Doyle 2017). A number of demand response options are available in the heating, cooling, and air conditioning end use for residential customers. To name a few, this includes smart thermostats, electric resistance heating direct load control, and dual fuel options.

As discussed above in the C&I section, smart thermostats are replacing legacy one-way radio or pager controlled switches. For example, Xcel Energy in Minnesota is now directing residential customers to its AC Rewards program, which offers discounts on smart thermostats, and an annual incentive to participate in its load control program (Xcel Energy 2018). Smart thermostats have the ability to tailor a program individually to a customer’s needs. Data from a home’s heating profile can take into account heat loss from a building, for example, so a leaky house may receive a different level of control than a more airtight house. A leaky house may need to be precooled more than an airtight house (Doyle 2017). However, savings results may vary depending on the makeup of a home and the vendor providing the smart thermostat (Schellenberg, Lemarchand, and Wein 2017). In addition, precooling could result in increased energy use and so demand reductions must occur in concert with energy savings overall. This is a topic of ongoing research (Robinson et al. 2016). Lastly, smart thermostats may offer a way for utilities to gain insights into customer’s homes even with the absence of advanced metering infrastructure. For example, Vermont Energy Investment Corporation, a non-profit in the Northeast, will soon be offering an open source tool to utilities and other customers that allows smart thermostat data to model heat loss in buildings, which could help tailor specific recommendations or incentives to customers in need of air sealing and insulation (Lang, Goldman, and Jurmain 2017).

In utility territory with a winter peak and low natural gas penetration, such as Otter Tail Power, demand response heating applications within the HVAC end use are more appropriate. Homes with electric resistance heat may participate in demand response through a controllable switch, an off-peak rate, thermal storage, or a smart thermostat (Minnesota Power 2017; Otter Tail Power Company 2017). Dual fuel programs are available to customers who primarily heat with electricity, but also have an auxiliary system such as propane that can provide backup during a demand response event (Minnesota Power 2017).

As mentioned in the emerging trends section above, end uses in the residential sector are increasingly becoming “smart,” by allowing appliances and electricity consuming devices to connect to Wi-Fi. This allows potential opportunity for utility control over these devices. For example, humidifiers and window air conditioner units can offer smart capabilities or be plugged into a smart outlet to provide control. The smart outlet can provide additional services to the customer such as remote control and thermostatic control. For example, in New York city, which has a high penetration of multifamily customers, control over window air conditioner units allowed the utility to gain access to a previously untapped market for demand response programs (Tweed 2014).

Pool pumps offer summer load reduction opportunities. As discussed below, these appear in a number of potential studies. However, Minnesota’s cooler summers, and a customer mix much different than areas of the country such as California, may have an impact on the number of pools and total demand available for utility control. For winter peaking utilities, portable spas (i.e. hot tubs) could offer demand response opportunities (Delcroix, Leduc, and Kummert 2017). Due to the nascence of portable spa technology and the low penetration of pools in Minnesota, this measure was not considered for this study.

Minnesota has long been a leader in terms of demand response with water heating end uses. As outlined in the above section Timescales of Demand Response, water heaters best fit within the *shift* category. Member cooperatives in Great River Energy territory offer overnight charging for oversized electric resistance water heaters, which save customers money by using low-cost wholesale power when demand is low (GRE 2018). Otter Tail Power and Minnesota Power are investor owned utilities in the state offering similar programs, as discussed above. Due to program operation that most likely favors comfort of the consumer, the best case scenario for the operation of these programs is for water heaters to use a neutral amount of energy over the course of the year. However, if the temperature setting of a water heater is increased for a customer to account for heat losses overnight to when demand occurs, this will inevitably result in a net increase in the amount of energy used by a water heater load control program. Therefore, water heaters are not considered as demand response measure in this study. Moreover, as water heater technology evolves into heat pump water heaters, this may change the value proposition for these utilities and cooperatives. Heat pump water heaters have different capital costs and capacity reductions compared to electric resistance water heaters due to their much higher energy efficiency (Cooke, Anderson, and Winiarski 2015).

Methods and Results

After narrowing the list of measures to be included in this study (Figure 10), these were run through a modeling scenario to determine the potential resource demand response may offer between 2020 and 2029 in Minnesota.

Methods

Measures

The first steps with each demand response measure included narrowing down a larger list of measures, as discussed above, to be applicable within CIP requirements and to satisfy operating conditions required of each sector and building type in Minnesota. As shown in Figure 10 above and in Table 1 below, the measures discussed in this study and their respective applicable sectors are as follows. Again, these measures only include ones that reduce overall energy use, and do not include rate-based measures, which is largely what would serve the industrial and large commercial sectors.

Table 1: Demand Response Measures by Applicable Sector

Residential	Commercial	Industrial
Central Air Conditioning Direct Load Control	Smart Thermostat (Cooling)	Rooftop Cooling Direct Load Control
Electric Heat Direct Load Control	Lighting Controls	
Smart Thermostat (Cooling)	Refrigeration	
Smart Thermostat (Heating)	Rooftop Unit Cooling Direct Load Control	
Dehumidifier with Smart Plug		
Window Air Conditioning with Smart Plug		

Inputs

Inputs for demand response modeling as part of this study consisted of the following variables. Each of these inputs is discussed further below:

- Measure life

- Load reduction (kW)
- Annual kWh saved
- Customer incentive (2018$)
- Participation rate
- Demand response participation growth rate
- Load growth escalation rate
- Demand response technology growth rates
- Annual enabling cost (2018$)

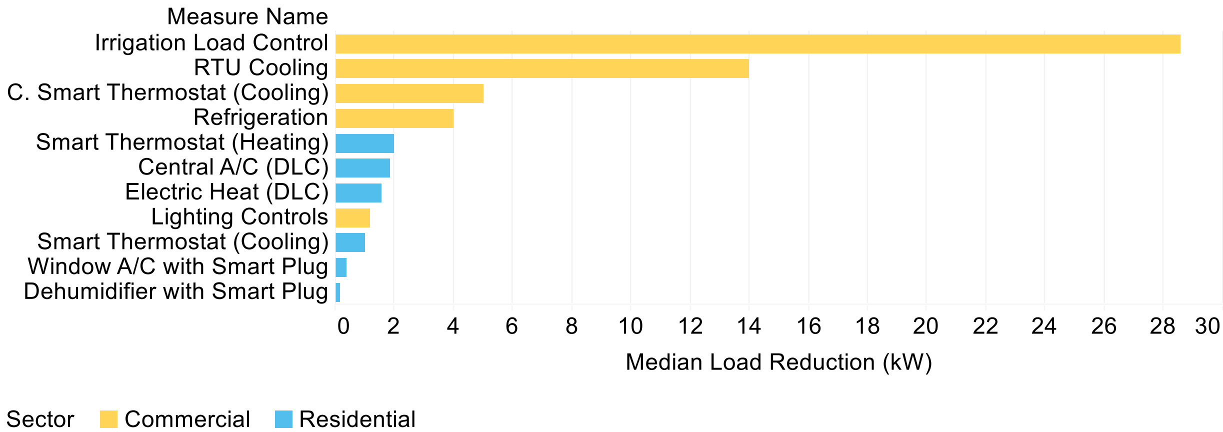
Measure Life

For all demand response measures, measure life was designated to be 1 year to represent the subscription-like nature of demand response. The measure life of the demand response program is different from the measure life of the demand response enabling technology, such as a load control switch. Lifetime enabling costs for each demand response measure were divided by enabling technology measure lifetime to yield an estimated annual enabling cost. These costs are discussed further below and are shown below in Figure 17 and Figure 18.

Load Reduction

Each demand response measure is associated with a different level of reduction, which is measured in kW. Figure 11 below shows the median load reduction aggregated by building type. Refrigerated warehouses have the largest load reduction – above 200 kW, which is not reflected on this chart as these are aggregated by building type. Although very few in number, refrigerated warehouse demand reduction may have locational value when a utility is faced with load growth on specific transformers or feeders. Irrigation load control was found to have a high degree of savings per irrigation customer. However, as discussed further below, these savings are achieved through a high cost per load reduction. In comparison with commercial measures, residential measures generally have a lower load reduction. However, the expected growth in technology such as smart thermostats and the ease of marketing demand response programs through methods such as push notifications to the device or to customer's phones allows this to be a large potential resource for load shedding.

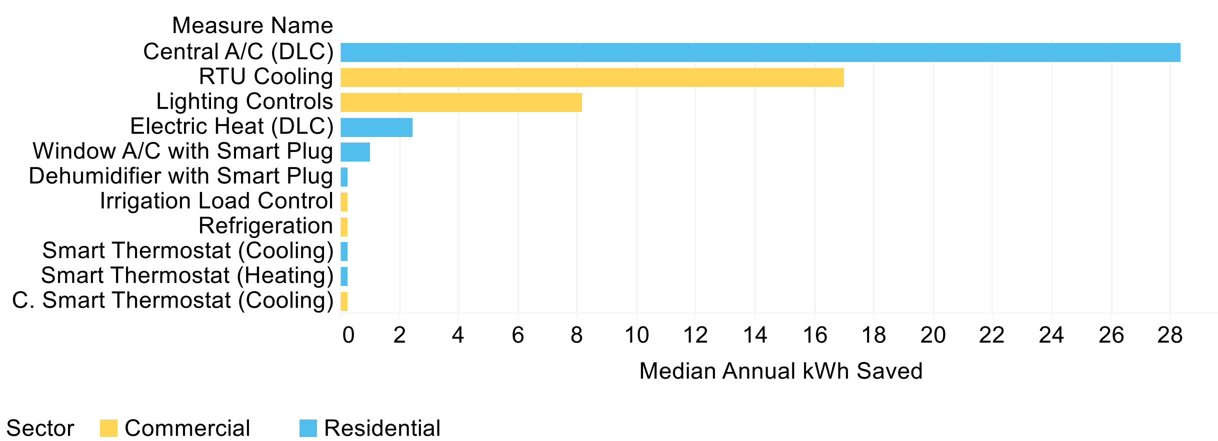
Figure 11 Load Reduction by Demand Response Measure



Energy savings

Energy savings for central A/C direct load control and rooftop unit direct load control measures were sourced from Conservation Improvement Program Annual Status Report filings. This study assumed minimal energy savings from irrigation load control due to the need to provide water to crops after the demand response event occurs. Some energy savings may occur from avoiding watering during hotter periods of the day. Minimal savings are also expected for refrigeration, heating, and cooling due to the presence of snapback after the event has occurred. As smart thermostats and demand response are further researched and offered more prevalently together in Minnesota, these values may be updated to reflect updated assumptions within a technical reference manual or Investor Owned Utility's Conservation Improvement Program Status Report filings. Figure 12 below shows annual energy savings aggregated by building type.

Figure 12 Annual Energy Savings by Demand Response Measure



Customer Incentives

This study focused on customer incentives and enabling costs, discussed below, as the largest part of costs, though program administration will also add costs as well. Since DR requires ongoing incentives year over year to participate, each measure is considered to have a 1 year lifetime, with the incentive calculated annually. Some of the programs included in the demand measure list are not currently offered in Minnesota. Sources were found outside of Minnesota when local data were not available. Irrigation load control was found to have the highest customer incentive before and after factoring the incentive per load reduction. The median incentives when aggregated by building type, before taking into account the ratio of incentive per load reduction amount (kW), are shown in Figure 13 below.

Figure 13 Customer Incentives by Demand Response Measure

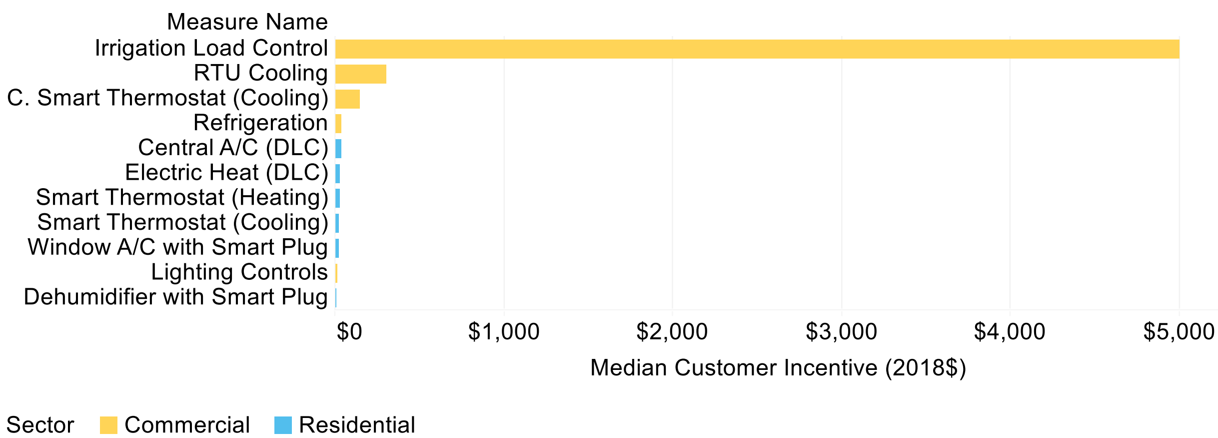
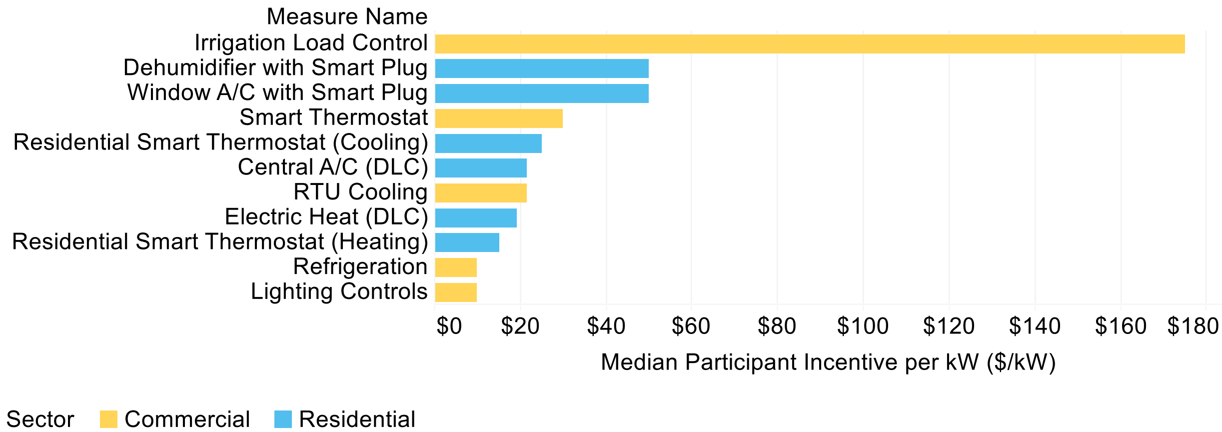


Figure 14 shows the customer incentive per load reduction (kW) of potential demand reduction per measure as an average when aggregated by building type. As noted in other potential studies, irrigation load control may not be a cost-effective measure for a utility as a stand-alone measure (Applied Energy Group 2017). However, this measure may screen as part of a larger portfolio of programs. In addition, each utility's incentive for each program will differ in terms of what is cost-effective to offer as a participant incentive.

Figure 14 Participant Incentives per Load Reduction



Eligible customers and devices

Penetration rates found below in Table 3 for demand response measures were applied against the number of eligible device counts and counts of businesses applicable to each measure. The count of eligible customers in each sector followed the same methodology as the energy efficiency potential analysis, described in Appendix A of the report. For residential measures, housing and device counts were derived from the larger load-disaggregation analysis within this study, which itself was based on a variety of data sources and models that predict the characteristics of Minnesota homes and households in a geographically refined way. The total number of eligible businesses were determined by building type and utility group using NAICS codes in census data and combining this with EIA data. Minnesota-specific irrigation permit data was used to determine the count and pumping capacity in each utility group (MN DNR 2018).

Building types

Inputs and results were broken out by building types, which are shown below in

Table 2. The measures and their associated building types are also shown above in Figure 10.

Table 2: Building Type Segmentation by Sector

Residential	Commercial	Industrial
Single Family	Small Office	Industrial
Multifamily (2-4 units)	Large Office	
Multifamily (5+ units)	Small Retail	
Low-Income Single Family	Large Retail	
Low-Income Multifamily (2-4 units)	Warehouse	
Low-Income Multifamily (5+ units)	Education	
	Healthcare	
	Lodging	
	Food Sales	
	Food Service	
	Data Center	
	Public Assembly	
	Agriculture	
	Other	

Participation Rates

The participation rates assigned to each measure were marginal above-and-beyond existing penetrations in demand response programs currently offered by utilities in Minnesota. For example, the penetration of air conditioner load control in this study is incremental to the existing air conditioning demand response programs already offered by utilities, such as the Saver's Switch program in Xcel Energy's utility territory.

We chose a conservative initial participation rate of 1% of eligible customers for the majority of measures. There were some exceptions to this rate. Some legacy programs are well established in terms of their program design, incentives, and marketing, and so are expected to continue the momentum of addition of new customers in the future. Where utility filings existed for these programs, the participation rate for year one of this study was modified to yield this number of incremental participants for all Minnesota utility groups.[6] This was derived by applying the rate to the pool of total eligible measures or business customers found in each utility group. This method was applied to central A/C direct load control, rooftop unit direct load control, and smart thermostat programs. Lastly, as

[6] To reiterate, this study only focused on new participants beyond the current pool of demand response in Minnesota. Therefore, when year one penetration was set to match utility filings, these were matched with annual additions filed by utilities, not the utility's total pool.

schools are not in session during the majority of the summer peak, a penetration of .3% was assigned to this building type for lighting controls, smart thermostats, and rooftop unit direct load control measures. These values are summarized in Table 3 below. While we designated a participation rate for the purposes of this model, it should be noted that demand response participation may be reliant on a number of factors such as different avoided costs of capacity, which varies among different utilities in Minnesota. If a demand response measure passes cost-effectiveness screening, program design, marketing, and the utility-designated incentive level may be primary drivers of participation rates. In addition, markets and the utility landscape may change in the future such as placing a higher value on ancillary services that could be provided by some demand response measures.

Table 3: Year One Demand Response Measure Penetration

Demand Response Measure	Year One (2020) Penetration
Central A/C (DLC)	2.0%
Dehumidifier with Smart Plug	1.0%
Electric Heat (DLC)	1.0%
Irrigation Load Control	1.0%
Lighting Controls	1.0%
Refrigeration	1.0%
Residential Smart Thermostat (Cooling)	2.0%
Residential Smart Thermostat (Heating)	2.0%
RTU Cooling	1.3%
Commercial Smart Thermostat	1.0%
Window A/C with Smart Plug	1.0%

Demand response adoption grows from these year one penetrations based on technology specific annual growth rates, defined as the percent change from the previous year's penetration. Measures that are being supplanted by newer technology were given a declining growth rate. Measures with a hard to reach markets were given a low rate. The medium rate was applied to programs with established markets or attractive incentives for customers. The high rate was applied to markets with easy entry to procure customers and favorable incentives. These four growth rates are listed below in Table 4. These rates were increased by 10% and decreased by 10% as part of a sensitivity analysis, which is discussed in the sensitivity analysis section below.

Table 4: Growth Rate Categories

Growth Rate Category	Rate
Declining	-15%
Low	15%
Medium	20%
High	25%

Table 5 shows the application of the growth rates discussed above. Central A/C (DLC) and electric heat (DLC) are assumed to have declining growth rates. Direct load control of air conditioners and electric heat is expected to give way to smart thermostat programs. Smart thermostats are widely beginning to be offered as efficiency measures by utilities. Enrollment in demand response programs can occur as part of an initial rebate for these customers, or events can be offered to customers in real time through push notifications through phones or through the thermostat, which simplifies marketing. For these reasons, smart thermostats were given a high growth rate. Dehumidifiers with smart plugs were given a low growth rate due to a relatively low amount of demand savings opportunity and a relatively high incentive per kW. Irrigation load control similarly has a high incentive per kW and so has a low growth rate. Lighting controls are expected to have a relatively low demand response shed value (kW) as they are primarily applied to LEDs, and so have a low growth rate assumption. Refrigeration has a relatively low cost per kW and a moderate amount of potential demand reduction (high reduction for refrigerated warehouses) and so were given a medium growth rate. Lastly, rooftop unit direct load control programs were given a medium growth rate due to being well established in Minnesota and providing a relatively high load reduction at a relatively low price per kW. Some of these rooftop unit direct load control programs may be supplanted by commercial smart thermostat programs, but smart thermostats are not expected to completely supplant this measure due to complexities of larger building systems where a smart thermostat is not applicable.

Table 5: Demand Response Participation Growth Rates by Measure

Demand Response Measure	Demand Response Program Participation Growth rate
Central A/C (DLC)	-15%
Dehumidifier with Smart Plug	15%
Electric Heat (DLC)	-15%
Irrigation Load Control	15%
Lighting Controls	15%
Refrigeration	20%
Residential Smart Thermostat (Cooling)	25%
Residential Smart Thermostat (Heating)	25%
RTU Cooling	20%
Commercial Smart Thermostat	25%
Window A/C with Smart Plug	15%

Utility groups

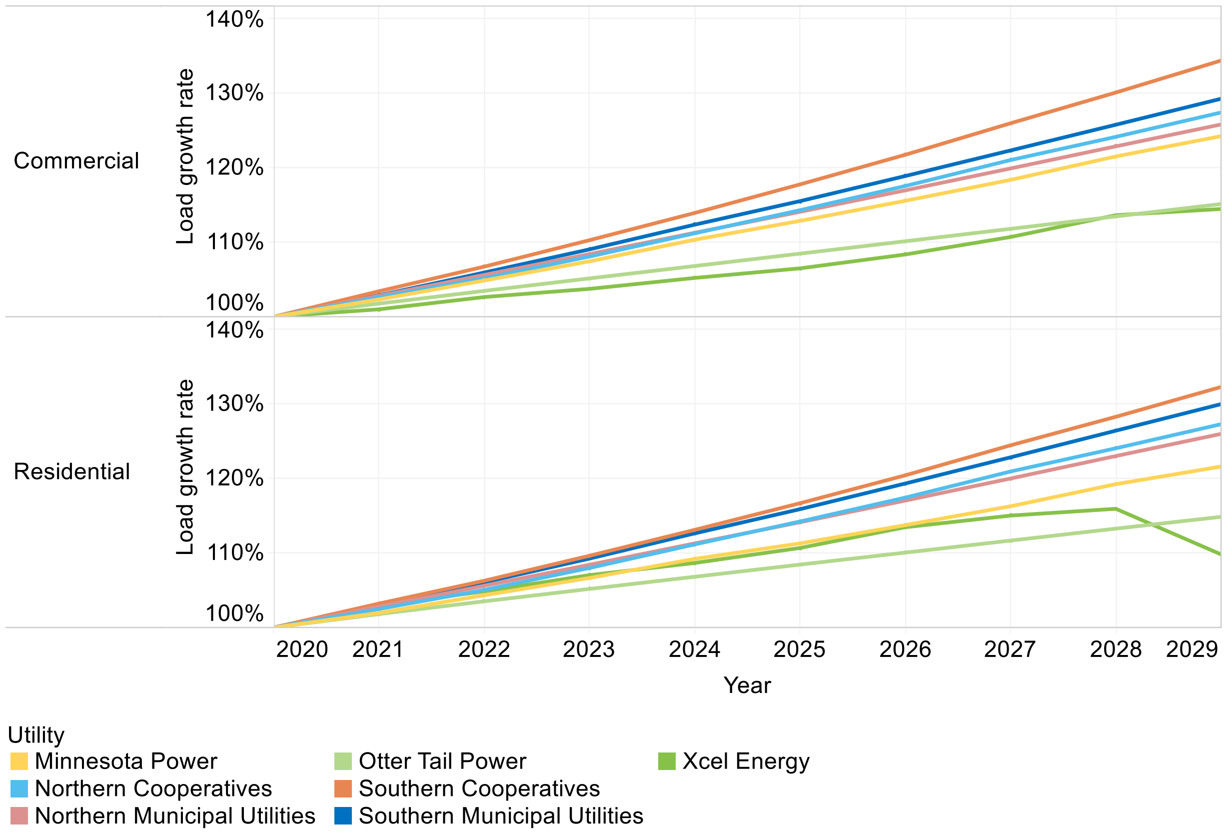
The penetration rate was applied against the count of eligible customers and devices to yield results specific to seven utility groups in Minnesota. The utility groups used are as follows:

- Xcel Energy
- Minnesota Power
- Otter Tail Power
- Cooperative electric utilities in northern climate zone
- Cooperative electric utilities southern climate zone
- Municipal electric utilities in northern climate zone
- Municipal electric utilities in southern climate zone

Load growth escalation rate

Load forecasts used for efficiency measures within this broader study's energy savings modeling were applied to the demand response measures. These growth rates effectively increased the counts of eligible devices or businesses by building type over time within each utility territory. These load forecast disaggregated by utility group are shown below in Figure 15. These load forecasts include efficiency, which causes the load in Xcel Energy's utility territory to flatten and then decline in 2029.

Figure 15 Utility Group Load Growth Rates



Technology growth curves

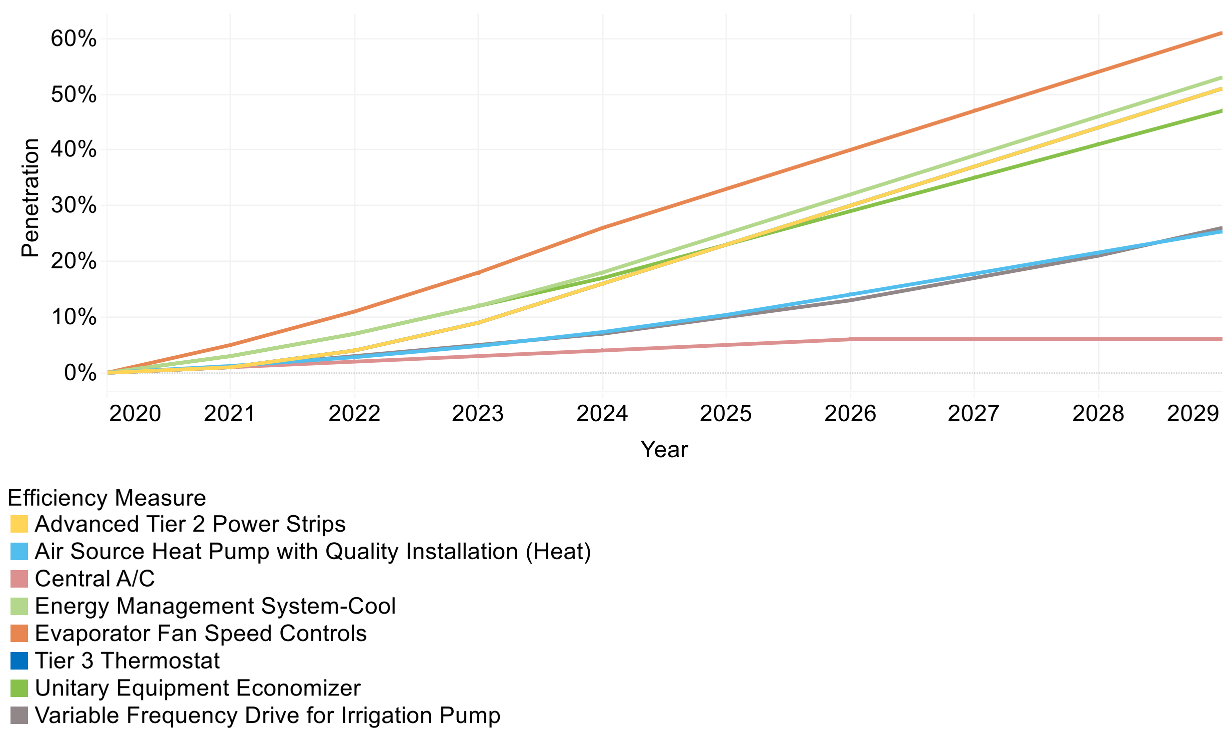
In addition to load growth, growth curves used for specific efficiency measures were applied to demand response measures to represent their future growth (see Appendix A). In other words, the eligible population for demand response is growing with general load growth, and also as new customers adopt the relevant technologies. This adoption growth is more pronounced for emerging technologies. The pairing of these efficiency measures with demand response measures is represented in Table 6 below.

Table 6: Demand Response Measures and Paired Efficiency Measures

Demand response measure	Efficiency measure
Central A/C (DLC)	Central A/C
Dehumidifier with Smart Plug	Advanced Tier 2 Power Strips
Electric Heat (DLC)	Air Source Heat Pump w/ Quality Installation (Heat)
Irrigation Load Control	Variable Frequency Drive for Irrigation Pump
Lighting Controls	Energy Management System -Cool
Refrigeration	Evaporator Fan Speed Controls
Residential Smart Thermostat (Cooling)	Tier 3 Thermostat
Residential Smart Thermostat (Heating)	Tier 3 Thermostat
RTU Cooling	Unitary Equipment Economizer
Commercial Smart Thermostat	Tier 3 Thermostat
Window A/C with Smart Plug	Advanced Tier 2 Power Strips

The cumulative technology penetration curves for each year in the study for the paired measures are shown in Figure 16 below. Note tier 3 thermostats and air source heat pumps with quality installation each have the same curve, and so are overlapping.

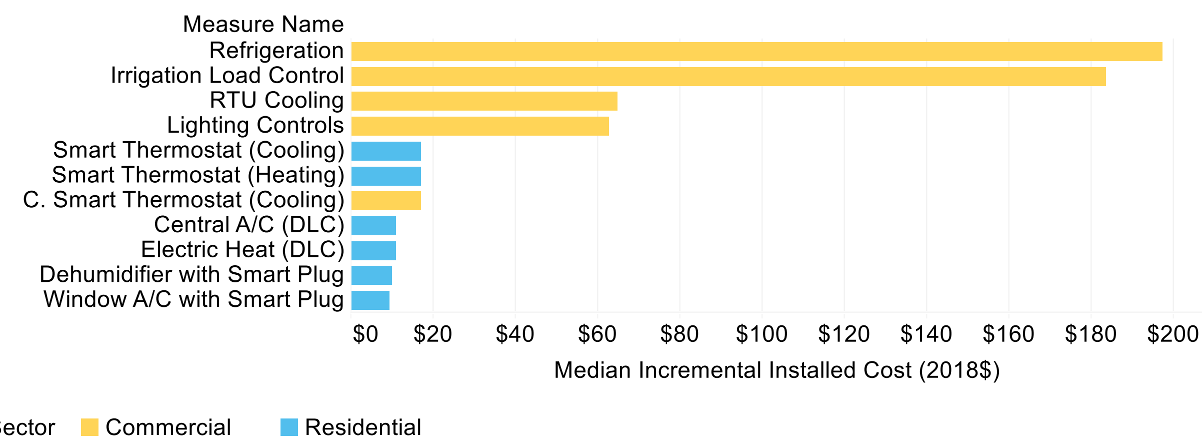
Figure 16: Efficiency Measure Technology Growth Curves



Annual enabling costs

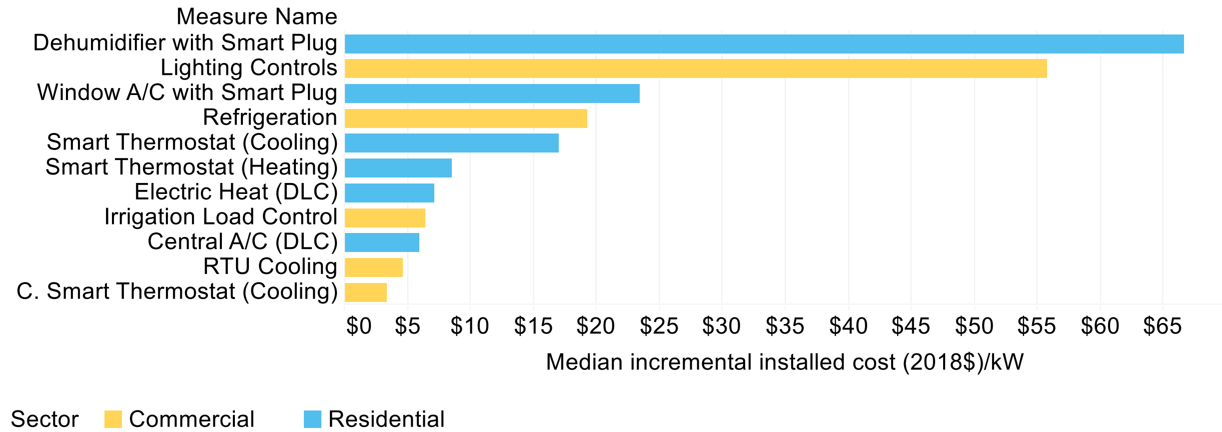
Enabling costs are equipment and labor costs required to initiate a demand response resource for a particular measure. For example, to run an air conditioning cycling program, a load control switch must be installed. Enabling costs for this type of demand response would include the time for a technician to travel to a home to install a load control switch as well as the cost for the switch. Enabling costs were largely sourced from a Lawrence Berkeley National Lab report on enabling technology costs for demand response (Potter and Cappers 2017). As discussed above, demand response measures in this study were given a measure life of one year. However, this does not represent the lifetime of the enabling technology. The enabling costs were divided by the enabling technology lifetime to yield an annual enabling cost. These median costs aggregated by building type are represented in Figure 17 below.

Figure 17 Incremental Installed Costs



After determining annual enabling costs for each measure, these were divided by load reduction estimates aggregated by building type for each measure. This division created a ratio of cost per load reduction ($/kW), and the results are shown below in Figure 18. Measures with a low enabling cost per kW, a low participant incentive per kW, and a high load reduction will be the most attractive for an electric utility.

Figure 18 Incremental Installed Costs per Load Reduction

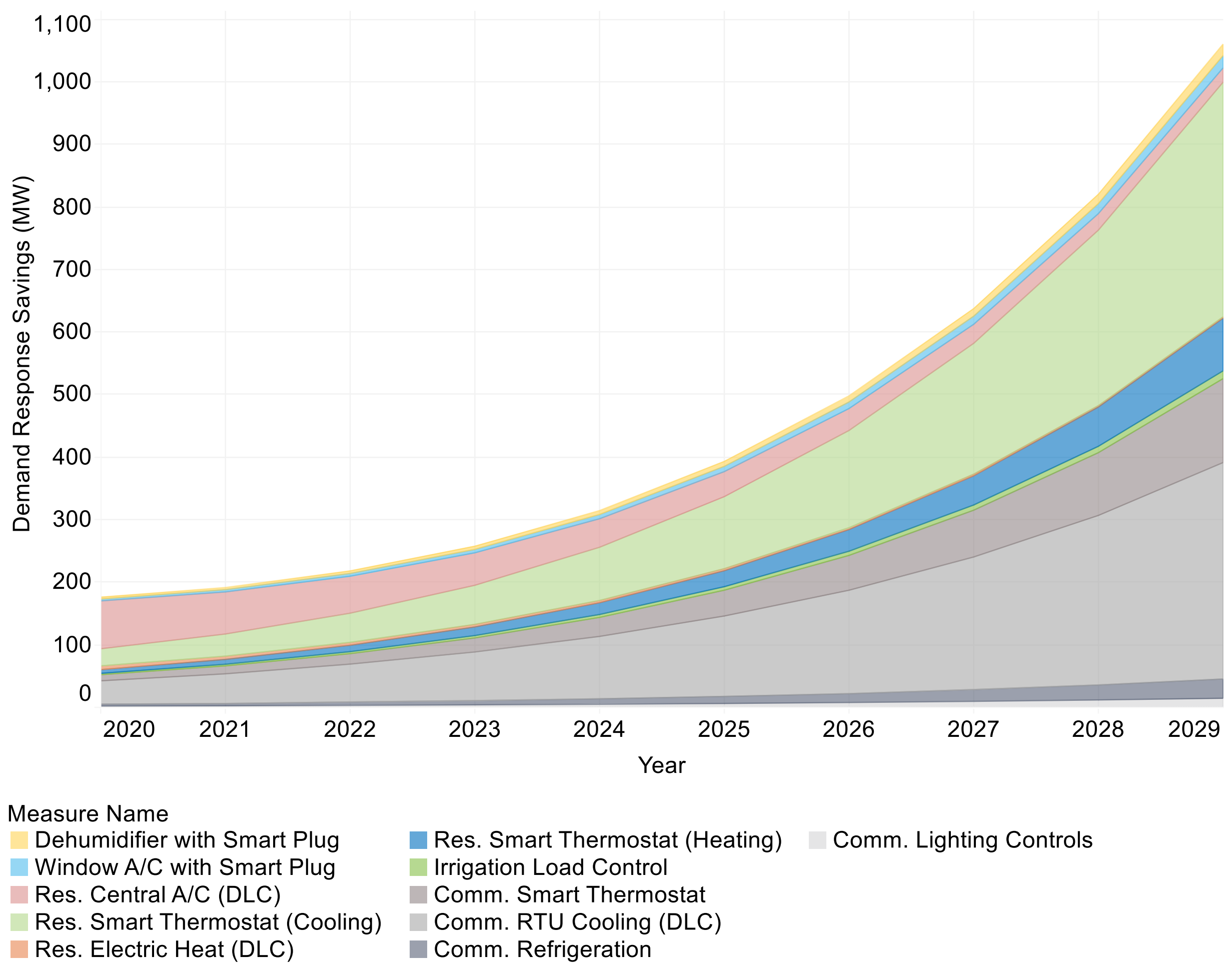


Results

Statewide

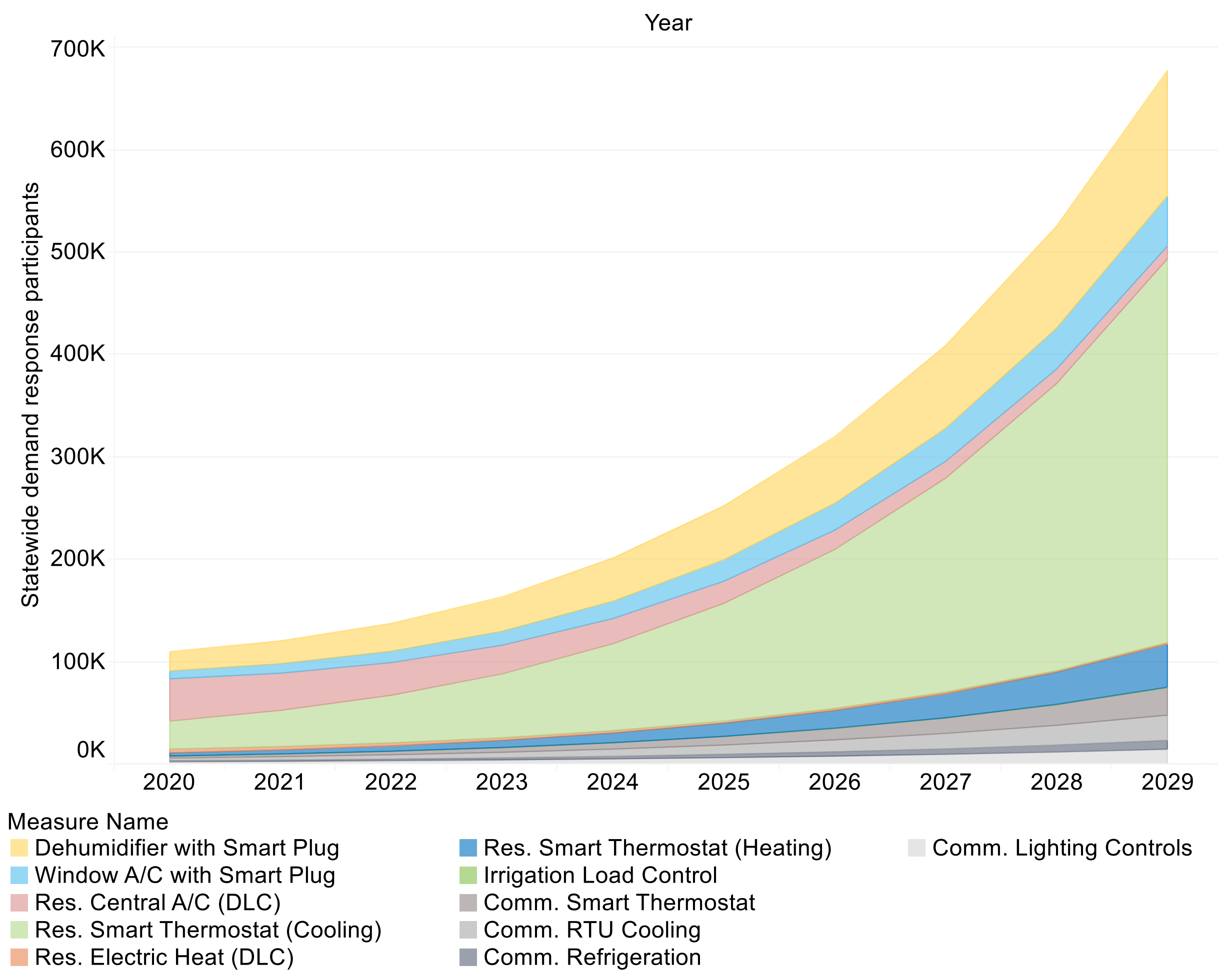
Below are results of potential demand response savings by measure over time, above-and-beyond the current capacity from existing customers. These results show the proportionality of different measures over time. For example, central air conditioning load control reduction potential shrinks as smart thermostat cooling programs grow in their share of cooling demand response. On a much smaller scale for winter peaking utilities, the same is true with electric heat direct load control and smart thermostat heating programs, respectively. The top three load reduction categories are residential smart thermostats, commercial smart thermostats, and rooftop unit direct load control, which are all cooling-related load control programs.

Figure 19 Annual Demand Savings by Demand Response Measure



A slightly different picture arises when looking at demand response program participation. Due to differing levels of demand reduction (kW) by the type of demand response, some measures are expected to have a relatively large number of participants as shown in Figure 20 below. For example, smart thermostats showed a relatively large portion of the total demand reduction above. This demand reduction is driven by a large number of participants in smart thermostat cooling programs. In addition, some programs may have a high number of participants, but may appear relatively small when looking at projected demand savings. This is true for dehumidifiers with smart plugs and window air conditioners with smart plugs – these measures have high participation, but low overall demand reduction on a per-unit basis.

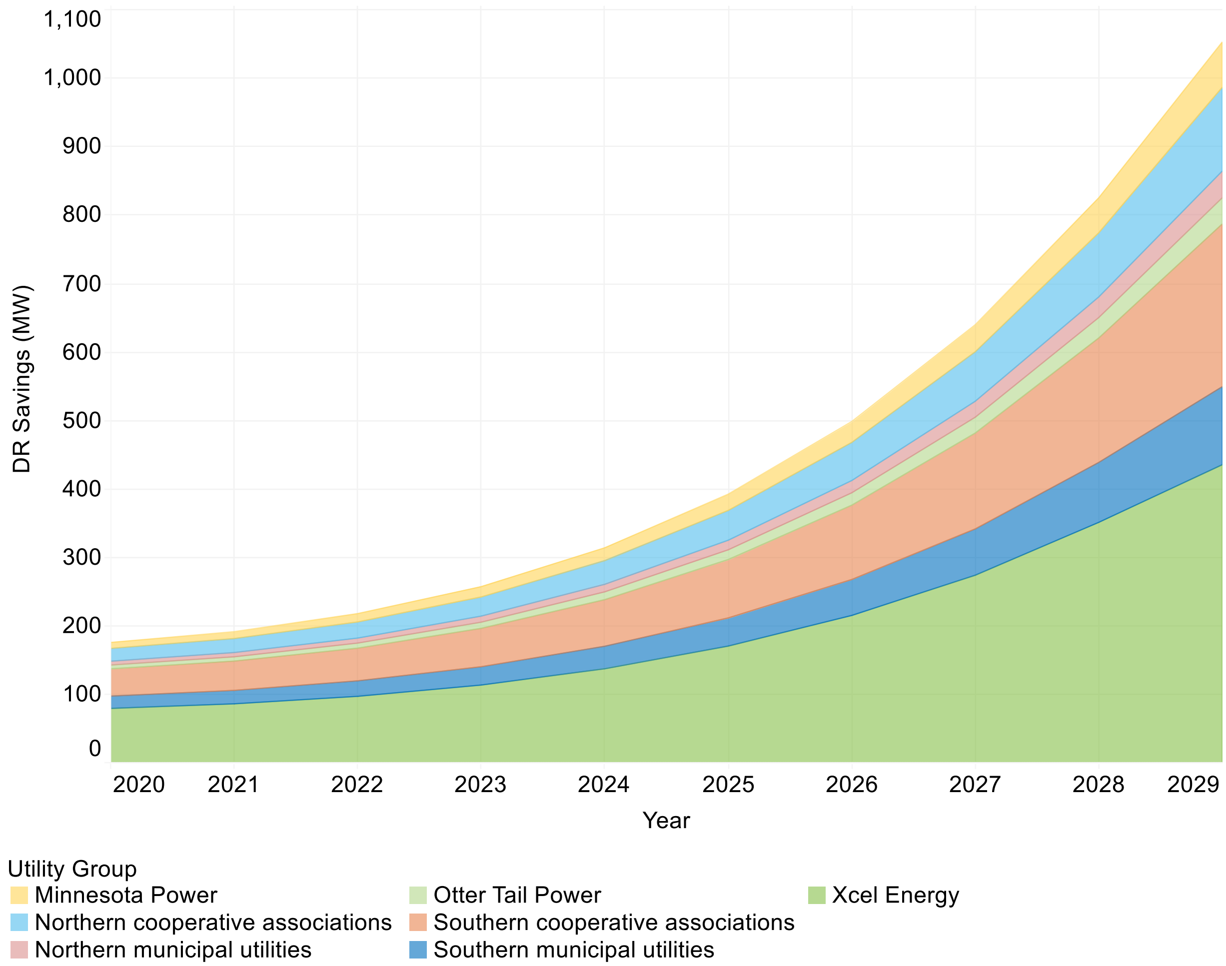
Figure 20 Annual Demand Response Participants by Measure



Utility Territory Group

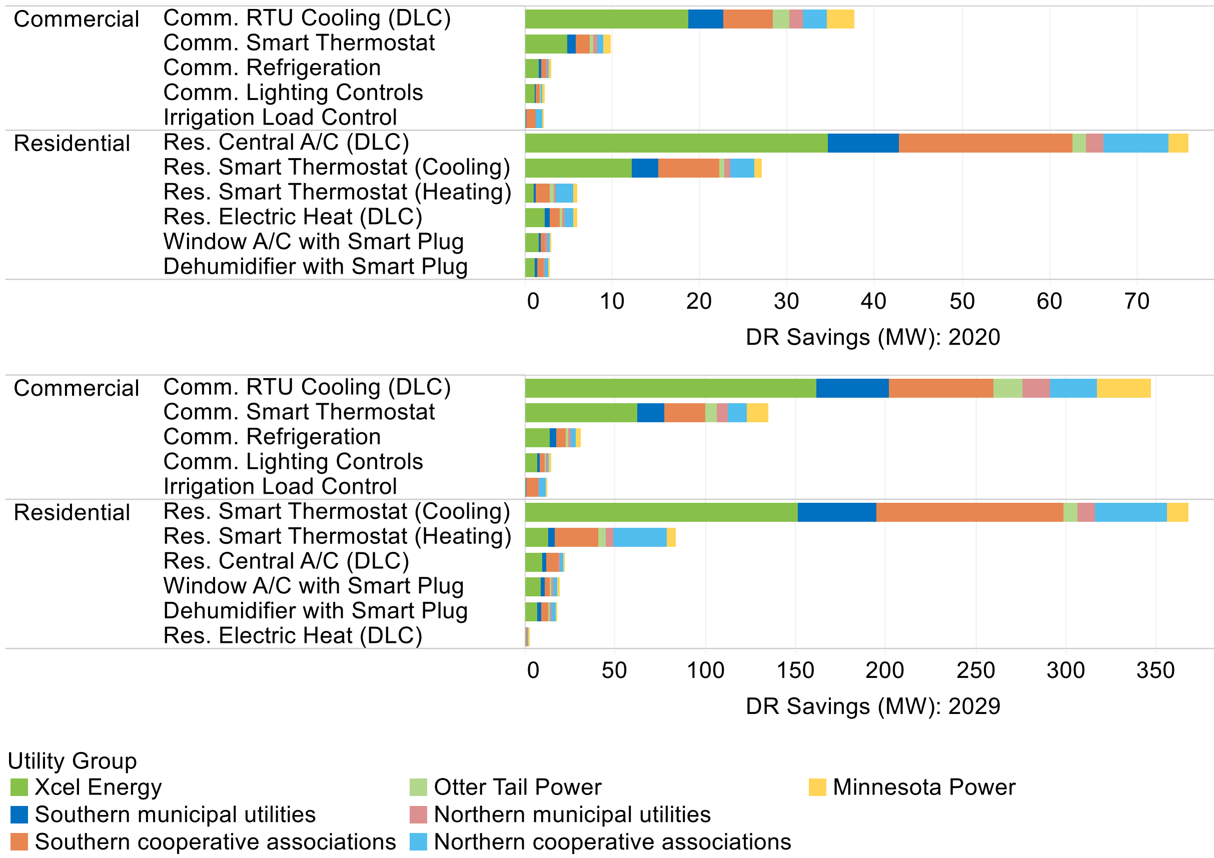
The amount of customers and end uses varies in each utility territory group. Some utilities territories have different composition of commercial building types, for example. These factors influenced the results by utility territory. High level results for each utility group are below.

Figure 21 Demand Response Savings by Utility over Time



Taking a deeper look, Figure 22 shows the breakdown of each measure within each utility group. The proportionality for each utility group between measures is dependent upon the makeup of customers in each group. As heating becomes electrified over time, this yields a larger share of the demand response savings in the 2029 time frame. A winter peak is mostly applicable for Otter Tail Power in the present day. However, as more heating shifts to be electrified, this resource may become more applicable for utilities closer to 2029.

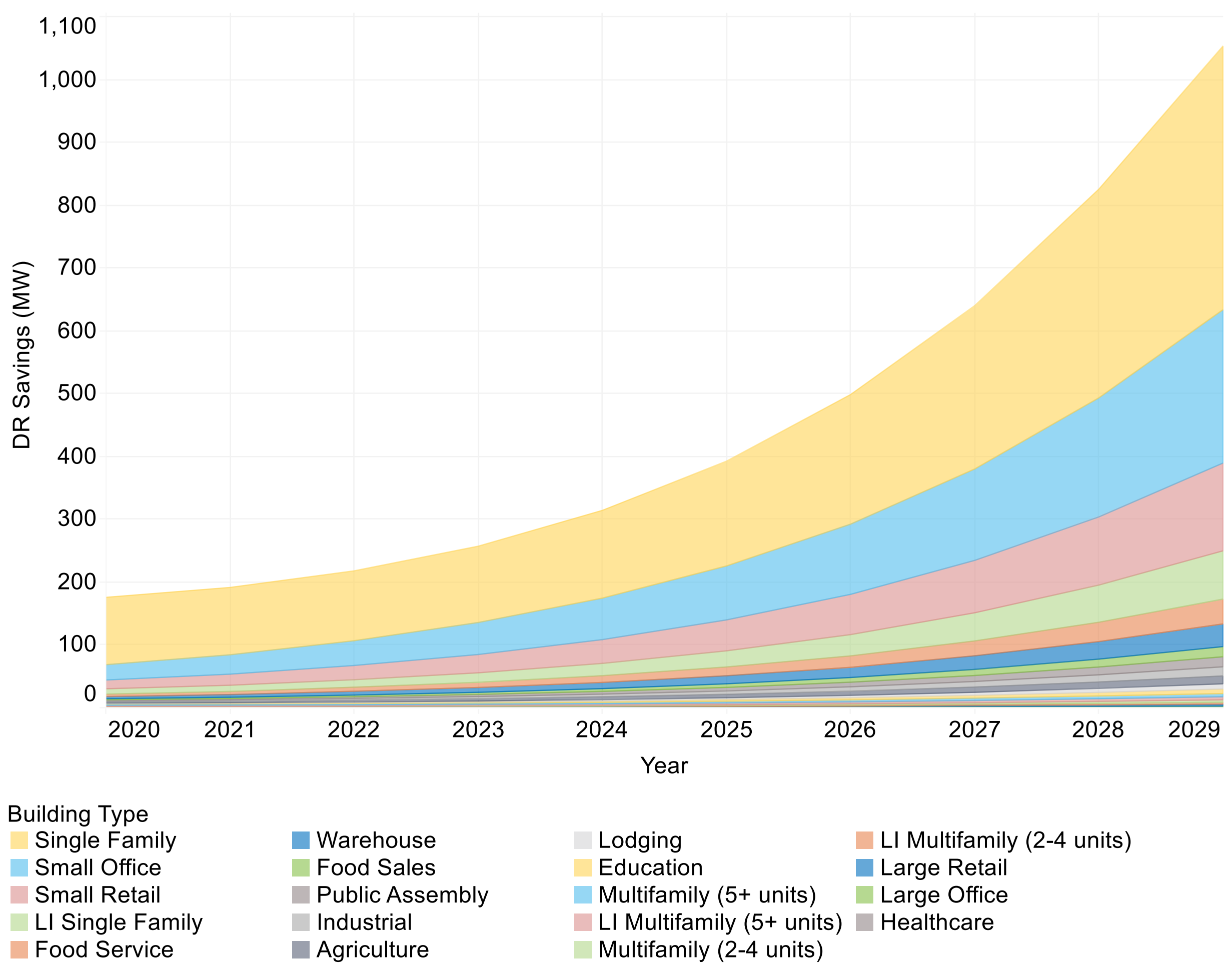
Figure 22 Demand Response Savings in 2020 and 2029 by Utility Group



Building Type

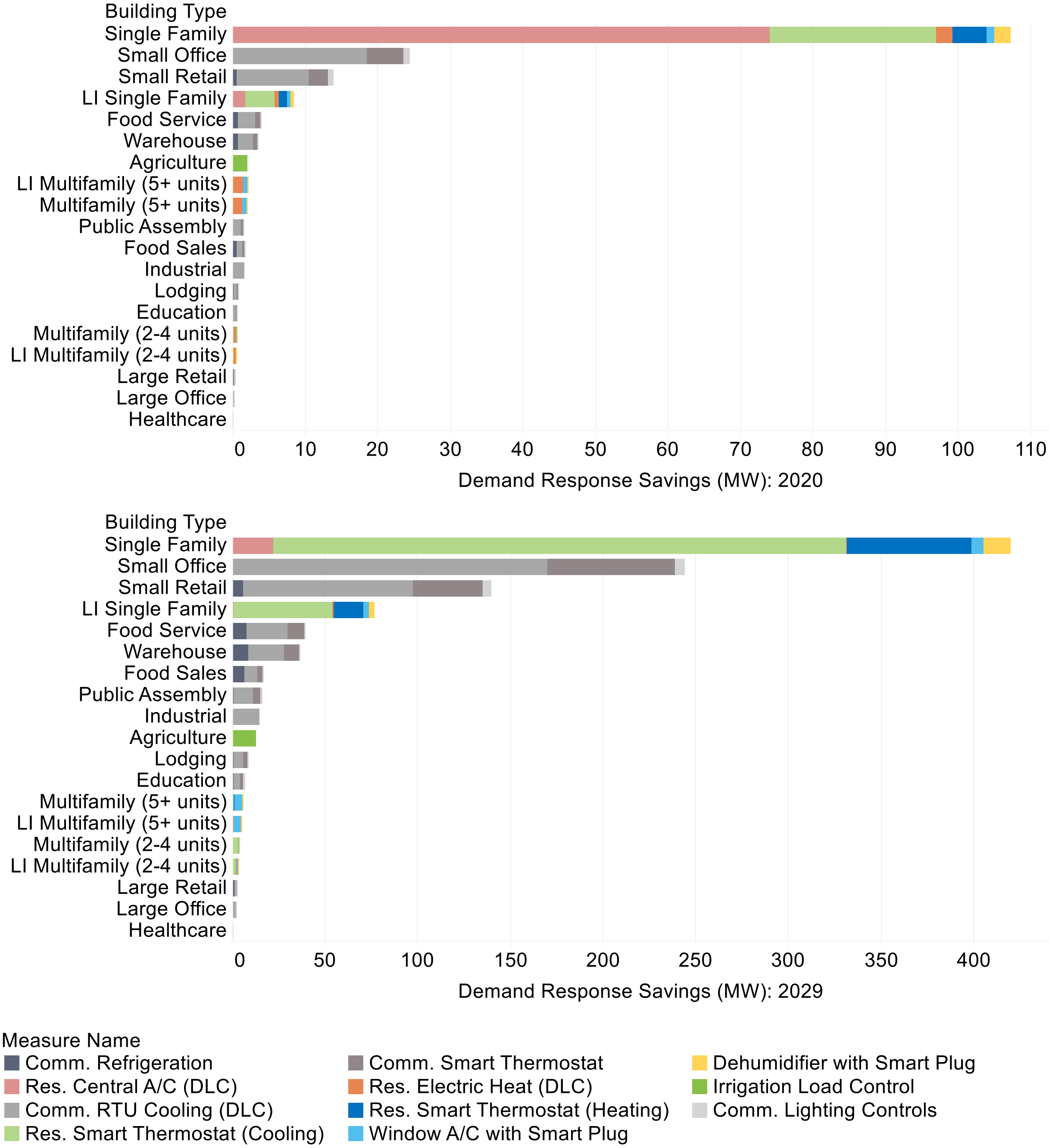
Building type, as opposed to utility territory, offers another lens on the potential study potential in Minnesota. Single family homes, small offices, small retail, and low-income single family homes offer the highest savings opportunities, as shown in Figure 23.

Figure 23 Demand Response Savings by Building Type over Time



Taking a closer look in the figure below, single family homes savings are largely driven by cooling opportunities. This manifests itself in central air conditioning direct load control in the earlier period of this study and shifts to smart thermostat based demand response at the end of the study, as discussed above. Heating-based demand response grows in the single family and low-income single family building types between 2020 and 2029. With the exception of heating-based demand response, the same is true for the commercial side with the addition of lighting opportunities for the building types with the highest potential.

Figure 24 Demand Response Savings in 2020 and 2029 by Building Type



Sensitivity Analysis

To explore variation in modeling assumptions, demand response participation growth rate assumptions shown above in Table 4 were increased and decreased by 10%. In addition, the assumption of participation rates in 2020, shown in Table 3 above, was modified to be 1% for all measures.

Participation Growth Rates

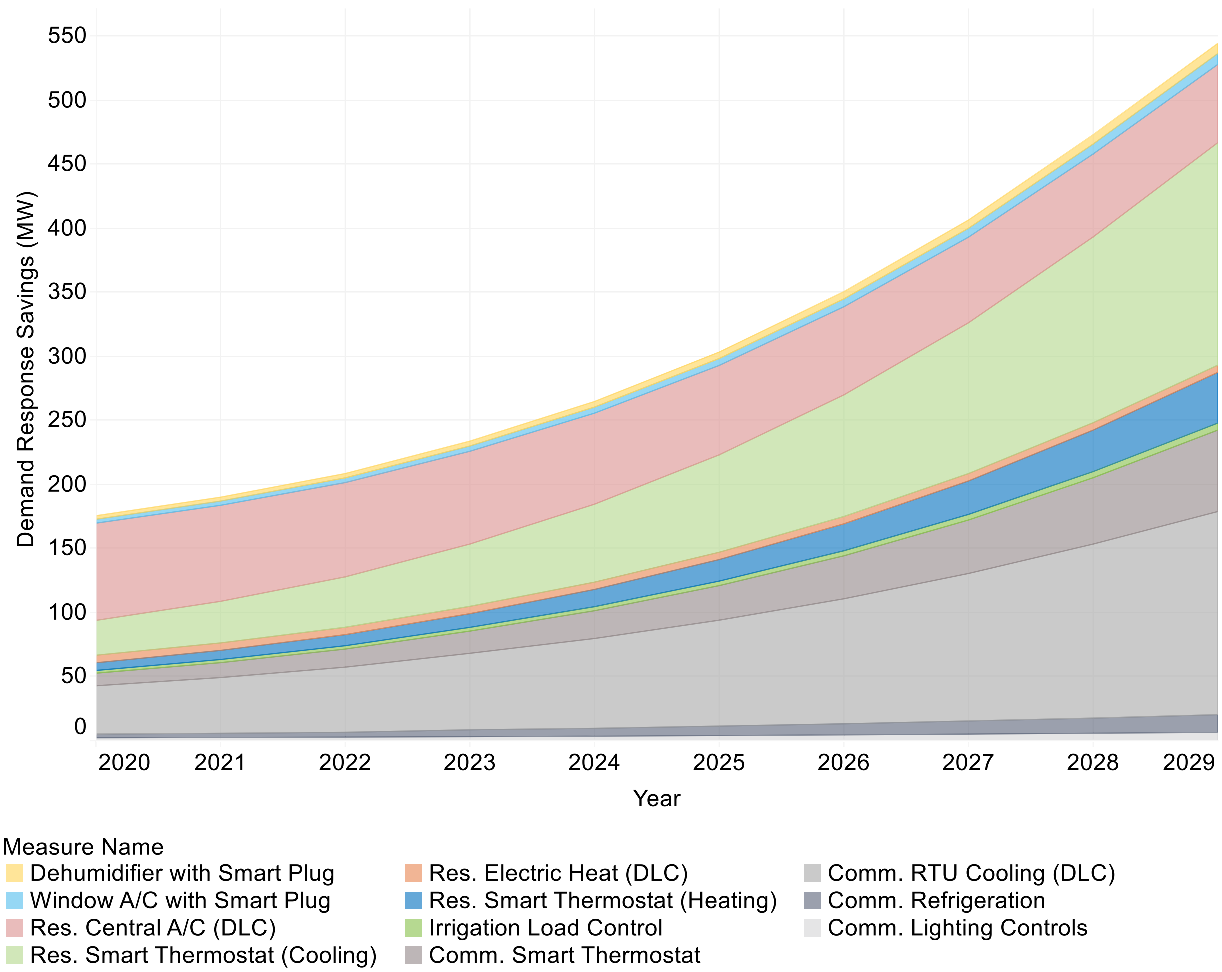
The first sensitivity analysis included a 10% decrease in growth rates. These measures and the changed rates are shown below in Table 7.

Table 7: Demand Response Participation Growth Rates by Measure with 10% Decrease

Demand Response Measure	Demand Response Program Participation Growth rate
Central A/C (DLC)	-5%
Dehumidifier with Smart Plug	5%
Electric Heat (DLC)	-5%
Irrigation Load Control	5%
Lighting Controls	5%
Refrigeration	10%
Residential Smart Thermostat (Cooling)	15%
Residential Smart Thermostat (Heating)	15%
RTU Cooling	10%
Commercial Smart Thermostat	15%
Window A/C with Smart Plug	5%

When growth rates are dropped by 10%, we see the potential demand response in 2029 halved to a total of nearly 550 MW, which is shown in Figure 25. The assumption of a less aggressive decline in direct load control for cooling and heating causes these technologies to persist longer out to 2029. This also creates a flatter curve between 2020 and 2029. In addition, the lower growth rate for smart thermostat technologies is a large driver of the lower amount of total demand reduction in 2029.

Figure 25 Demand Response Savings over Time by Demand Response Measure with 10% Decrease in Participation Growth Rate Assumption



Next, growth rates for demand response participation were increased by 10%. These values are shown below in

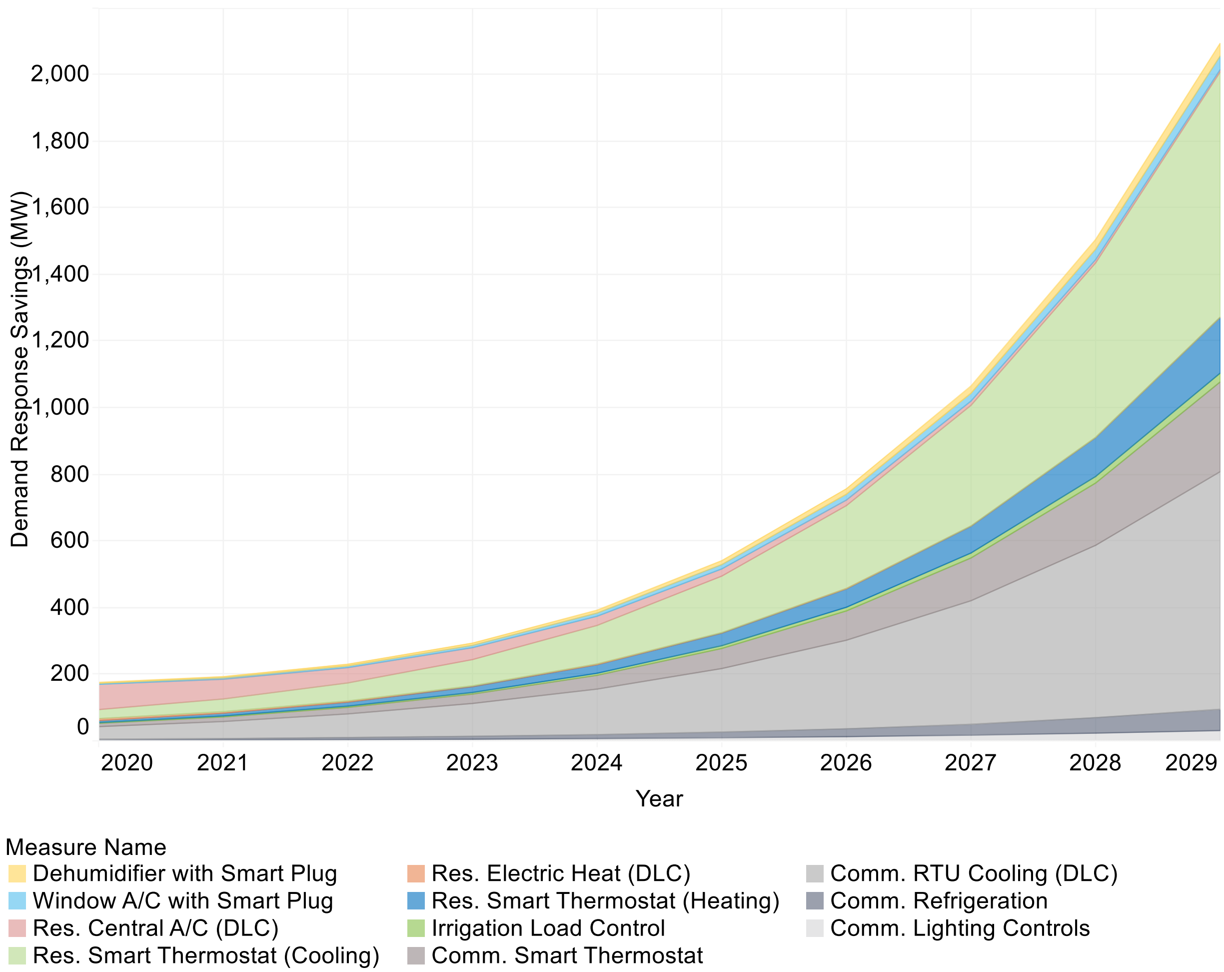
Table 8.

Table 8: Demand Response Participation Growth Rates by Measure with 10% Increase

Demand Response Measure	Demand Response Program Participation Growth rate
Central A/C (DLC)	-25%
Dehumidifier with Smart Plug	25%
Electric Heat (DLC)	-25%
Irrigation Load Control	25%
Lighting Controls	25%
Refrigeration	30%
Residential Smart Thermostat (Cooling)	35%
Residential Smart Thermostat (Heating)	35%
RTU Cooling	30%
Commercial Smart Thermostat	35%
Window A/C with Smart Plug	25%

Figure 26 shows that increasing the participation rate by 10% roughly doubles the potential demand response reduction in 2029 to just over 2,000 MW. In addition, the beginning part of the decade appears flat due to the rapid decline in direct load control programs for air conditioning and electric heat.

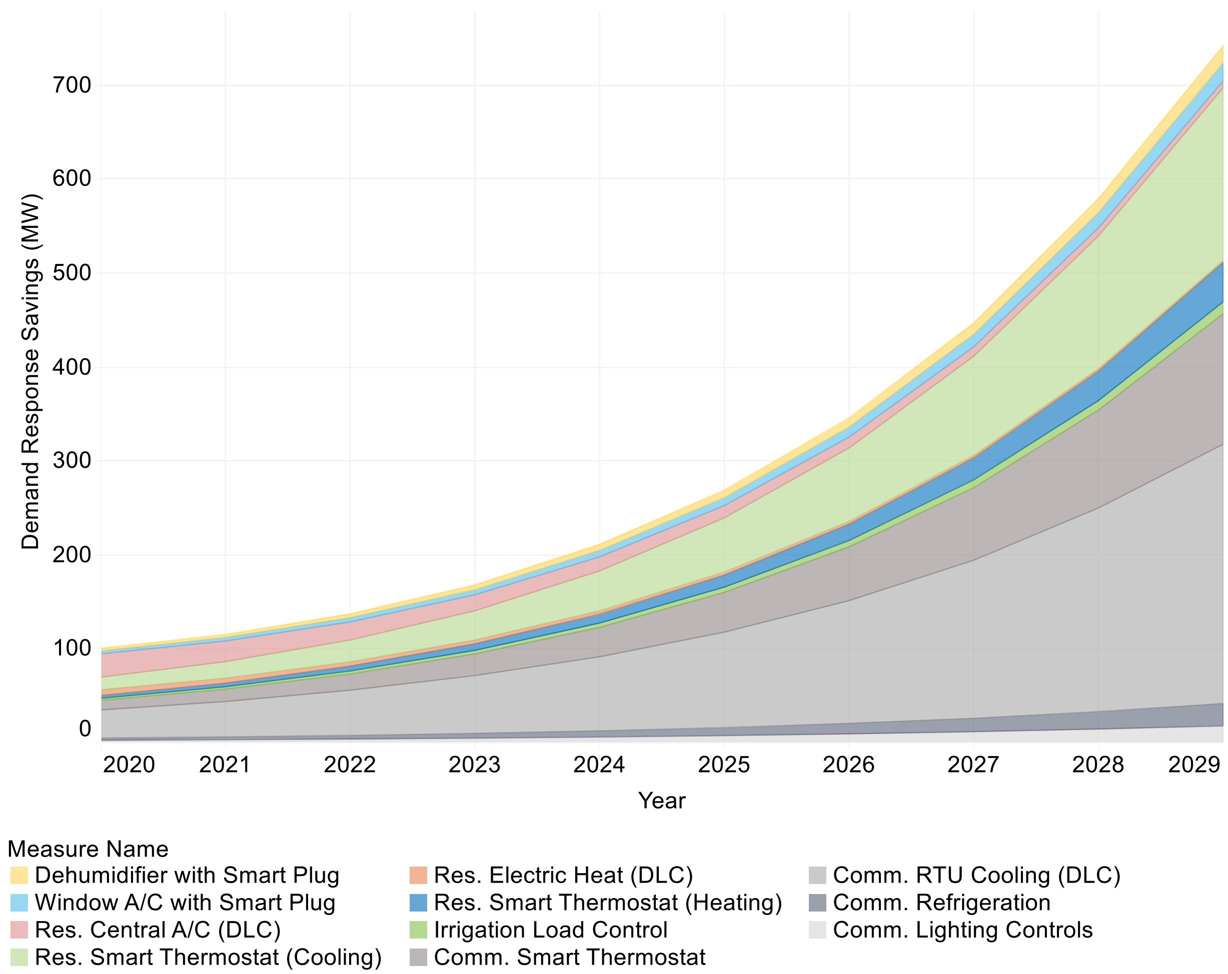
Figure 26 Demand Response Savings over Time by Demand Response Measure with 10% Increase in Participation Growth Rate Assumption



Year One Participation Rates

Varying the growth rates above showed a range of impacts on demand savings throughout the course of the time-frame for this study. Varying the initial participation rate in each program has a similar impact on total demand savings. In Year 1, 2020, total demand drops from roughly 175 MW to 100 MW. In 2029, this lowers the total demand savings from over 1,000 MW to over 700 MW. The proportionality of programs also changes in 2020, with a larger portion of commercial cooling savings in comparison with residential cooling savings through direct load control and smart thermostat programs in these sectors.

Figure 27: Demand Response Savings by Measure over Time with 1% Participation in 2020



Interpretation of Results

As with any modeling effort, generalizations were made for the scope of this study and there are caveats surrounding uncertainties with the assumptions in the methodology section above. For example, many of the year one penetration rates are low at 1% of eligible customers where they may in actuality be feasibly higher. In other cases, market segments for demand response could be saturated. For example, the 97% penetration rate of irrigation customers in Dakota Electric Territory, which is in the southern cooperative associations group, would be challenging and potentially costly to increase to 100%. In addition, there are uncertainties surrounding technology and system costs in the future that could drive the economics supporting growth rates and penetration rates for particular demand response measures.

Conclusion and Recommendations

The demand response potential in Minnesota is moderate to high, amounting to 4% of estimated peak capacity in 2029. What is also notable is there is a significant existing resource in the state, used for a variety of purposes, which are not all related to the Conservation Improvement Program. These baseline estimations reflect over a doubling of that existing resource by 2029. How to validate and engage that existing resource will be an important question, as well as whether some customers would shift to newer technologies, and how that existing resource should therefore be counted.

A large portion of the growth is in single family homes, and cooling specifically. This reflects the higher adoption potential of marketing direct load control programs as well as assumptions around growing smart thermostat penetrations. It also reflect that residential cooling is still a growing load in Minnesota, as homes built without central AC continue to convert, and as new construction continues to add residential cooling loads in larger homes.

The demand response potential studied here shows the largest potential in single family and small commercial buildings. This reflects a few assumptions. First, the results reflect new demand response additions, and larger customers already have a fair amount of penetration. Second, many larger customers are offered demand response opportunities like rate savings programs, which were not included as measures in this study.

Some additional considerations include the following:

- As advanced metering infrastructure is installed, it may be useful to consider a time-of-use program, which offers a low price per kW-yr in comparison with other demand response options and an opportunity to further take advantage of the large capacity resource offered by the residential sector. It will be worthwhile to observe the Xcel Energy Time-of-Use pilot as it unfolds (Northern States Power Company 2017).
- Each utility has a different portfolio of customer classes, meter types, and capabilities to manage these resources. In addition, each utility has varying values of capacity. Therefore, there are differing levels of achievable technical potential as well as cost effectiveness of demand response resources among utilities in Minnesota.
- Demand response has the potential to increase energy usage, and care must be observed regarding how this may conflict with both Minnesota's goal to reduce CO_2 emissions by 80% below 2005 levels by 2050 as well as the requirement for utilities to obtain 1.5% savings as a portion of annual sales (MN State Legislature 2007).
- As metering infrastructure and customer end-use devices evolve, there will be increasing opportunities to take advantage of different demand response types such as shift, shed, and shimmy. These additional demand response types can provide stacked economic incentives besides strictly avoiding expensive peak generation. These additional services could include ancillary services as well as wholesale capacity bidding.

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