QUANTA TECHNOLOGY

A QUANTA TECHNOLOGY WHITE PAPER

Climate Change, Electrification, Electric Vehicle Adoption, and Load Growth

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Acronyms and Abbreviations

The following acronyms and abbreviations are used in this white paper:

AC	Air conditioning
DER	Distributed energy resources
EV	Electric vehicle
IC	Internal combustion
LEAF®	Load and Energy Analysis and Forecasting
LDS	Local delivery system
LED	Light-emitting diode
NWA	Non-wires alternatives
SEER	Seasonal energy efficiency ratio
T&D	Transmission and distribution

Introduction and Executive Summary

Before the end of this decade, electric power usage across the United States will begin to rise due to electrification—the gradual and increasing replacement of stationary fossil fuel use by electricity—and electric vehicle (EV) adoption, the replacement of fossil fuel road vehicles with EVs. The cost/benefit ratios of electric space- and water-heating systems for homes and businesses have quietly improved in recent years, creating a slow but steady increase in the use of electric power for those purposes throughout North America, Europe, and the Pacific Rim. Technical progress in the design of EVs has made them more appealing to private owners and, in many cases, more efficient and lower cost in commercial applications. As a result, EV sales are growing each year exponentially. More important, governments around the globe are encouraging both trends through subsidies, policy changes, and in some cases, mandates in an effort to stem the effects of global warming by eliminating manmade carbon emissions.

The widespread use of electric cars, trucks, and buses is often lumped together or viewed as part of "electrification." Here, the authors use that term strictly for the replacement of stationary fossil fuel uses with electric power, as for water, space heating, and commercial cooking, drying, and process facilitation purposes. The increasing use of electric-powered cars, trucks, and buses is referred to as EV adoption. This paper looks at both trends and the expected impact they will have on local delivery system (LDS) utilities across North America. Both trends will take three or more decades to play out completely as America slowly weans itself off fossil fuels a few percentage points each year. But the potential magnitude and character of the changes in the electric load they will jointly make is so large that their impact, even at only a few percentage points of change each year, will dominate electric utility load growth across the United States within the next decade.

Ultimately, electrification and EV adoption will lead to a noticeable increase in annual electric energy sales in every electric utility system in the United States but make their most profound impact on those electric utilities serving metropolitan areas, where extensive natural gas distribution systems mean a large majority of homes and businesses currently use natural gas to meet their heating needs, and large public and commercial vehicles consume a good deal of fuel during their 16-to-24-hour-a-day schedules. In order to study the character and magnitude of this impact on metropolitan LDS systems in detail, the authors produced 30-year distribution-level load forecasts, with and without the anticipated effects of electrification and EV adoption included, for a large metropolitan area in the United States, selected to be as representative as possible of the anticipated nationwide load growth impacts and trends.

Over a 30-year period beginning within a decade, many metro electric utilities are likely to see up to three times as much load growth each year as they have seen at any time in the last several decades. Ultimately, and long before these trends play out completely, and electricity has replaced fossil fuel energy use completely, electric sales in these metropolitan systems will have more than doubled, peak load will have shifted from summer to winter, and annual load factor and system utilization will have improved significantly.

But in order to make those additional energy sales and meet those peak demand needs, metro area LDS utilities will need to upgrade their power delivery capabilities significantly. A majority of the electric demand growth that electrification and EV adoption are expected to create will be off-peak, but nonetheless, electrification, in particular, will cause significant growth of winter peak loads, necessitating, in some cases, substantial reinforcement of local distribution systems. Some of those reinforcement needs may be met by new alternate resources, such as distributed energy resources (DER) and non-wires alternatives (NWA), rather than traditional transmission and distribution (T&D) expansion, but LDS utilities are likely to find that they still must invest heavily in the expansion of their local T&D system in order to keep up with the steady, 30-year growth trend of energy and peak load that electrification and EV-adoption are expected to create.

This report is the first of three reports Quanta Technology has prepared that look at the challenges that electrification, EV, and distributed energy resource adoption will create for North American electric LDS utilities. This paper focuses on electrification, EV adoption, and the expected magnitude, timing, and character of the impacts they will make on electric utility load. The second and third reports look, respectively, at the load forecasting and planning methodologies that the industry will need to accurately track, analyze, and plan for electrification and EV adoption load growth, and the strategic planning challenges and DER-NWA planning technologies that utilities will be able to use to serve that load growth most effectively and economically.

Rising Temperatures and the Electricity Grid: Climate Change

Global warming is the term most often used to describe the change in climate that has been and is expected to continue. Across the planet, the average temperature is expected to increase by about 2.5°F between 2022–2052.[1,2] This average will not be distributed evenly over all areas of the globe, nor will it affect all hours of the year to the same degree. Figure 1 shows that it is expected to affect the middle and higher latitudes more. The average temperature rise over the United States by 2052 is predicted to be about 3°F, not the global average of 2.5°. Some areas within the United States will see more and others less than that 3°F average.

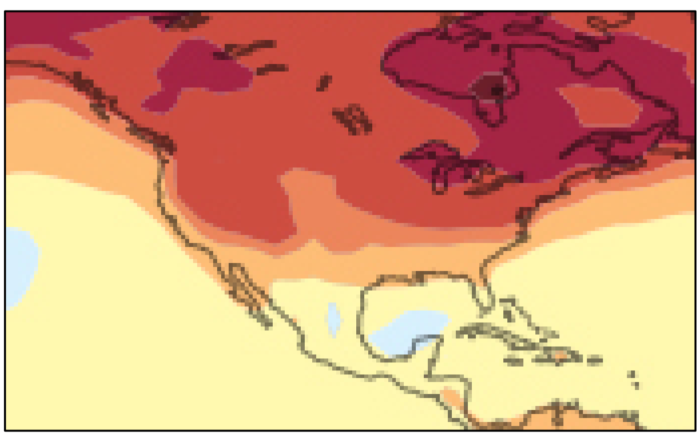

Figure 1. Map Showing Severity of Expected Summer Hottest Day Temperature Rise Regionally across North America

But while the effects of climate change will vary with location and time, the causes are thought to be independent of location. Carbon emissions from Corpus Christi, Texas, well to the south and in the lightest band of temperature rise shown in Figure 1, are considered just as damaging to global climate as those

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[1] *Climate Science Special Report,* a report by the U.S. Global Change Research Program (USGCRP) mandated by the Global Change Research Act of 1990, https://science2017.globalchange.gov/

[2] *A Degree of Concern: Why Global Temperatures Matter,* By Alan Buis, NASA's Global Climate Change Website https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/

from Edmonton, Canada, far to the north and in an area expected to see intense temperature increases. For this reason, electrification and EV adoption, both aimed at reducing carbon emissions due to the burning of fossil fuels, are considered a priority *everywhere*, even if the effects in a particular location are among the lesser expected.

Rising Temperatures Leading to Higher Summer Peaks, Lower Winter Peaks

Rising temperatures themselves, independent of electrification and EV adoption, will cause higher peak summer temperatures in most places throughout the United States and milder winter peak cold weather. For example, across the PJM system in the Mid-Atlantic region, the expected 3°F rise in summer peak temperatures would lead to about a 3.6% rise in summer peak load, as calculated from the weather response sensitivity for an area of the PJM system which is used in an example forecast given later in this report (Figure 2).[3]

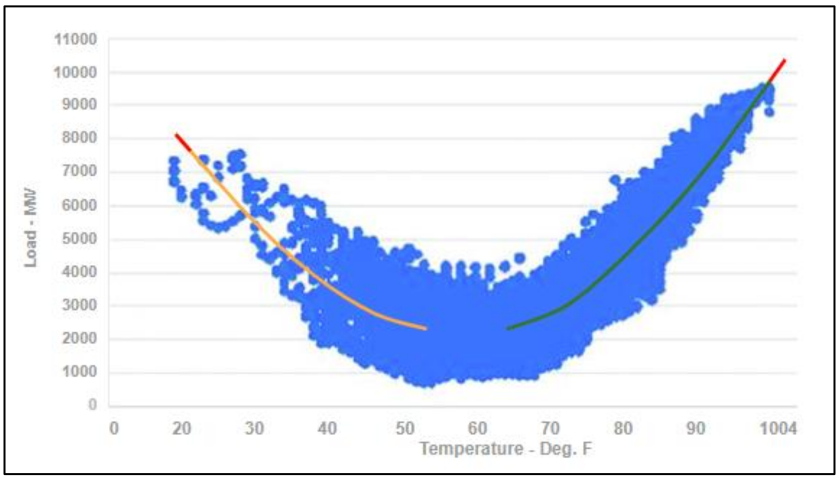


Figure 2. Plot of Daily Peak Temperature vs. Daily Peak Load for the Metropolitan Utility System Whose Load Is Analyzed Later in this Paper—a Fairly Average Midlatitude U.S. City

Equally important is the effect on energy and the annual load curve shape. Figure 3 shows long-term trends in average annual heating-degree days and cooling-degree days for the United States.[4] The long-term trends are very clear, and no evidence exists to suggest they will not continue in the future. Even without the impacts of global warming, summer energy sales will be higher and winter energy sales a bit lower. The annual (8,760-hour) load curve shape will be affected as well.

[3] A typical AC unit, set to maintain inside temperature at 72° while outside temperature is 100°, will have to work to maintain that 28° differential. A 3°F increase in temperature will raise that to a 31° differential that summer cooling units must maintain, a 10.7% increase in cooling burden. That added 10.7% temperature differential will increase AC load by a nearly proportionate amount, which works out to an increase in overall system peak load of about 3.6%.

[4] From Statista: https://www.statista.com/statistics/245940/number-of-cooling-degree-days-in-the-united-states/ and https://www.statista.com/statistics/245632/number-of-heating-degree-days-in-the-united-states/

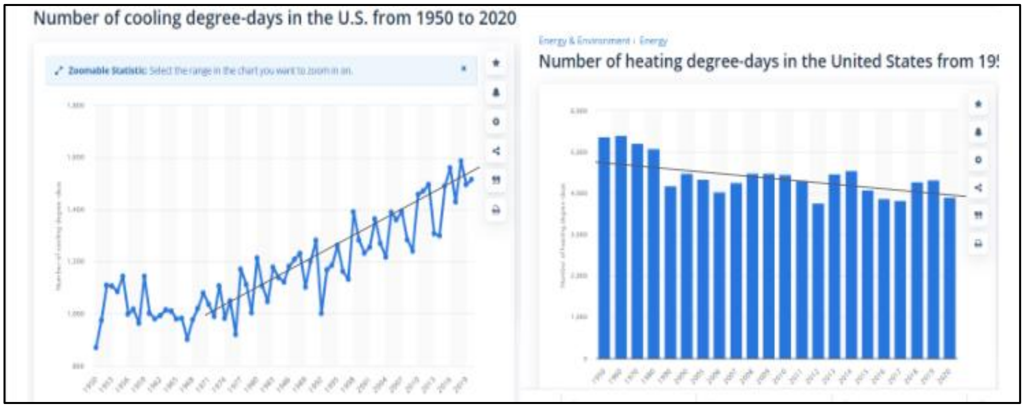


Figure 3. Plots of U.S. Average Cooling-Degree Days and Heating Degrees over Time Reveal Rather Remarkable and Consistent Trends Going Back Many Decades

Loss of Capacity Due to Global Warming

The peak load ratings for almost all types of power equipment are based on the amount of heat rise above ambient temperature (due to internal power losses) that the equipment can tolerate before it reaches a temperature limit that depends on the materials used and its design. Thus, a transformer designed for a maximum core temperature of 120°C can be operated to a certain level of power flow through it when the ambient temperature is 38°C (which generates an 82°C rise in hot spot temperature), but if global warming raises that ambient by 3°F (1.7°C), the permitted heating drops to only 80.3°C, a loss of 2% in permitted temperature rise. Losses from electrical losses are proportional to the square of the amperage, so this means the expected loss in capacity from the expected average rise in ambient over the three decades is only about 1%. Still, that is a real loss equal to about a 1-year expansion of the T&D grid for many utilities and will affect virtually all overhead conductors, underground cables, transformers, regulators, and capacitors. Together with a 3.6% average rise in summer peak load, that puts global warming's expected impact on T&D peak needs over the next three decades on the order of 5% in total.

Loss of Service Life Due to Global Warming

More important to planners and utility management than the impact on capacity needs might be the impact global warming will have on equipment service lifetimes. Equipment lifetime is largely dictated by the cumulative, long-term effects of that heating from losses, and while it is most extreme at peak, it occurs in some measure every hour that an electric device is used. Deterioration is nonlinear with age and time in service, and older units can be affected somewhat more than new ones by extreme heating. The annual equipment loss of life due to 2052's expected temperatures (3°F higher) compared to today, if spread evenly over the whole year, would mean a noticeable reduction in the expected service life of units. Quanta studies have shown that much of the wound T&D equipment in some systems would have to be derated by an additional 3% to bring annual heating stress down to the expected lifetime as originally expected.

Finally, climate change will lead to more volatile weather: more frequent storms, more violent storms, higher winds, and heavier precipitation than in the past. These will affect the operations of electric utilities, but as important as they are, they are not directly related to load forecasting and system planning for load growth and will not be addressed here.

Pollution is Still Problematic and Equally as Impactful as Rising Temperatures

Understanding the impact rising temperatures will have on the grid doesn't mean the other main motivation for electrification disappeared—air pollution and its impact on societal health. Transportation electrification was first viewed as a societal benefit due to the reduction of air pollutants the transition would bring. Emissions from internal combustion (IC) engines—nitrous oxide (NOx), sulfur oxide (SOx), and particulate matter (PM)—are still viewed as extremely problematic, particularly in cities such as Los Angeles and Phoenix, where emissions contribute to heavy smog and clean air issues. The desire to reduce these emissions via electrification was not simply for aesthetic reasons but rather directly related to the health of citizens breathing the air, where defined, measurable, negative impacts on health are directly related to the emissions from vehicle IC engines.

Electrification

Electrification is the replacement of the use of fossil fuel with electric power. Strictly speaking, that means it includes EVs, too. However, the term electrification has come to be used for the replacement of *stationary* uses of fossil fuels, while electric transportation, or EV adoption, is the term used for non-stationary road applications: cars, trucks, and buses. The major portion of electrification involves the conversion of residential, commercial, industrial, and institutional space and water heating from the combustion of fossil fuels or wood to electric power, along with the conversion of commercial and industrial fossil fuel heating processes that can be converted.

Heat Pumps

By far, the biggest segment of electrification load will be a shift to heat pumps to warm homes, businesses, and factories in winter. Currently, 37% of U.S. homes use electricity to heat their homes in winter. A roughly equal portion of businesses do as well. The vast majority of those homes and businesses are located in the South and the Southwest United States and use resistive heaters, which have a very low initial cost but a relatively higher operating cost due to their relative inefficiency compared to more expensive types of electric heaters. In areas with mild winters, resistive heaters are the preferred type of heater because the low initial cost more than offsets the higher operating cost in a region with mild winters. In the northern parts of the United States, where winters are longer and colder, natural gas or some other fossil fuel is used for the vast majority of home heating.

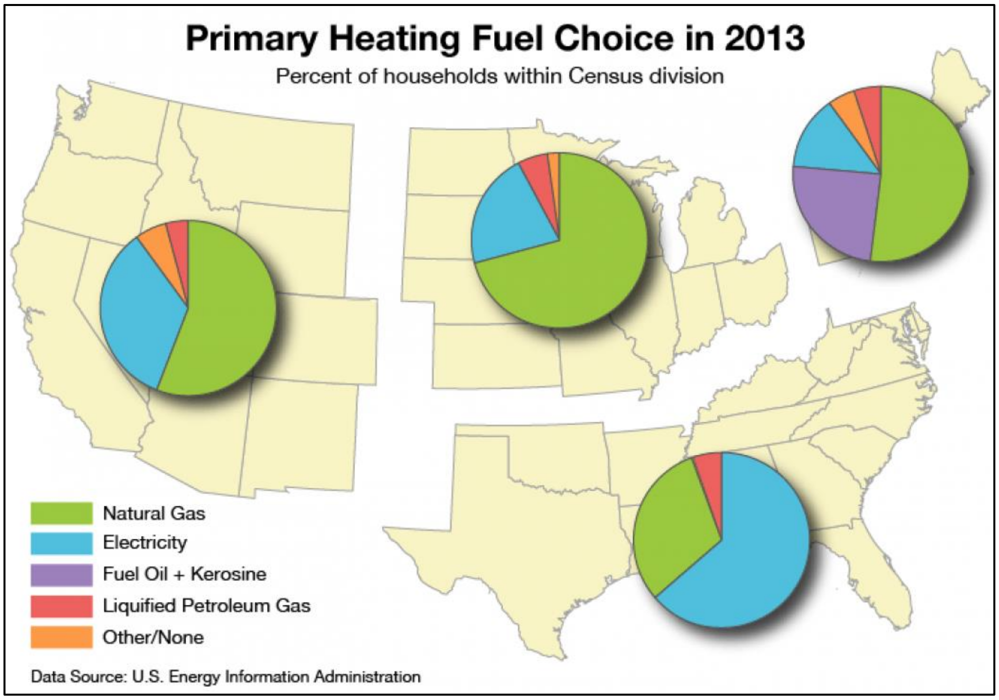


Figure 4. Electric Heating Fuels Used Varies Depending on the Region of the United States

Electric heat pumps are expected to be the type of space heater used throughout most of the United States to replace fossil fuel or natural gas-fired space heating. Heat pumps are basically air conditioners that work in reverse. The best of them can be up to four times as efficient as resistive electric heat—using only one-fourth as much power to heat a building. In some political jurisdictions, their adoption will be heavily subsidized, perhaps even mandated instead of resistive heat or fossil fuel, due to that superior energy efficiency. Heat pumps have been available for decades but were not popular despite their low annual fuel and operating cost because they had an initial cost several times that of resistive heaters, and they did not perform well in extremely cold weather. Currently, between 2%–3% of American homes and a slightly higher portion of businesses use heat pumps for space heating.

However, in the last decade, the use of heat pumps has begun to grow to the point that in 2020 they were installed in 38% of all new homes built in the United States. The reason has little to do with electrification and everything to do with improvements their manufacturers have made in their cost and performance. The initial cost has come down quite noticeably, and their performance in extremely cold weather has significantly improved. An important point in their sales now is that a heat pump acts as a heater in winter and an air conditioner in summer. Compared to the cost of buying *both* an air conditioner *and* a resistive heater or an air conditioner *and* a natural gas heater, heat pumps are constantly moving closer to being cost-competitive with combustion heating. Even without a push for electrification for climate change reasons, a continuation of the current trend of gradually expanding market share could be expected, along with the winter load growth that would cause.

Simplicity of Heating Individual Rooms: Use in Other Countries

Adoption of the use of heat pumps in the United States will not require creating a new, global market. Rather, the use of heat pumps in Europe and Asia is much more common as the markets are more mature in these areas. There are a number of reasons for this. For example, the fact that many homes in the United States have ducted central heating and cooling makes them less likely to move to heat pumps. In other parts of the country, low-cost window air conditioning units are often used in homes in cooler climates that do not have central air conditioning. The bottom line is that though heat pumps are improving and breaking into colder climate areas of the United States, the technology has mature market shares in Europe and Asia. Understanding global trends are important because it highlights that even without incentives, the technology can successfully be adopted. Technology cost declines coupled with better efficiency will likely make the heat pump the cheaper alternative, even absent incentives.

Winter Peaks in Many Places

Most LDS electric utilities in the United States currently see their annual peak load in summer due to widespread air conditioning use in their service territories but will see that switch to a winter peak after electrification has led to a high usage rate for heat pumps. A common misconception is that this will not happen because a heat pump is basically an air conditioner running in reverse: thus, there will be roughly the same load connected in winter as in summer, and that means summer and winter peak loads will be the same. Fueling this misconception is the fact that "waste heat" contributes noticeably to the heating of almost any building. For example, lighting—even the most efficient LED type—creates a small amount of heat that warms the air around it. The same happens to some extent with any electric use—motors and power supplies get warm, and that heat flows into the interior of a home or office. Body heat from human activity contributes, too. The heat pump has to remove that heat from a building in the summer in order to cool the space, but in winter, all that "waste heat" helps to heat the building so that the heat pump has to work less.

All that is true: the same heat pump will be cooling a building in summer and warming it in winter, and "waste heat" does heat a building. But heavily outweighing those facts is the fact that heat pumps are far less efficient in cold weather than in warm, so they have to work harder in winter to do the same amount of heating as they do cooling in summer. To work harder, they use more energy, and that means the winter peak will be higher than in the summer.

Figure 5 shows the relative electric efficiency of a typical modern heat pump as a function of temperature when it is cooling or heating. Shaded areas at the top plot show the relative amount of heating (left side) and cooling (right) load in a typical year as a function of temperature. The bottom plot shows the electrical efficiency of a modern heat pump as a function of temperature. The red dashed line shows the efficiency level of pure resistive heating. Operating efficiency falls off somewhat in the extremes because the manufacturer engineered the unit to be most efficient when operating at temperatures it will see most often (40°F–55°F in winter, 68°F–85°F in summer) so that it achieves the best possible seasonal (weighted average over all operating hours). In this case, it is a 17 SEER in the average summer and the equivalent of 13.5 over the average winter. Whiles its instantaneous performance falls as it nears the extremes in both summer and winter due to those design characteristics, it falls off very dramatically at colder temperatures due to the unavoidable physical effects of having to operate near or below the freezing point of water. At around 20°F, heat pump efficiency drops to about that of resistive heat (red dashed line in Figure 5). A heat pump has to work *much* harder during extreme winter weather than it does during summer peak extremes, enough to more than make up for any help that "waste heat" gives it during winter. The sidebar discussion on the next page demonstrates this.

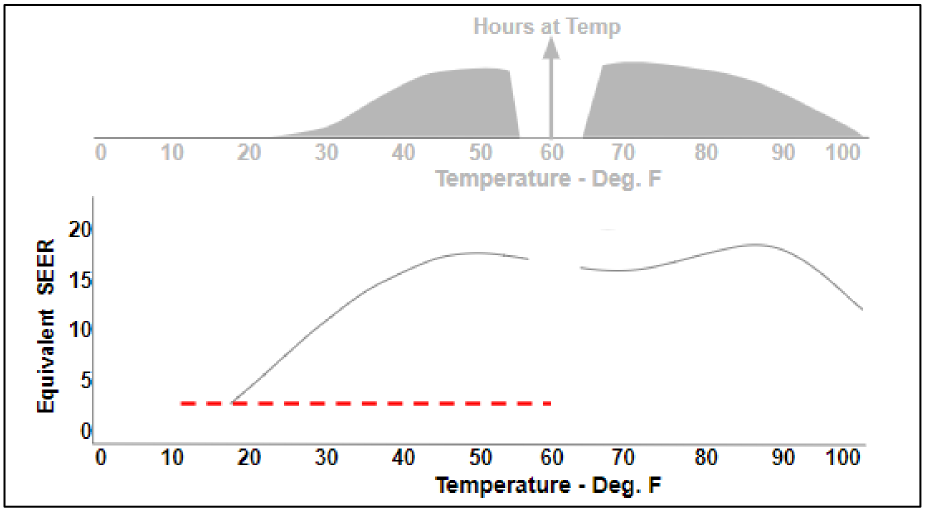


Figure 5. Heap Pump Heating and Cooling Annual Energy Use and Efficiency As a Function of Temperature.

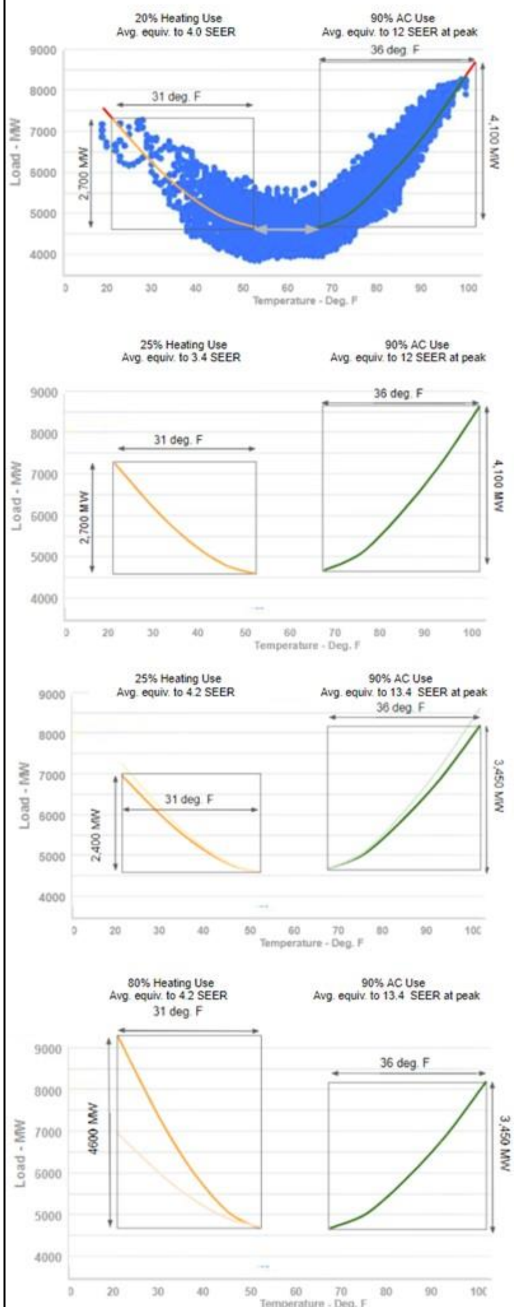
A Mixed Bag of Effects Depending on Where You Live

Full electrification (100% use of heat pumps and electric water heaters) would affect electric utilities in some areas of the country much more than those in other areas.[5] In parts of North America, where winters are long and bitter and summers mild, annual heating-degree days outnumber cooling-degree days by as much as ten-to-one. As a result, a noticeable portion of homes and businesses do not have space cooling equipment, but the portion using fossil fuel for winter heating is extremely high. Utilities in these areas will see a huge increase in peak load as those customers abandon fossil fuel use for electric space heating, and rates of load growth due to electrification will be far above the national average.

In contrast, in the Deep South and Gulf Coast regions, summers are long, hot, and humid, and air conditioning use is nearly ubiquitous, while winters are so mild that up to 40% of energy consumers choose to use resistive electric heating in winter, even though it is inefficient with high "fuel" bills because heating is needed so infrequently. Utilities in these areas of the country will see far milder electrification impacts on peak loads, and EV usage will be the major driver of any load growth they see.[6]

[5] "Most American Homes Are Still Heated with Fossil Fuels," by David Hunter, Vox, https://www.vox.com/energy-and-environment/2018/6/20/17474124/electrification-natural-gas-furnace-heat-pump

[6] And in some measure EV impact in the Deep South will be worse than in the North. While light vehicle use across the United States is much more heterogeneous than space heating usage characteristics, it does vary from state to state by a range of nearly 60%. For whatever reason(s), car owners in Mississippi, Alabama, and Arkansas drive about 50% farther each year than drivers in Vermont, Connecticut, or Massachusetts, and will therefore both buy more energy and probably create longer and higher charging peaks each day as a result.



ELECTRIFICATION MOVES ANNUAL PEAK TO WINTER

This set of diagrams walks through a simple demonstration of how and why electrification widespread use of heat pumps a will create a new winter peak higher than the summer peak in many summer-peaking systems. Here, in the top diagram, we take the existing (2021) customer base and usage patterns as they are, using the plotted values and summer and winter temperature vs. load curves from Figure 2. We account for global warming expected in the next 30 years (red portions of fitting load-vs.-temp lines, as explained in the text of this paper) which raises summer temperature & load compared to 2021, and lowers them in winter.

Base (no weather sensitive load) peak-day usage is 4,600 MW. The gray arrow (again, see text for details) shows that and the roughly 8 degree standoff at that load, where "waste heat" in the interior of buildings, etc., warms buildings. Current AC usage is at 90% of the customer base with an average equivalent SEER at peak of 12.5. Current heating usage is at 25% (mostly energy consumers outside the metro areas gas distribution network, the vast majority using resistive heating) with a equivalent SEER for the mixture of unit types, at peak, of 3.4. Weather sensitive summer and winter loads are respectively 4,100 MW and 2,700 MW, for a summer peak of 8,700 and winter peak of 7,300 MW.

We remove all the blue dots to make it easier to focus on the weather-sensitive curves along (they are exactly the same as in the diagram above).

We increase the efficiency of AC and heaters to what is expected in thirty years as technology improves. Summer SEER rates have been improving by nearly .3 to .5 SEER point per decade, so the equivalent performance at peak increases to 13.4, lowering summer load significantly, to 8250 MW.

The authors think that in the next thirty years, heat pump performance at cold temperatures will improve by a similar margin of slightly better. Average SEER here at 20 deg F has been increased to 4.2. All resistive heat users in the system are also modeled as having been converted to the more efficient heat pumps, again, an optimistic assumption but one made to emphasize that it would not matter: peak will still be in winter. With these efficiency improvements, the winter peak when serving the current 25% base of customers who use electric heat drops 7,000 MW.

We now leave the summer AC use as it is, but increase the usage of heat pumps to 80% as modeled in this paper. This 220% increase in the usage of electric heat increases peak weather-sensitive winter load to 4,600 MW, making winter peak 9400 MW, 12% more than summer peak. As electrification continues and heating usage reaches the 90% level of usage as with summer air conditioning,, winter peak will rise to just under 10,000 MW

Figure 6. How and Why Widespread Use of Heat Pumps Will Create a New Winter Peak Higher than the Summer Peak in Many Summer-Peaking Systems

Electric Transportation

Only about 3% of new light vehicles sold in 2022 are expected to be EVs. However, EV sales are expected to grow each year rapidly as EV performance and price continues to improve, the driving range on a fully charged battery increases, their electric charger infrastructure grows, and most importantly, manufacturers ramp up their ability to produce them. There is every reason to think that EV and electrification load growth trends will accelerate rapidly. In 2021, President Biden set a national goal for 50% of new light and personal vehicles to be EVs by 2030, which at the time seemed a bit optimistic.

Bloomberg predicted at that time that it would take an additional 3 years to reach that level (Figure 7). But this year's Inflation Reduction Act which includes $378 billion in subsidies and support for clean-air efforts, much of it for EVs and electrification, means that something like that trend, perhaps even slightly more aggressive than that, is very likely.

But while a figure of 50% of all new cars might sound impressive, it means that conversion to high levels of EV use will still take decades. In the U.S., new vehicles represent only 6% of all cars and light trucks, and light trucks by EVs of only about 3% a year. At that rate, it would take over 30 years to reach nearly 100% EV usage. Of course, full conversion to EVs would add significantly to overall electric energy sales, more than doubling it, so even at a 30-year period to reach full EV conversion, the increasing use of EVs will add 2%–4% growth in energy sales annually, and depending on EV charging habits and patterns, a potentially significant increase in annual peak loads on utility feeder systems.

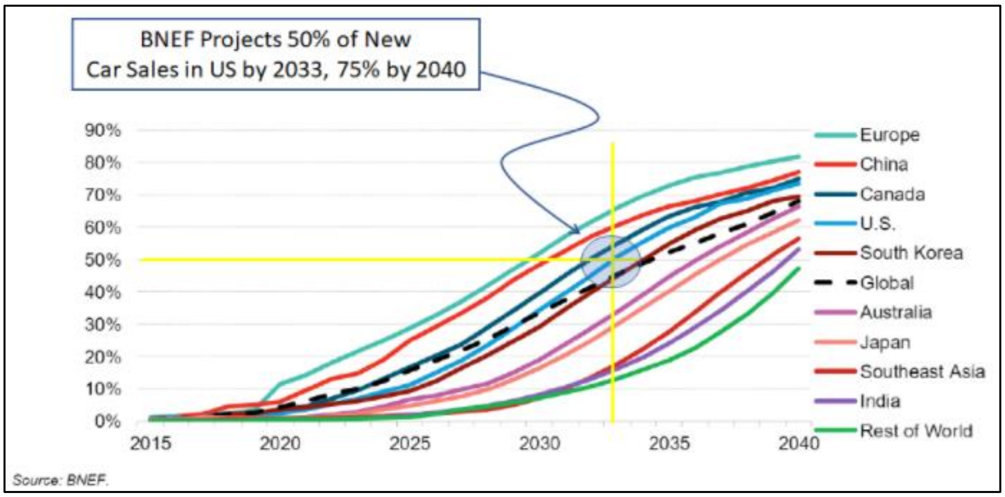


Figure 7. Predicted EV New Car Sales Rates for Various Countries Compiled by One Source

An important part of EV adoption is the increase in distribution loading expected from the electric conversion of "non-light vehicles." These include trucks used for delivery, service, cargo, and construction, and buses for transit. There are far fewer of these in the United States than private cars and light trucks, but they are heavier and driven on average about three times as far each year. Cumulatively they use about 80% as much energy as all those cars and light trucks. Businesses are likely to convert to EVs faster than the general population because the increased mileage driven each year means that EVs will save them money quickly. Once anything approaching initial cost parity is achieved, adoption of EVs is likely to occur due to the vehicles being less expensive to operate—meaning even without incentives, we are likely to see an adoption of EVs in the commercial and light-duty segments.

As stated earlier, the technology for EVs is not very mature. Future EVs will likely be a bit more energy-efficient than today's EVs, although probably not enough to materially change their expected energy requirements. What will improve and will have a big effect is battery capacity and range on a single charge. A steady increase in this has been a trend for the last 10 years. As a result, today, the average range of an EV on the street is about 125 miles (about half the distance a typical car owner drives each week), while the average range of new EVs on the market is about 260 miles. This situation is expected to continue until the range on a single charge reaches about twice the average distance driven in a week or 500–600 miles.

Demand and Load Curve Shapes

Although only a small portion of automobiles, trucks, and buses in the United States are electric, energy and daily hourly load curve shapes have been well studied, and data on average daily charging curves are readily available (Figure 8). Details vary, as they come from numerous sources. The four diagrams shown demonstrate the great amount of uncertainty that currently exists regarding *when* EV charging will occur. Most studies conclude that the bulk of EV charging load will be off-peak, but they differ on the times and details of daily charging cycles. See references for details about each study.[7]

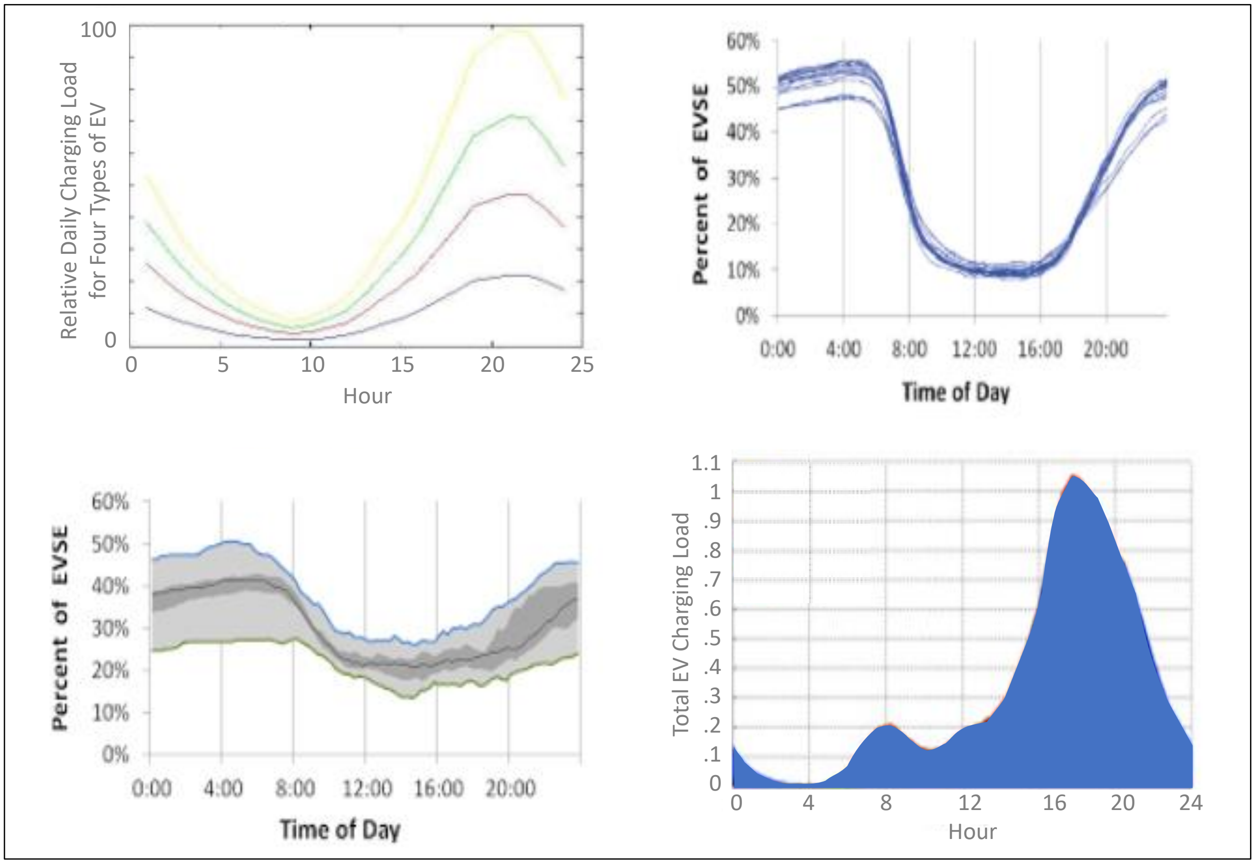


Figure 8. Four Studies of EV Charging Cycles

Currently, the average driving range of pure EVs on the street is about 125 miles, and surveys of EV users indicate nearly all EV owners have some "range anxiety" about keeping their cars fully charged, to the extent that most private EV owners charge their EV at home, overnight, every night, and businesses generally charge every weekday night in order to operate them the next day. Surveys also indicate considerable concern, if not resistance, to any efforts utilities would make to alter or control charging times to improve utility system efficiency (unless accompanied by large incentives). But both the "natural" charging cycle and EV owner acceptance of load control could change dramatically when the commonly available EV driving range on a single charge reaches 500 miles,[8,9] which is expected to occur by about 2035. At that point, daily charging cycles may evolve into weekly charging cycles (charge during the weekend evenings, when the price is lowest) and resistance to load control of chargers, or even the

[7] Sources clockwise from upper left: from studies done by ResearchGate, Nissan and Idaho National Lab, NREL and DOE.

[8] This is roughly twice the 260 miles that the average car is driven each week in America.

[9] Currently the longest available range in a normal electric car on the U.S. market (Lucid Air).

utilities' use of vehicle-to-grid—drawing power out of charged cars while parked, for emergencies to assist the grid at peak—may be of far less interest than it would be today.

It is also important to keep in mind all those cars, trucks, and buses owned and operated by businesses. But there is no doubt that many, if not most, would have significantly different daily, weekly, and annual charging cycles than they have today as compared to private vehicles.

Winter vs. Summer EV Efficiency and Load

Americans currently drive about 20% farther in summer than in winter. This pattern will very likely continue with EVs. That alone would mean the EV load would go down somewhat in winter. But EVs get much poorer mileage in winter than in summer, as much as 40% less at temperatures below 20°F. Some of this increase is due to battery chemistry: they operate best at moderate temperatures and much less well when cold. In severe winters, EVs use some of their stored power just to heat their battery to make it perform well, losing a noticeable amount of range due to this effect alone.

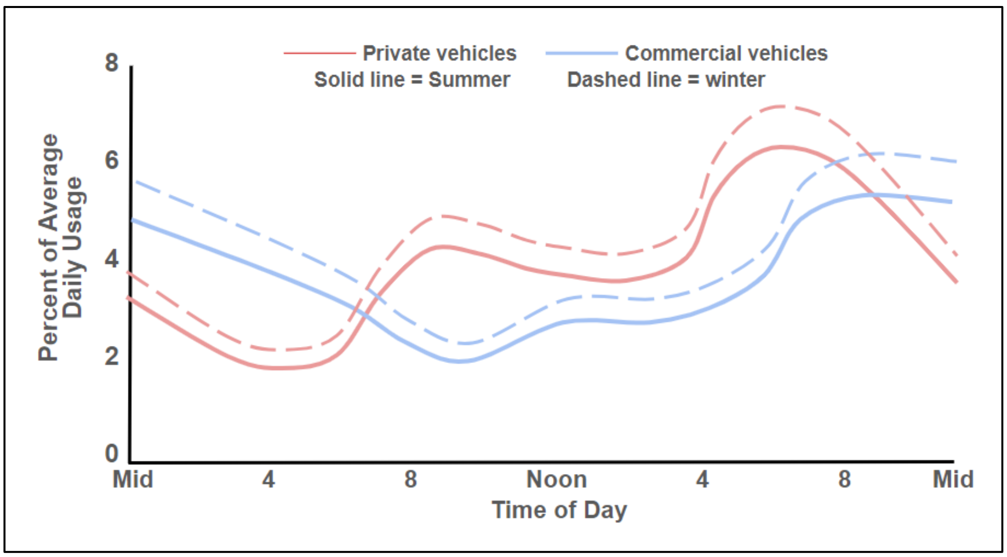


Figure 9: Weekday Daily EV Charging Load Curves Used in This Study

A major "winter effect" on EV driving range is the heater used to warm the interior of the car so its occupants are comfortable. Ironically, perhaps, given the topics discussed here, currently, nearly all EVs use resistive heaters to warm the interior of the car, truck, or bus: resistive heaters weigh and cost next to nothing and are simple and nearly maintenance-free. However, since most EVs have a heat pump—currently used only as an AC unit for cooling in summer—the authors think it likely that manufacturers may, in time, upgrade and modify that summer-only design to work as a heater in winter, improving winter seasonal EV energy efficiency noticeably. Still, these units would have efficiency curves similar to that shown earlier for stationary heat pumps in Figure 5, so they will not work quite as well in winter as in summer. The authors estimate that with this improved technology, EV kWh use per mile in winter will still be about 15% higher than in summer. **Error! Reference source not found.** shows the daily summer (broad l ine) and winter (dashed line) EV charging load curves that the authors used to model EV usage in the load forecast given in the next section, with red indicating private cars and blue those EVs owned by businesses. The curves are in percent of average daily usage (1/365th of annual EV energy use).

Representative Load Forecast for a Typical American Metropolitan Area

In order to study the effects that electrification and EV adoption will have on electric load growth, the authors prepared a pair of 30-year feeder-level load forecasts of electric peak load for a metro area utility system in the United States—one without electrification and EV adoption included, and one with electrification and EV adoption included. The load forecasts were done using a screening-level load forecast tool from the authors' Load and Energy Analysis and Forecasting (LEAF®) toolkit, which they use in utility studies. It was designed specifically for the forecasting of metro-suburban area systems and a hybrid land use/trending approach to forecasting load at the system and feeder level, with which the authors have had considerable experience and success.[10]

No one example can completely cover the range of varying impacts and effects that electric utilities across North America can expect to see, given differences in weather, terrain, demographics, and economies across North America. However, the modeled system was selected and set up to be as representative as possible. It covers a large city in the mid-latitudes of the continental United States, its suburbs, and sufficient surrounding countryside to show how impacts outside of the metro area and its natural gas distribution network differ from that inside. In order to make the forecast as representative as possible, national averages were used wherever possible for key factors in the forecast, including:

- Continuation of all historical trends based on U.S. averages:
  - Slow, if steady, customer base growth is driven by the U.S. population growth rate as forecast by the U.S. Census Bureau (a slowly decreasing growth rate each year, averaging about 0.5% per year).
  - A resulting customer growth rate is slightly above the national average (due to changing demographics and economic trends), averaging about 0.65% a year.
  - An annual increase in electric end usage (use of devices that use electricity) of about 0.3%.
- Continuation of all ongoing energy efficiency improvement trends:
  - Modeled as a 0.5% per year decrease in electric usage for the same end-use effect.
  - The expected national average climate/global warming impacts (Figure 2 and Figure 3).
  - Weather for the mid-latitude non-coastal eastern United States adjusted to those climate change trends modeled as at 90/10 extreme seasonal weather.

Figure 9 shows how market penetrations of heat pumps and EVs were modeled as growing over the 30-year period. Not shown are similar assumptions made about the adoption/substitution of electric power for water heating and other current natural gas and fossil fuel uses (cooking, etc.). Despite the 30-year forecast period and the significant acceleration of adoption rate expected, neither electrification nor the adoption of EVs is expected to reach its ultimate potential—100% market penetration—by the end of that period. The forecast *assumed* that both trends reached a market penetration of 80% and tracked S-curve growth rates shown in **Error! Reference source not found.**.[11] EV loads were modeled with residential and c ommercial daily charging load curves as shown in Figure 9 (about 6% of daily EV power needs coincident with peak summer load and 5% with winter load).

[10] For descriptions of the basic algorithm, see *Spatial Electric Load Forecasting—2nd Edition*, Chapter 15, Section 5. The algorithm is an improved version of that described in 15.5, with the ability to generate 8,760-hour load curves for each feeder. In this case the model used the city government's published long-term development plan, using the method described in the book.

[11] Meaning that 80% of all fossil-fueled space heaters, etc., in the United States have been replaced with electric heat (all space heating being heat pumps), and 80% of cars, trucks and buses on the road are powered by electricity.

The forecast is not represented as being accurate for the system modeled here or in any area of the United States. That was not its purpose. The authors do believe it is *representative* of the average effects that electric utilities throughout North America could expect to see over the next 30 years if current trends in electrification and EV adoption continue. It serves as a good case for the purposes it is used here.

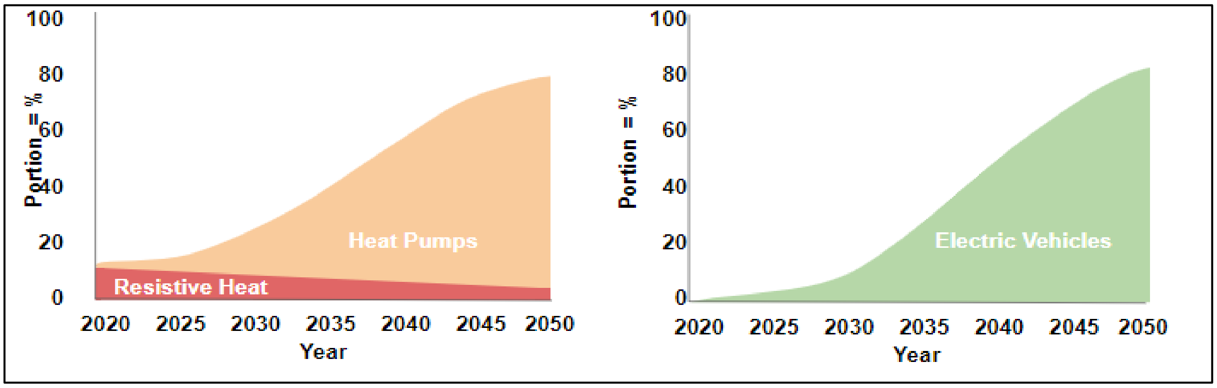


Figure 9. Both Electrification and EV Adoption Were Modeled as Reaching 80% Market Penetration by 2052, Each Following an S-curve Based Curve as Most Emerging Technology Sales Follow

Forecast without Electrification and EV Adoption

In Table 1, parts A and B compare the forecast load growth without and with the effects of electrification and EV adoption included. Without these effects (Table 1, part A), the forecast is a continuation of all current national trends and averages. Population grows by 17%, and the number of utility customers by 23% (the difference is due to demographic and economic factors affecting most U.S. cities). Surprisingly, perhaps, given the growth in customers and population, all load-related values increase by just two-thirds of a percent over the period. This is due to the long-term trend in annual improvement in the energy efficiency of electric usage. Over 30 years, that steady—if small—0.5% improvement each year results in a 16.2% decrease in power usage for the same end use, almost completely balancing the population growth of 17%. Despite this, during the 30-year period, utility planners will have to make additions of roughly 8% to their system to serve new customers, not within the reach or capacity of the existing distribution system.

Table 1. Peak Load and Energy Growth from 2022–2052 for the Modeled System

Table 1A: Without Electrification and EV Adoption			
Factor	**2022**	**2052**	**Growth**
Population	3,300,000	3,861,000	17%
Customers	1,550,000	1,906,000	23%
Annual Energy Sales–TWh	44,000	44,300	<1%
Annual Summer Peak Load	8,700	8,750	<1%
Annual Winter Peak Load	7,300	7,350	<1%
Annual Peak Load	8,700	8,750	<1%
Annual Load Factor	0.57	0.57	-

Table 1B: With Electrification and EV Adoption			
Factor	**2022**	**2052**	**Growth**
Population	3,300,000	3,861,000	17%
Customers	1,550,000	1,906,000	23%
Annual Energy Sales–TWh	44,000	89,100	103%
Annual Summer Peak Load	8,700	11,750	35%
Annual Winter Peak Load	7,300	15,500	111%
Annual Peak Load	8,700	15,500	78%
Annual Load Factor	0.57	0.69	21%

Forecast with Electrification and EV Adoption Trends

Table 1, part B gives peak load and growth values for the "with electrification and EV adoption" forecast. Energy use doubles in 30 years. Peak load increases by 78%. The system load factor increases from 0.57 to 0.63. Figure 10 plots key aspects of the load growth of this at the system level for the forecast that includes electrification and EV adoption by 5-year increments over the period. Table 2 summarizes the character of that growth for key periods during the 30-year forecast period.

For the first 5 years of the 30-year forecast period, electrification and EV adoption trends are quite small, and the system load growth trends basically replicate load growth trends of the preceding decade. Mirroring U.S. population growth patterns, customer growth continues to grow at just under 1% a year.[12] Per customer, electric usage by the utility's existing electric consumers adds another 0.3% peak load every year. However, that is more than offset by a 0.5% drop in electric usage due to the lower appetite that Energy Star replacements for older appliances and newer "light bulbs" have for electric power. The net system peak load growth rate in the first few years of the 30-year period is thus about 0.75% annually.

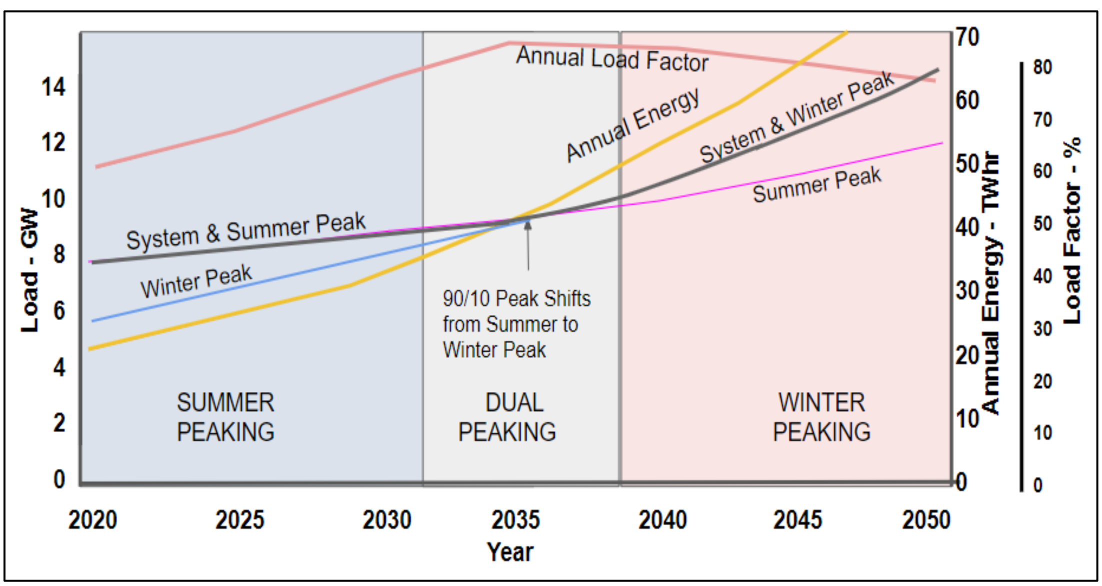


Figure 10. Trends at the System Level for the Load Forecast with Electrification and EV Adoption Plotted in Five-Year Increments

[12] Both trends slow considerably by the end of the period, as forecast by the U.S. Census Bureau for population, but are at this level in the initial five-year period only.

Table 2. Summary by Five-Year Period for Forecast with Electrification and EV Adoption

Year	Peak Load Growth	Energy Growth	LF Change	Annual Peak	Comments
2030	Noticeable Increase	2X 2021 rate	Little change	Summer	Winter peak is growing 3X faster than summer peak. Annual peak load growth rate equals 2022's.
2035	1.5X 2022 Rate	2X 2022 Rate	Improved by 2%	Summer	Winter peak is still growing 3X faster than summer. Winter's peak is now close to summer's.
2040	3X 2022 Rate	2X 2022 Rate	Improved by 10%	Dual	Winter peak passes summer peak. System peak growth suddenly jumps by a factor of 2.5.
2045	3X 2022 Rate	2X 2022 Rate	Improved by 8%	Winter	Annual peak is growing 3X faster than it was in 2022 or 2040.
2052	3X 2022 Rate	2X 2022 Rate	Improved by 5%	Winter	Winter peak is now much larger than summer peak. Peak load growth is still strong but beginning to drop as EVs and electrification near saturation.

Starting in 2029, those small-but-growing rates of electrification and EV adoption first become noticeable, adding nearly half a percent to energy sales growth that year, a small amount compared to what they will add in a few years. The following year they add even more growth in energy, and the year after that, even more, as both electrification and EV adoption trends accelerate (see Figure 9). By 2033, they are creating as much growth in annual energy sales *as all other causes of growth combined.*

Still, the annual peak load grows at only a tiny bit more than it has in the recent past, gradually ramping up from that initial 0.75% per year rate in the early 2020s to about 1.1% by 2035. The reasons are, first, that EV adoption makes little impact on summer or winter peak loads. Second, electrification makes very little impact on summer peak load. During this period winter peak load is growing 2.5 times faster than the summer peak but is playing catch up, still not greater than the summer peak. For planners, this changes in 2038: the 90/10 winter peak becomes greater than the 90/10 summer peak load. System peak for planning purposes changes to winter, and after that year, planners see the full effect of the higher winter peak load growth rate on planning needs each year, roughly three times what it had been up through 2037.

For several years before and after 2038, the system is *dual peaking,* meaning the 90/10 to 10/90 ranges of summer and winter peak loads due to extreme weather overlap. Depending on the weather, the system could peak in winter or summer during those years. The actual observed annual peak load on the system will likely fluctuate back and forth between the seasons for several years during this period due to the vagaries of weather. But all the while, winter peak will continue to grow much faster than summer peak, so that eventually the system becomes dependably winter peaking every year. By 2052, assuming planners have done their job and the system is up to it, it will be serving 23% more customers and delivering a bit more than twice the energy it did in 2022, with an annual peak load occurring in winter that is more than 1.5 times 2022's annual (summer) peak load, and a load factor far better than in 2022.

Load Growth Impact of Global Warming, Electrification, and EV Adoption

The difference between the two forecasts is attributable to the combined effects of electrification and EV adoption. Table 3 shows the net contributions of the driving forces and factors acting on the peak load growth as a percent of total peak load growth for the "with EVs and Electrification" forecast. They are shown as the percentage of the total net peak load increase (that 78% increase is shown in Table 1b).

Table 3. Breakdown of Peak Load Increase Influences 2022–2052
(As a Percentage of Total Net Load Growth)

Peak Load Increase Influences	Growth
Customer base growth	12%
Global warming effect on winter (annual) peak	-2%
Energy efficiency improvement	-71%
Winter space heating impact of peak load	101%
Increase in water heating on peak load	26%
EV use impact on peak load	29%
Growth of other per-customer uses	4%
Total	100%

Summary and Conclusion

This paper examined the expected impact that electrification (the conversion of fossil fuel energy use to electricity in stationary applications) and EV adoption) the increased use of electric-powered vehicles in both the private sector and business and industry) is expected to have on power distribution systems in large metropolitan areas in the United States over the next 30 years. Due to a combination of improving technology, increasing product appeal, and government policy aimed at reducing greenhouse gas emissions, these trends are expected to accelerate to the point that by 2035 they will substantially increase the annual electric energy sales growth rates in many metro areas, and within the next decade, create noticeable increases in annual peak load growth rates in many of the electric distribution systems serving those areas.

As stated earlier, the authors do not claim that the load forecast given here is quantitatively accurate. There are far too many uncertainties. However, they do think the forecast examined here is representative of the type of load growth local distribution utilities in metro areas will begin to face in the next decade and that qualitatively the conclusions reached here are accurate. To that end, it is worth noting that from the statistics shown in Tables 1 and 3, one can calculate that even if the adoption rates used here were cut in half, EVs and electrification would still create substantial additional growth in annual energy sales, still eventually shift the annual peak load to winter, and still create noticeable increases in the peak load on the local distribution system.

The expected continued increase in the adoption of heat pumps and electric water heating, as well as electric usage for cooking and other appliance use, is the dominant force moving the annual peak load from summer to winter. This electrification of stationary fossil fuel use causes the winter peak to grow much faster than the summer peak, but because the winter peak is currently far less than the summer peak in most utility systems, the annual peak load will not grow at a rate above what it has in the recent past for another decade or more. During this period, annual energy sales will increase at a rate much faster than the annual peak grows. Then, suddenly, the winter peak will exceed the summer peak, and the annual peak load growth rate will be about two to three times what it was in the years leading up to that event. Anticipating and planning for this change in growth or peak capacity needs on the system will be a key to both efficient system expansion and good business performance of the utility.

With respect to EV adoption, the majority of the load growth it creates is expected to be off-peak, but for a variety of reasons, the exact nature of that load, including when and where it occurs, is rather uncertain at this time. Though currently there is an accepted understanding of the charging impact of vehicles, including a large body of data about daily load cycles, there are numerous changes occurring that make historical trends poor indicators of future impacts. It is almost certain that EV batteries will increase in capacity and driving range until EV driving range on one charge equals or even slightly exceeds the driving range that most fossil fuel vehicles have on one tank of fuel today. This will likely change the charging habits of private car owners and businesses alike, from a focus on daily "refueling" to weekly cycles, but exactly how is difficult to predict. Availability of fast-charging options outside of the home—electric filling stations—will also affect where and how vehicles will be charged and how long charging sessions will last. Exactly how the charging infrastructure will develop and operate is difficult to forecast at this time. Finally, electric utility planners must keep in mind that although there are many more light-duty vehicles compared to heavy-duty trucks and buses, heavy-duty vehicles will ultimately consume nearly as much energy as their more numerous, smaller counterparts, with much of that consumption concentrated at distribution centers and business hubs where local load densities, off-peak, could be quite high.

As a result, about all that can be confidently forecast for EV adoption is that it *will* occur, most likely becoming a significant trend of additional annual energy sales growth for LDS utilities by the end of this decade, and probably not affecting peak loads, in summer or winter, to any large extent. However, it appears highly likely that, at many locales within most distribution systems, there will be a need to reinforce local distribution resources due just to that increase in the amount of energy that must be delivered. There will also be intense spot loads in some places, where a dense accumulation of EV owners, or the hubs of large EV fleet operators, will create very dense local peak loads, even if off-peak with respect to system resources, necessitating considerable augmentation of local distribution capability.

Finally, the authors note that in addition to the trends of electrification, EV adoption, and the electric energy and peak load growth they cause, there is another very significant trend affecting local delivery utilities in North America at this time. In the past decade, the availability of effective DER that can be deployed by the utility or contracted with third parties as NWA to traditional T&D construction has markedly increased. The authors doubt these resources can completely service the large increase in energy and peak load expected due to global rising temperatures, electrification, and EV adoption, but they can have a role in reducing the costs and improving the performance of future T&D system expansion needed to serve that load growth. How utilities can integrate DER as a component of the overall grid planning solution will be the topic of the third paper in the series.

This paper is the first of three on the challenges that electrification and EV adoption will create for the industry. The second will cover changes needed in load forecasting and system needs planning that these trends will create for LDS utilities. The third will present a comprehensive process for integrated T&D+DER+NWA planning.