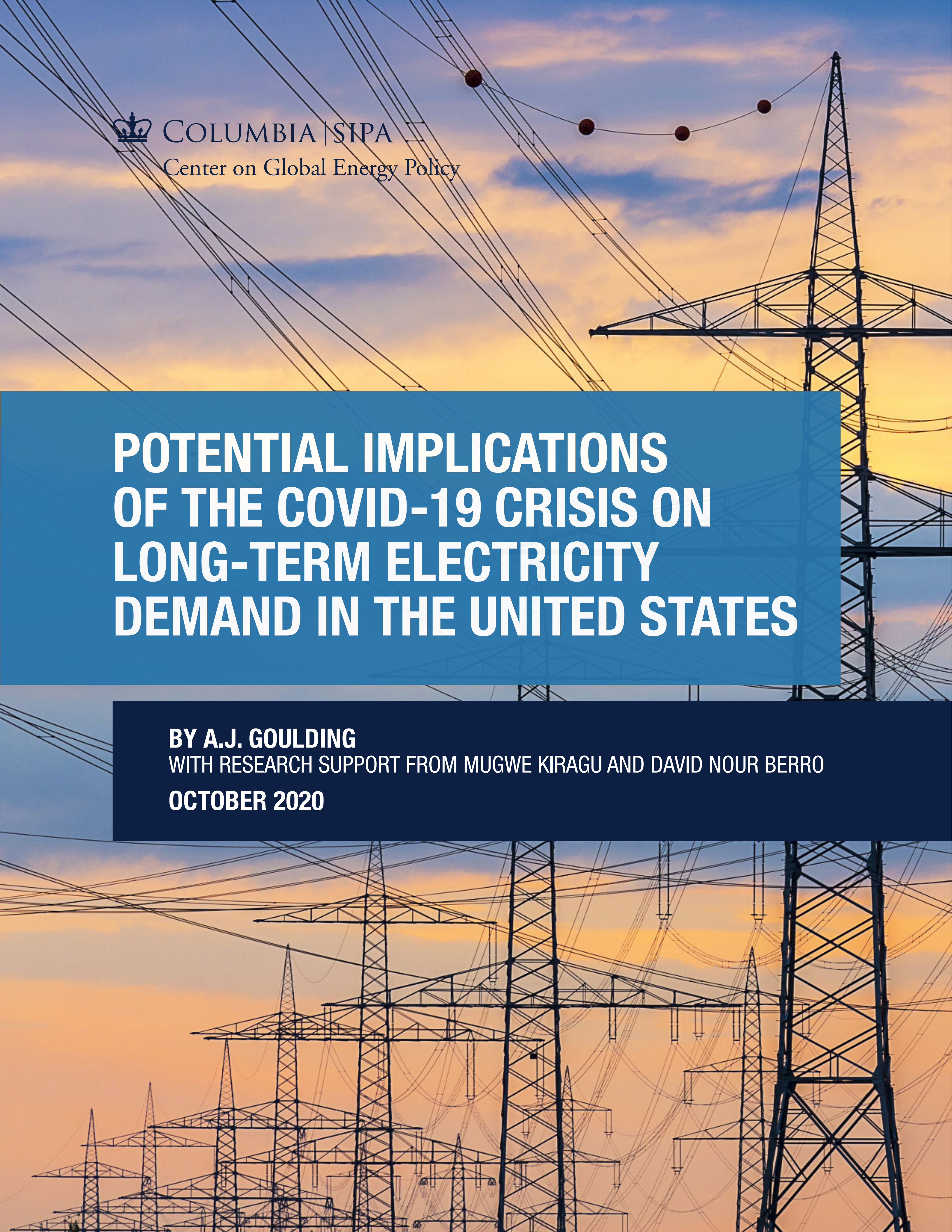

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POTENTIAL IMPLICATIONS OF THE COVID-19 CRISIS ON LONG-TERM ELECTRICITY DEMAND IN THE UNITED STATES

BY A.J. GOULDING
WITH RESEARCH SUPPORT FROM MUGWE KIRAGU AND DAVID NOUR BERRO

OCTOBER 2020

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EXECUTIVE SUMMARY

The ongoing COVID-19 pandemic has caused unprecedented changes in the ways people interact and approach economic activities. Electricity demand has declined and usage patterns have been altered, changes that could remain even after the pandemic ends. Failure to properly account for these declines in demand could lead to excess capacity in the electric power sector, added costs for consumers, and losses for investors.

This paper, from the power sector program at Columbia University's Center on Global Energy Policy, presents a methodology to quantify potential permanent reductions in demand triggered by the pandemic. The authors first identify how electricity demand changed in the United States following the 2008–2009 global financial crisis, or "Great Recession," the last event to cause a major reduction in consumption. They then analyze the unique ways in which demand patterns may change over the next three to five years as a result of the coronavirus, followed by some illustrative calculations of the potential impact. Finally, the authors discuss the implications for policy makers with regard to electricity sector evolution.

The paper finds that the COVID-19 crisis is likely to result in a long-term decline in annual electricity consumption, though less than that observed after the global financial crisis. It is also likely to accelerate changes in the structure of electricity demand that were already underway. In addition, the research shows:

- Patterns of load growth changed significantly after the Great Recession, with average annual consumption (load) growth in the preceding decade (1998–2007 inclusive) of 1.7 percent versus 0.5 percent in the decade after (2010–2019 inclusive);
- Behind-the-meter generation (which is generally a small-scale and often renewable resource installed on a customer's premises) and energy efficiency were the key drivers of the reduction in load growth after the Great Recession, reflecting trends gathering force before the downturn;
- Experience from the global financial crisis suggests that load is unlikely to immediately revert to previous levels following the impact of COVID-19, and that load growth may be further dampened;
- Primary drivers of changes in electricity demand following the coronavirus Great Lockdown are likely to be due to changes in residential demand and shifts in commercial usage, resulting in a potential net incremental reduction in load of 65.2 Terawatt hours (TWh) to 158.8 TWh, or approximately 1.6 to 4.0 percent of US 2018 load; and
- As a result of this potential reduction in demand, all else remaining equal, future need for baseload generating capacity may fall by more than 28 GW.

This paper is intended primarily to explore the magnitude of potential long-term permanent demand destruction due to COVID-19. Because it explores policy implications at a high level, detailed analysis of particular policy recommendations is beyond the scope of the research.

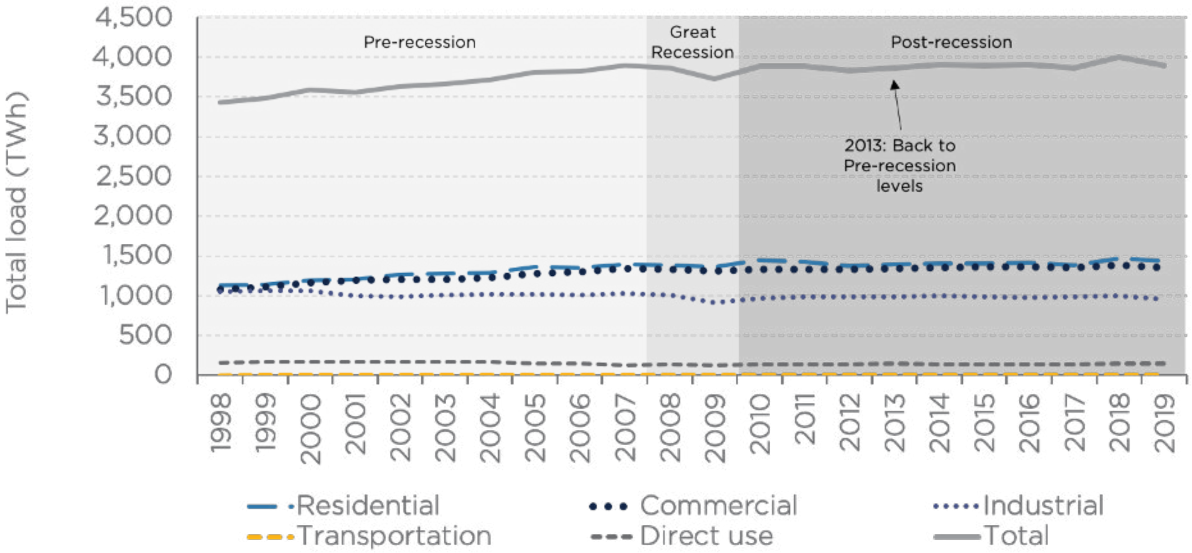
1. CHANGES TO ELECTRICITY DEMAND FOLLOWING THE GLOBAL FINANCIAL CRISIS

To assess the potential impact of the COVID-19 economic crisis on future US electricity load[1] growth, it is useful to examine how US electricity demand changed following the Great Recession. Using the Great Recession as a reference point is not intended to suggest that the economic impact of COVID-19 is exactly analogous. Rather, the intent is to explore changes in load growth after the largest preceding economic shock and assess their magnitude as a means of placing modeled scenarios of potential COVID-related demand destruction in context. COVID's impact on the economy was more sudden and remains far more widespread; unemployment rates are significantly higher.[2] Furthermore, the economic impact of COVID is a result of government-mandated shutdowns affecting all sectors of the economy, rather than a deterioration in the financial sector that impacted various industries differently and more gradually over a more prolonged period.

A review of the literature suggests that while studies have assessed the impact of the recession that followed the financial crisis on natural gas demand in Europe,[3] on carbon emissions in Europe,[4] and on consumption in the provinces of northern China,[5] there are few long-term studies on this topic.

In the years during the Great Recession, i.e., 2008 and 2009, electricity load growth declined by 0.6 percent and 3.7 percent relative to prior years.[6] However, an expansion followed the recession, and by 2013, load in the US had returned to pre-recession levels, i.e., equal to or greater than total consumption in 2007, a recovery period of four years.[7] This is shown in Figure 1, which illustrates total load by customer class. Notably, industrial consumption has not returned to pre-recession levels.

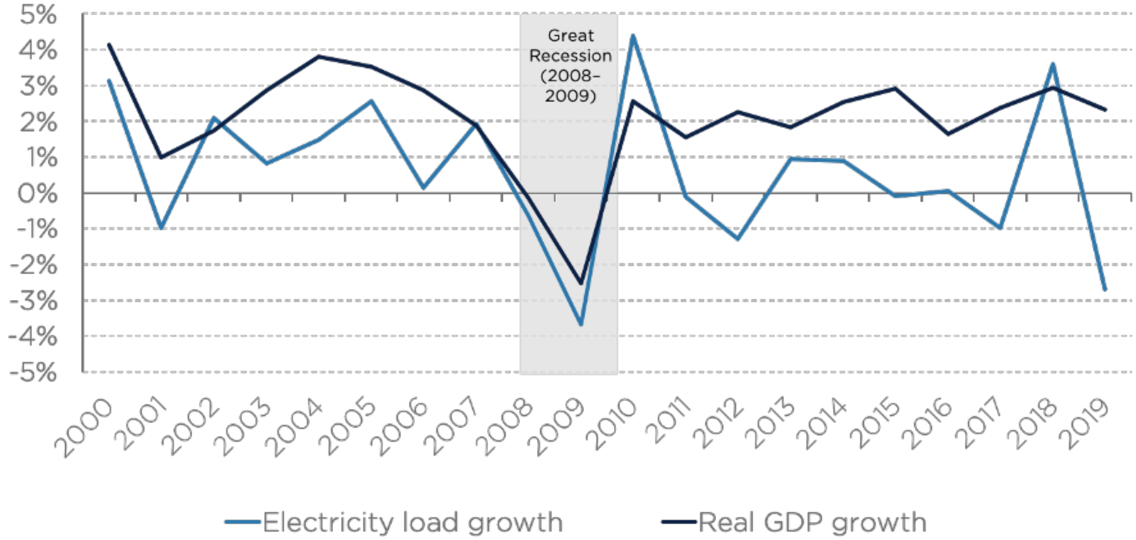
Figure 1: US electricity consumption by customer class, 1998–2019



Sources: Energy Information Administration, Annual Electric Power Industry Report (EIA Form 861), October 2019; Energy Information Administration, Monthly Energy Review, March 2020.

Although the US economy recovered steadily after 2009, the ratio of electricity load growth to real GDP growth dropped. From 1998 to 2007, inclusive, the ratio of electricity load growth to real GDP growth was 0.54; from 2010 to 2019, inclusive, the ratio was 0.21.[8] Had electricity load grown at the same ratio to GDP growth that it did before the Great Recession, electricity load would have been, on average, 64.7 TWh higher.[9]

Figure 2: Annual real GDP growth and electricity load growth, 1998–2019



Sources: Bureau of Economic Analysis, National Income and Product Accounts, Accessed April 2019; Energy Information Administration, Annual Electric Power Industry Report (EIA Form 861). October 2019; Energy Information Administration, Monthly Energy Review, March 2020.

To identify potential explanations for this "missing load," we examined drivers of load growth other than aggregate GDP growth. Several factors can influence electricity load growth in addition to economic activity; for example the number of heating and cooling degree days, the transition of the economy from manufacturing to services, and declines in population growth. Table 1 compares the average annual change in each of these parameters before and after the global financial crisis. Subsequently, we discuss the contribution of other significant trends, such as the increasing materiality of behind-the-meter generation and continuing improvements in energy efficiency, on reducing front-of-meter load.

Table 1: Average change in load growth drivers, 1998–2019

Variable	Units	Pre-recession (1998–2007)	Post-recession (2010–2019)
Heating degree days	Annual average growth rate	-0.6%	0.0%
Cooling degree days	Annual average growth rate	2.5%	2.3%
Share of services as a % of GDP	Period average	42.9%	46.1%
Share of industry as a % of GDP	Period average	20.9%	18.2%
Population growth rate	Period average	1.0%	0.7%

Sources: Bureau of Economic Analysis. National Income and Product Accounts, Accessed April 2019; Energy Information Administration, Annual Electric Power Industry Report (EIA Form 861), October 2019; Energy Information Administration, Monthly Energy Review, March 2020; US Census Bureau, Current Population Survey: Annual Social and Economic Supplement.

The increase in cooling degree days relative to heating degree days can be expected to be mildly supportive of electricity load, since electricity has a greater air conditioning market share than it does for heating. The evolution of the US economy from manufacturing to services would be expected to have the opposite effect, although muted by the impact of growth in electricity-using services such as data centers.[10] This is demonstrated through differences in energy intensity of the industrial sector relative to the rest of the economy over time, where the ratio of load to industrial output is slightly higher than the same ratio for the commercial sector.[11]

Declining population growth is an additional factor weighing on electricity demand. A small portion of the missing load is explained by slower population growth, which impacts residential load growth. Both the US population growth and growth in the number of households have declined in the post-recession period relative to the pre-recession period.[12] If population growth had continued at the same rate as in the pre-recession period, assuming a similar residential per capita consumption as observed in 2018, load would have been on average 14.2 TWh higher, representing an increase of around 1 percent.[13] Regional shifts in population may also have had an impact, though increases in cooling demand caused by shifts in population southward may have been offset by reductions in electric heating demand.

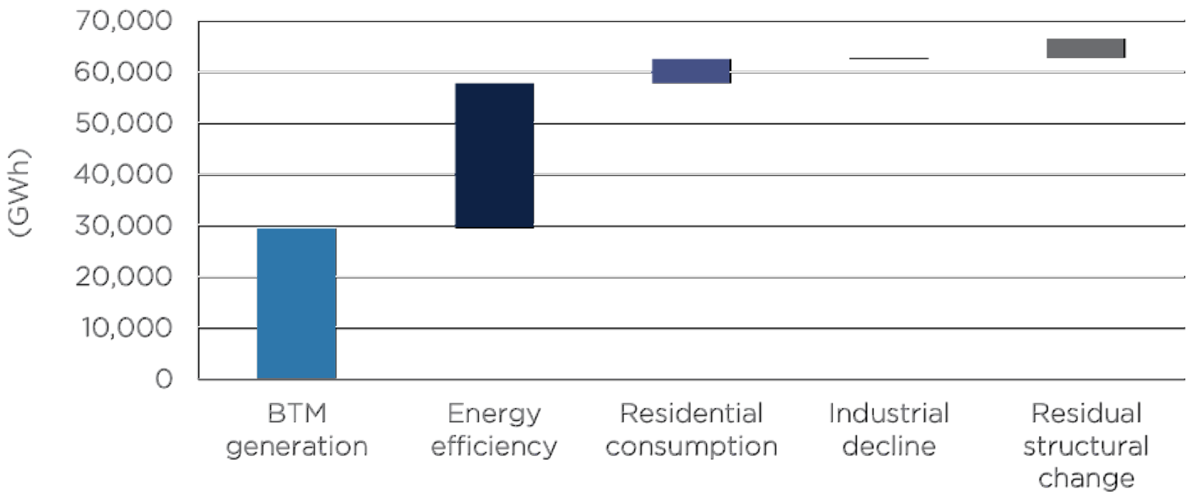
While behind-the-meter incentive programs such as net metering predate the Great Recession in many states, the confluence of declining costs for small-scale and renewable resources coupled with elements of the post-recession stimulus package added momentum to the pace of behind-the-meter investment. Growth in behind-the-meter generation is having a measurable impact in some US regions:[14] the Energy Information Administration (EIA) reports 29.5 TWh of behind-the-meter generation as of end of 2018.[15] However, behind-the-meter generation would only explain 30 percent of the lost load after the Great Recession.

An additional source of declining load growth is continuing improvements in energy efficiency. An increase in energy efficiency standards over time has significantly lowered energy use for appliances across the economy. Most notably, refrigerator standards have driven down energy use per refrigerator among households in the US, with a refrigerator using less than 500 kWh/year in 2015, down from 1,800 kWh/year in 1972.[16] Researchers at the American Council for an Energy Efficient Economy (ACEEE) estimated that federally mandated energy efficiency appliance standards have reduced US consumption by 3.6 percent on average per annum between 1987 and 2010.[17] A similar analysis undertaken by Meyers et al. for the Lawrence Berkeley Laboratory estimated that in 2013, the national impact of energy standards was the equivalent of 3 percent of total US energy consumption.[18] Changes in standards have been augmented by incentives and initiatives from the federal government, such as the US Department of Energy's Better Buildings program and regulatory mandates on utilities to include energy efficiency in long-term resource planning. Technological and institutional change also played a role, including both the development of smart meters and the evolution of aggregators to help customers benefit from energy savings.

Increasing energy efficiency savings from electric utilities and differences in energy intensity in sectors of the economy may explain much of the rest of the lost load. Since the EIA began reporting on energy efficiency savings from the electric power industry in 2008, utilities have reported an annual average increase of just below 12 percent between 2008 and 2018.[19] In 2018, the EIA reported 28.4 TWh of incremental energy efficiency savings.[20]

Figure 3 shows the impact of the various potential contributors to slowing load growth following the Great Recession. To start, the authors calculate what load would have been had GDP electricity intensity remained unchanged. The actual load in 2018 and the hypothetical load in 2018 (had the load grown at the same load-to-GDP ratio as in the pre-recession period) are considered. The 66.5 TWh "missing" load can largely be explained by behind-the-meter generation and increasing energy efficiency, which together are responsible for 87 percent of the total. The residual is attributed to other factors discussed above, including structural changes in the US economy and slowing population growth relative to the pre-recession period, leading to a reduction in residential load.[21]

Figure 3: Illustrative impact of structural and sector shifts since 2009 on load in 2018



Sources: Energy Information Administration, Annual Electric Power Industry Report (EIA Form 861), October 2019; Energy Information Administration, Monthly Energy Review, March 2020.

Indeed, most recent demand outlooks from independent system operators (ISOs) across the US incorporate these trends, as forecasters widely expect these to be key drivers of load growth in the medium- to long-term. While the Great Recession may not have been the cause of any of these factors, it likely accelerated trends that were already underway. In turn, many of these trends have already been internalized in load forecasts performed prior to the COVID-19 crisis. However, as will be discussed below, COVID-19 may likewise hasten other trends that contribute to demand destruction.

2. GENERALIZED NEAR-TERM IMPACT OF COVID-19

Before considering the long-term impact of COVID-19 on electricity demand, it is useful to summarize the observed short-term impacts. Prior to COVID-19, most ISOs were predicting moderate growth. Table 2 summarizes the most recent demand outlooks released prior to the onset of the economic crisis triggered by the Great Lockdown. The numbers shown in Table 2 are consistent with those of the US Energy Information Administration's most recent *Annual Energy Outlook* released in January 2020, which for the US as a whole was projecting load growth of 0.9 percent in 2020, and annual average growth of 0.8 percent projected for the 2020–2050 horizon.[22] Permanent structural changes to electricity load could result in these outlooks being adjusted materially lower.

Table 2: ISO demand outlooks before economic crisis resulting from COVID-19

ISO/Planning Authority	Description	Long-term load forecast	Key drivers described (non-exhaustive)
California Energy Commission	• Forecast peak demand and electricity sales • Mid-case presented, forecast 2020–2030	• Peak demand CAGR: 0.2% • Energy demand CAGR: 1.5%	• Behind-the-meter generation • Storage technologies • Increased electrification
ISO-New England	• Forecast peak load and (net reductions for energy efficiency and BTM solar) • Forecast for 2020–2029	• Peak demand CAGR: 0.1% • Total energy CAGR: 0.4%	• Growth in energy efficiency and behind-the-meter generation
Midcontinent ISO	• Gross MISO system energy and non-coincident peak forecast • Forecast for 2020–2029	• Non-coincident peak CAGR: 1.0% • System energy CAGR: 1.0%	• State-specific drivers including economic growth and weather factors
New York ISO	• Long-term energy usage and summer peak forecast • Forecast for 2020–2050	• Summer peak annual average growth: -0.09% • Energy use annual average growth: 0.05%	• Behind-the-meter generation • Energy efficiency • Electrification and weather trends
PJM	• Independent forecast of load, summer and winter peak • 15-year forecast for 2020–2035	• Summer peak annual average growth: 0.5% • RTO net energy forecast average growth: 0.7%	• State-specific factors including economic growth, increase in BTM generation and energy efficiency measures
SPP	• Non-coincident peak and energy forecast • Forecast for 2020–2029	• Non-coincident peak CAGR: 0.06% • System energy CAGR: 0.92%	• State-specific factors including energy efficiency and economic growth

Sources: California Energy Commission, 2019 Integrated Energy Policy Report, February 2020; ISO-NE; MISO, 2019 MISO Energy and Peak Demand Forecasting for System Planning, November 2019; NYISO, 2020 Load and Capacity Data, March 2020; PJM, PJM Load Forecast Report, January 2020; SPP.

The near-term impact of COVID-19 on weather-adjusted load is increasingly well documented. As the crisis emerged in March, ISOs began to report declines in load, with Midcontinent ISO (MISO) showing a 9–13 percent decline in daily weekday demand relative to temperature comparable days in March 2019.[23] Similarly, the New York ISO (NYISO), serving one of the states hardest hit by the pandemic, has indicated a weather-normalized reduction in March and early April of 4–8 percent below expected demand.[24] Table 3 illustrates estimates of the demand impacts for each ISO as of May 30, 2020.

Table 3: Demand impact of COVID-19 across US ISOs

ISO	Description	Period observed	Demand impact from COVID-19
CAISO	Weather-normalized evaluation of full stay-at-home orders	March 17 to May 24	Weekday reduction: 4.2% Weekend reduction: 1.4%
ISO-New England	Weather-normalized assessment	March 1 to May 23	Reduction of 3–5% in demand
Midcontinent ISO	Declines relative to temperature-comparable days	Late March to early April	Daily weekday demand decreased 9–13%
New York ISO	Weather-normalized reduction	Week of March 8 to Week of May 23	Reduction of 4–9% below expected demand
PJM	Weather-normalized assessment based on complete data available	March 1 to May 26	Weekday reduction: 10%, Weekend reduction: 2–4%
SPP	Compared to similar days in recent years with temperatures within 3 degrees	April 26 to May 14	Load reduction of 7–10%

Sources: CAISO; ISO-NE; MISO; NYISO; PJM; SPP (as of May 30, 2020).

While the near-term impact is dramatic, and may persist to some degree for as long as a year, data from the global financial crisis as shown in Figure 1 suggests that after a major economic shock we should not expect load to immediately revert to previous levels, nor should we expect long-term load growth patterns to re-establish themselves. Although the events differ greatly, the four-year period that it took load to recover after the Great Recession provides a planning benchmark for thinking about deferring or reconfiguring future power sector investments.

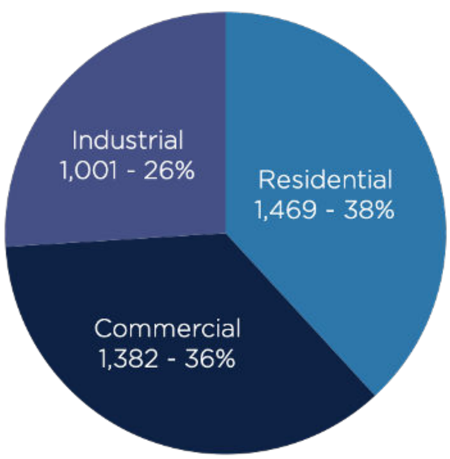
3. CHANGES IN DEMAND PATTERNS ACCELERATED BY THE COVID-19 CRISIS

We expect that primary drivers of incremental changes in electricity demand after the Great Lockdown will be due to changes in residential demand and shifts in usage among commercial customers.[25] Industrial load may revert to trend, with long-term energy efficiency measures moderating growth. An increase in permanent work-from-home arrangements may flatten load shapes, without increasing residential load greatly. However, the allocation of load among commercial users may change significantly as the retail sector shrinks, balanced by an increase in warehouse and logistics space dedicated to e-retailers. Although over time some retail spaces may be repurposed, subsequent uses are likely to be less electricity intensive. Office space may be less impacted, as moderate increases in permanent work-from-home positions are balanced by a perceived need to increase minimum workspace area to provide ongoing social distancing. These changes will likely take time to be fully realized; for example, some companies may wait until the end of their leases before implementing reductions.

To explore the impact of these trends in greater detail, this section presents some background on each; the following section utilizes data presented to design scenarios regarding the impact these trends may have on long-term electricity demand.

When considering load growth, it is important to first understand the composition of load. Figure 3 shows the share of electricity demand by customer class, illustrating the importance of residential and commercial load in future load growth scenarios.

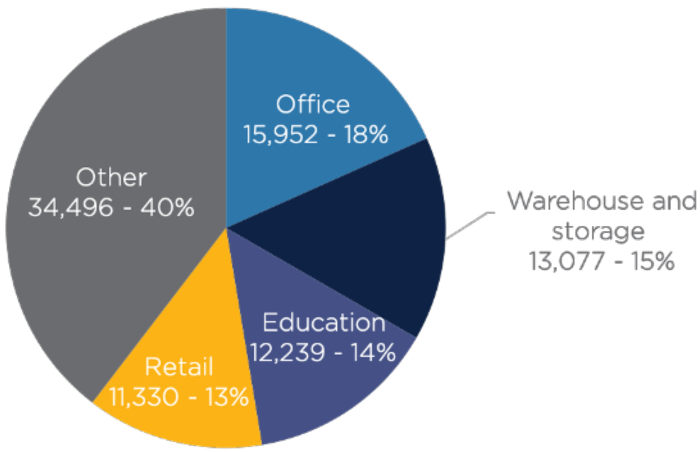
Figure 4: US electricity demand by customer class (TWh) and share in 2018



Source: Energy Information Administration, Electric Sales, Revenue, and Average Price. (Data from forms EIA-861- schedules 4A, 4B, 4D, EIA-861S and EIA-861U.).

After understanding how load is categorized at a high level, it is necessary to delve more deeply into attributing load within each customer class to various customer types. To explore how changes in commercial space utilization could impact future load, the authors examined square footage and energy intensity for a range of commercial uses. There are approximately 87 billion square feet of commercial space in the United States, based on the EIA's latest survey of commercial buildings. As Figure 5 shows, four categories stand out: (i) offices, (ii) warehousing and storage, (iii) education, and (iv) retail.[26] Industrial properties contribute another 20.7 billion square feet of space.[27] Office and retail are highlighted, as these are the focus of subsequent analysis.

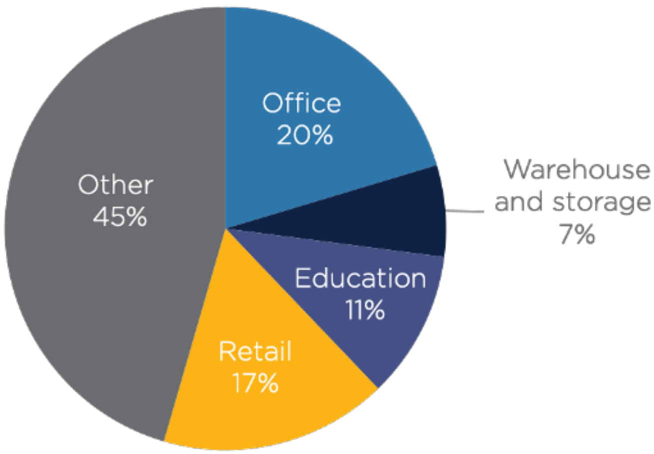
Figure 5: Breakdown of US commercial space (million sq. ft.)



Source: Source: Energy Information Administration, Commercial Buildings Energy Consumption Survey, May 2016, https://www.eia.gov/consumption/commercial/data/2012/bc/cfm/b23.php.

A survey released by the EIA in 2016 identified the energy consumption of each commercial subsector in the US by building activity. Retail activities constitute approximately 17 percent of electricity consumption in the commercial sector, compared to approximately 3 percent for distribution and shipping centers, which falls under the "warehouse and storage" category.

Figure 6: Breakdown of US commercial electricity demand



Source: Energy Information Administration, Commercial Buildings Energy Consumption Survey, May 2016, https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/pba4.php.

Based on US Department of Energy data on energy usage for commercial buildings, 16 main building types can be identified, which represent over 70 percent of all commercial space in the US, shown in Table 4. For our scenario design, we focused on the office, retail, and hotel categories, as we believe these will be among the sectors most affected by lasting changes in business and consumer behavior.

Table 4: Identified commercial building types and energy intensities (electricity consumption from utilities only)

Building type	Energy intensity (kWh/sq. ft.)	Average floor area (sq. ft.)	Number of floors
Large office	**16.5**	498,588	12
Medium office	**17.3**	53,628	3
Small office	**16.5**	5,500	1
Warehouse	**4.3**	52,045	1
Stand-alone retail	**22.2**	24,962	1
Strip mall	**23.7**	22,500	1
Primary school	**15.4**	73,960	1
Secondary school	**19.8**	210,887	2
Supermarket	**46.7**	45,000	1
Quick service restaurant	**79.3**	2,500	1
Full service restaurant	**64.8**	5,500	1
Hospital	**53.7**	241,351	5
Outpatient health care	**41.1**	40,946	3
Small hotel	**18.6**	43,200	4
Large hotel	**42.6**	122,120	6
Midrise apartment	**8.5**	33,740	4

Source: Source: US Department of Energy, Commercial Reference Buildings, Reference Buildings by Climate zone and Representative City, https://www.energy.gov/eere/buildings/commercial-reference-buildings.

Note: These 16 building types represent approximately 70% of the commercial buildings in the US, according to a report by the National Renewable Energy Laboratory. Data shown is representative of the climate of City of Atlanta, Georgia.

The COVID-19 crisis can be expected to accelerate trends that were already apparent with regard to commercial space utilization, particularly in the retail sector. Nielsen reports that both retail store count and store sizes have declined recently. Through 2017–2018, 2,248 major stores closed, after significant growth through 2010–2017. Moreover, the square footage per store has declined 4.7 percent over 2010–2018, or 0.6 percent per year.[28] Between Q2 2019 and Q4 2019, general retail total square footage declined by 2 percent.[29] As of Q4 2019, the US had a total gross leasable area (GLA) between 11 and 14 billion square feet of retail space.[30] The US also has the highest number of GLA per capita in the world, at 20–23 square feet per person—significantly larger than other developed economies (see Table 5). This suggests that retail space per capita could fall significantly without harming consumer welfare; these international comparisons are used as one of the inputs to the scenario designs discussed below.

Table 5: Comparison of gross leasable area per capita in developed economies

Country	Gross leasable area per capita (sq. ft.)
United States	23.5
Canada	16.4
Australia	11.1
United Kingdom	4.6
France	3.8
Italy	2.8
Germany	2.4

Sources: Cowen & Company, via The Atlantic: What in the World Is Causing the Retail Meltdown of 2017?, April 2017, https://www.theatlantic.com/business/archive/2017/04/retail-meltdown-of-2017/522384/; Morningstar, via the New York Times: Why we should be optimistic about retail, April 2018, https://www.nytimes.com/2018/04/13/business/dealbook/retail-industry.html.

Retail and logistics demand are interrelated. Online shopping has been driving an increase in demand for warehouse space. Through 2012–2018, demand exceeded the supply of industrial and logistics area, leading to 34 consecutive quarters of "positive net absorption."[31] Retail activities consume almost five times as much electricity per square foot compared to logistics. For example, a warehouse on average consumes 4.3 kWh/sq. ft. per year, whereas a stand-alone retail store consumes 22.2 kWh/sq. ft.[32] As described below, the scenario design assumed that retail store closings are not accompanied by any additional need for logistics space, as these stores were already served by distribution centers which would be repurposed. However, given the relative energy intensity, even if some growth in logistics occurred as a result, it would have minimal impact on load. Furthermore, load forecasts prior to the COVID-19 crisis already assumed continued expansion of the logistics sector.

In addition to changes in the retail sector, the scenarios in this report include changes in how offices are used. Though some companies may deploy measures such as alternate day in office schedules, additional square footage per employee may be required to enforce social distancing, even as companies otherwise seek to reduce their office footprints. Offices had been increasing the density of employees in workspaces. It is estimated that in 2017, North American offices averaged approximately 150 square feet per worker, down from 176 square feet/worker in 2012 and 225 square feet/worker in 2010.[33] Additionally, Jones Lang LaSalle, a commercial real estate professional services firm, reports that up to 325 square feet per worker was allocated in office plans during the early 2000s, compared to 75–150 square feet allocated in recent office plans.[34] The need to increase square footage per worker in dense office spaces may be more pressing; for example, to enforce physical distancing requirements, it is estimated that at least an extra 20 to 40 square feet may need to be added to each open-plan desk.[35] As discussed further below, however, any potential increase in square footage per capita is offset by an increasing number of employees working permanently from home.

The scenarios discussed subsequently are differentiated, among other factors, by differences in the impact on the hospitality sector. The long-term effects of COVID on the hospitality sector, including hotels and restaurants, may be muted, depending when a vaccine becomes available. While demand destruction is anticipated over 2020–2021, a recovery to 2019 rates is anticipated by some observers as soon as 2023. According to recent forecasts from the April 2020 edition of CBRE Group's US lodging industry baseline forecast, hotels are anticipated to witness "rapid economic turnaround" starting in 2021. CBRE anticipates that by 2023, occupancy rates, average daily rates, and revenues per available room will recover to 2019 rates.[36] Occupancy rates are shown in Table 6. Additionally, social distancing requirements may lead to a decline in the energy intensity of these hotels, as demand for amenities at larger hotels, such as gyms, swimming pools, and ballrooms, may decline. Hospitality architects are identifying a need for changes to hotel layouts and amenities to minimize contact, such as: (i) the removal of check-in areas, replaced by technologies that are phone-enabled, (ii) combining multiple venue types into a single venue that can accommodate multiple functions, (iii) extended grab-and-go options for diners instead of restaurants, and (iv) removing gyms and providing in-room, on-demand exercise equipment.[37]

Table 6: Historical and forecasted hotel occupancy rates

Year	Occupancy rate
2018	66.1%
2019	66.1%
2020 (forecast)	41.0%
2021 (forecast)	55.9%
2022 (forecast)	65.0%
2023 (forecast)	66.6%

Source: "CBRE Hotels Research: Full demand recovery by late 2022," Hotel Management, May 21, 2020, https://www.hotelmanagement.net/operate/cbre-hotels-research-full-demand-recovery-by-late-2022.

We expect the impact of COVID-19 on commercial load growth will reinforce the patterns that were already taking shape, such as declining retail space and increasing warehouse space. Conversely, the trend of increasing employee density is likely to be slowed as a result of the need to enforce physical distancing within office spaces, even as more employees opt to or are transitioned to work from home.

4. ILLUSTRATING THE POTENTIAL IMPACT OF THESE CHANGES

To gain an understanding of the potential magnitude of these changes, the authors created a Coronavirus Load Reduction Impact Model (CLR-IM). While a number of simplifying assumptions are used, the intent is to provide an understanding of the magnitude of potential long-term demand destruction from the COVID-19 crisis. Two cases are distinguished by the extent of permanent work-from-home transitions and changes in allocated office space per employee, as well as differences in the retail sector. For the purposes of this analysis, the pace of behind-the-meter generation additions is assumed to be the same in each case.

4.1 Moderate-Impact Case

The following assumptions were used:

- 10.8 percent of office workers transition to working from home permanently;[38]
- The observed increase in residential load due to work-from-home orders was 8.9 percent, and the proportion of that increase which persists is consistent with the proportion of workers who remain working from home;[39]
- Demand for office space changes consistent with the proportion of workers remaining at home, as calculated above, adjusted for increases in the amount of space allocated per employee for social distancing. Office space per employee for those remaining in traditional office settings increases by 10 percent;[40]
- Retail space per capita falls by 30.2 percent, to the level of Canada;[41]
- No growth in warehousing and logistics space linked to COVID-19 takes place, as the stores that are assumed to close are already served by warehousing and logistics, which are reoriented to direct shipping;[42]
- Electricity consumption per square foot by type of commercial space remains unchanged;
- Load from the industrial sector,[43] as well as hospitality sector (hotels and restaurants), reverts to pre-pandemic levels; and
- 2019 load is used as a baseline.

The long-term load impact is then as follows:

- Residential load can be expected to increase by 3.4 percent relative to pre-coronavirus levels, or 49.0 TWh, driven by permanent changes in workforce habits;
- Load from office buildings is expected to decrease by 1.9 percent, as reductions in employees working from offices is significant enough not to be offset by increases in square footage allotted to the remaining employees, leading to a decrease of 3.6 TWh;

- Load from retail stores falls by 110.6 TWh;[44] and
- The combined impact of these changes is a reduction of 65.2 TWh, or the equivalent of 11.4 GW of generating capacity at a 65 percent capacity factor.[45] This is in addition to the impact of energy efficiency and other measures already incorporated into existing ISO forecasts. It is similar in magnitude to the entire "missing load" from the 2009-2018 period, and may occur more rapidly.

4.2 High-Impact Case

The following assumptions were changed for a high-impact case:[46]

- 25 percent of office workers transition to working from home permanently, and employers do not make any adjustments to the amount of square footage allotted per remaining employee;
- As a result of a larger proportion of workers remaining at home, and the lack of physical distancing measures, office space needs and load fall consistent with the percent of office workers working from home;
- Retail space per capita falls by 52.7 percent from current levels, to the level of Australia, which is 32.3 percent lower than the level assumed in the moderate-impact case;[47]
- In the hospitality sector, the energy intensity (kWh-year/sq. ft.) in large hotels decreases by 28.1 percent, as load from larger hotels is reduced by half of the differential between large and small hotels, since large hotels that contain multiple facilities that enable large congregations (ballrooms, conference rooms, gyms, swimming pools) would need to close the facilities or operate them at a reduced capacity; and
- 2019 load is used as a baseline as well.

The long-term impact on electricity load is then as follows:

- Residential load is higher than the moderate impact case, increasing by 7.9 percent, or 113.5 TWh;
- Load from office buildings is expected to decrease by 25 percent or 47.5 TWh, a significantly greater decline than the moderate impact case;
- Load from retail stores falls by 193.2 TWh, driven by a 52.8 percent decline in retail space;
- Load from large hotels decreases by 32.6 TWh, as the energy intensity of larger hotels declines by 28.1 percent; and
- The combined impact of these changes is a reduction in load of 159.8 TWh, or the equivalent of 28.1 GW of generating capacity at a 65 percent capacity factor. This exceeds the total amount of new capacity added in the US in 2019, which was 23.6 GW.[48]

A comparison of the long-term demand impact by sector for each scenario is shown below in Figure 7.

Figure 7: Summary of long-term demand impact drivers and net demand effect

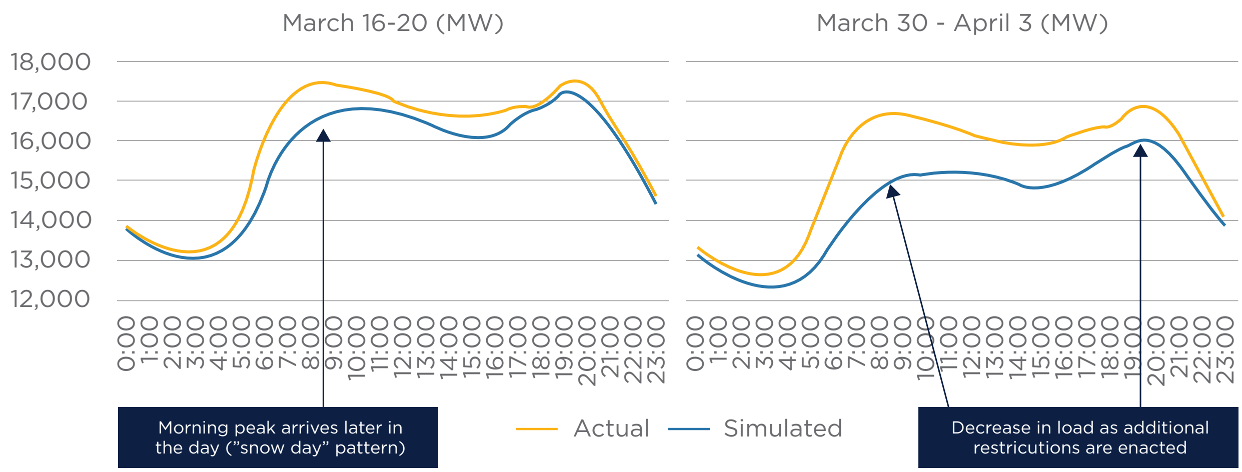
Source: Authors' calculations.

4.3 Changes to Load Profile

There will also be a change in peak load as a result of changes in the underlying load shapes. While detailed projections of changes in load shapes is beyond the scope of this paper, increasing residential load during the day will change the residential load shape, while declining commercial load (albeit with little change in its shape) will change the relative influence of the two load curves on the composite load curve. As a result of the changing consumption patterns driven by COVID-19, i.e., increased share of work-from-home and reduced commercial and retail activity, the morning peak may be shifted later. Residential electricity demand is anticipated to increase during the daytime hours, as more individuals work from home, increasing midday residential load but spreading the afternoon peak over a greater number of hours.

ISOs have analyzed changes in load shapes due to stay-at-home orders. In some jurisdictions, a "snow day" (a day in which travel is restricted due to inclement weather) pattern has been observed, with system operators reporting a morning peak arriving later in the day as a result of COVID-19. New York ISO's modeled impact of COVID-19 to the load profile of the state suggests later morning peaks, with the largest observed decline occurring in the morning (see Figure 8).

Figure 8: System-wide load shape impact in New York ISO



Source: New York ISO, Impacts of COVID-19 on NYISO Demand: Information current as of 4/6/2020, April 13, 2020.

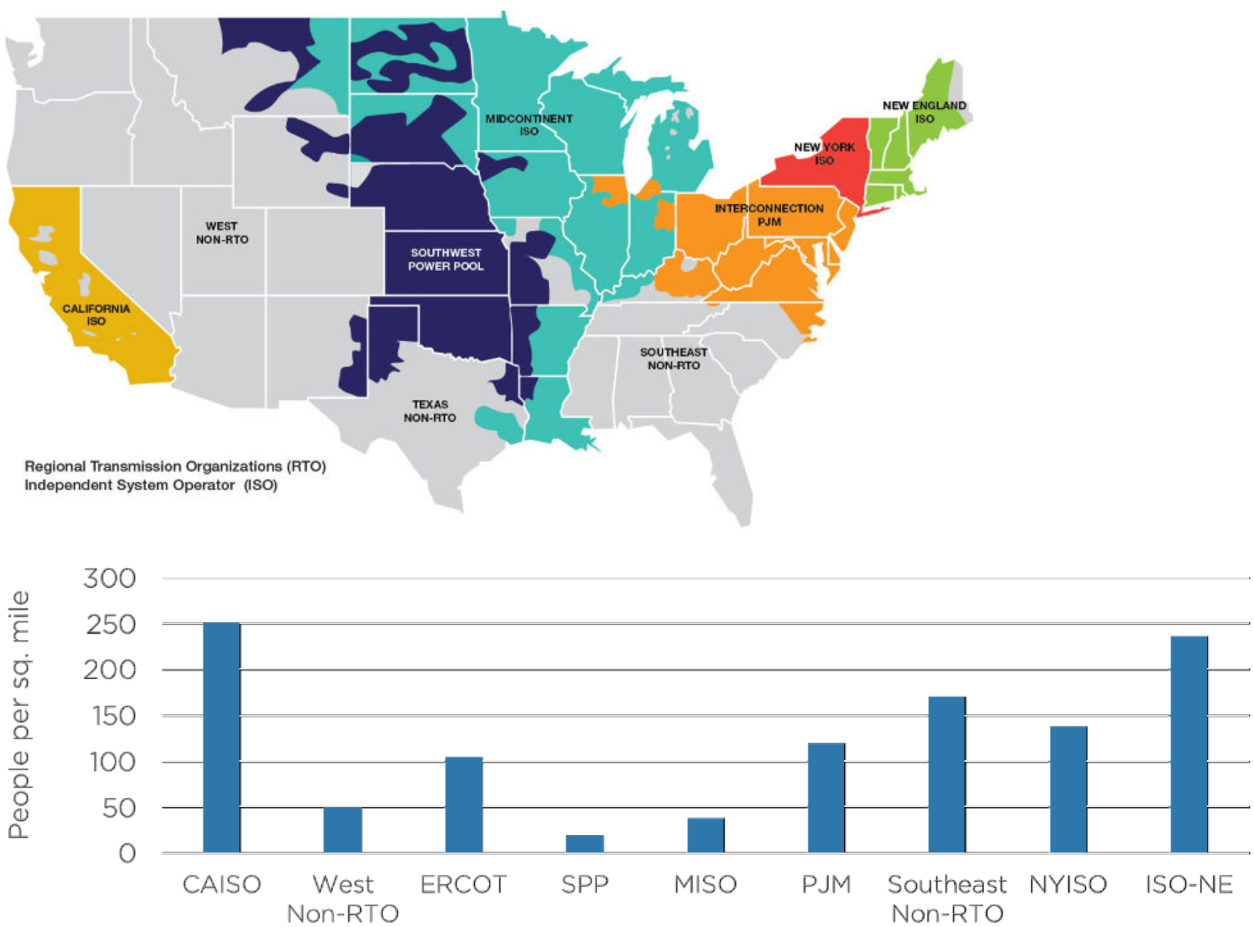
The Electric Reliability Council of Texas (ERCOT), the ISO which covers much of Texas, has observed similar patterns. Since April 2020, ERCOT has released a COVID-19 impact analysis report, updating the analysis weekly. The analysis shows that in all weeks of April and May 2020, loads were between 5–10 percent lower in the hours between 6 and 10 a.m. than a backcast model would predict. The largest deviations occur between 7 and 8 a.m. In April, daily peaks were lower by 4–5 percent.[49] Similarly, in California, the California ISO (CAISO) that operates most of the state's grid reported on the impact of COVID-19 to load and markets for the period between March 17 and July 26. In its analysis, the ISO reported weekday average load reductions of 2.4 percent, and the largest percent reductions occurring between 7 a.m. and 12 p.m.[50]

Changes in the timing of peak load and the rate at which load increases or decreases pose challenges to system operations in determining the appropriate mix of power plants to operate; the more that patterns deviate from historical behavior, the harder it is for ISOs to optimize the power system.

4.4 Demographics Will Cause Regional Variation in Impact Levels

While the results presented here are on a national level, the impact could vary widely across regions, with the greatest changes in load concentrated in more populous regions. This suggests that California, New England, New York, and parts of PJM could be more affected; areas of the Midcontinent Independent System Operator (MISO) and the Southwest Power Pool (SPP), less so. This is further exemplified via an overlay of US population density on top of a map of ISOs and regional transmission organizations (RTOs) in the US, shown in Figure 9.

Figure 9: Population density of US ISOs and RTOs



Source for graphic: FERC, Electric Power Markets, https://www.ferc.gov/market-assessments/mkt-electric/overview.asp;Source for population density data calculated using population and area data from US Census Bureau: 2010 Census of Population and Housing, 2010, September 2012, https://www.census.gov/prod/cen2010/cph-2-1.pdf.

5. CAVEATS

The results in this paper are based on only one range of indicative assumptions; robust scenario analysis would be required on a region-by-region basis to fully validate the conclusions. Seasonal variations have not been captured given the short period of observation. Furthermore, the calculations rely on data from a variety of sources; category definitions may not be consistent across sources. Impacts are expected to vary widely depending on the characteristics of specific utility service territories.

Some commentators have speculated on the potential for de-urbanization following the COVID-19 crisis. Were this to occur, the authors believe that the effect would be to redistribute load regionally, but at the lower level implied by the scenarios explored here, even if residential living space per capita increases. As a result, the impact would be more a matter of changing patterns of regional transmission congestion and offsetting regional increases and decreases in load, but at a lower consolidated total. Because there is not yet sustained empirical evidence of such a shift, the authors have not included it in the analysis.

The scenarios did not explore changes to the education and restaurant sectors, both of which could see long-term structural changes. Closings of many small colleges are possible, as is an increase in online-only degree programs. While the authors assume that the restaurant sector will return to pre-COVID levels once a vaccine is found, with bankrupt locations replaced by new outlets, some permanent demand destruction may take place in this sector as well.

The pace of transportation and heating electrification was one of the primary uncertainties for load forecasting prior to the COVID-19 crisis, and continues to be so thereafter. As the text box shows, assumptions regarding increasing load from electric vehicles (EVs) and heating were projected to add significant load. In some ISOs, transportation and heating account for all of projected load growth and make up for declines due to energy efficiency.

Electrification Estimates Vary Greatly

Assumptions regarding rates of electrification, specifically with respect to transportation and heating, vary greatly among planners and policy makers. For instance, recent literature demonstrates that current EV penetration outlooks from institutions such as the EIA, International Energy Agency (IEA), and Bloomberg New Energy Finance vary by nearly five times for a time frame as soon as 2030. Similarly, US ISOs have incorporated various scenarios for the rate of transportation and heating electrification. Table 7 summarizes the most recent forecasts among northeastern ISOs.

Table 7: Electrification estimates among US ISOs

ISO or planner	Forecast description	Forecast total
ISO-New England	2020 Heating Electrification Forecast	Cumulative 1,715 GWh by 2030 and 661 MW added to winter peak
ISO-New England	2020 Transportation Electrification Forecast	Cumulative 1,728 GWh by 2030 and 414 MW added to winter peak
New York ISO	Power Trends 2019 (Electric Vehicles)	Increase energy use by 4.2 TWh by 2030, and 650 MW added to winter peak
PJM	PJM Load Forecast Report 2020 (Plug-In Vehicles)	1,248 MW increase to load by 2030

Sources: Foss, M. & Zoellmer, K. Will Electric Vehicles Transform Distribution Networks? Only Time will Tell. IAEE Energy Forum. Second Quarter 2020; ISO-New England. 2020 Heating Electrification Forecast. 2020; ISO-New England, 2020 Transportation Electrification Forecast. 2020; NYISO. Power Trends 2019." 2019.

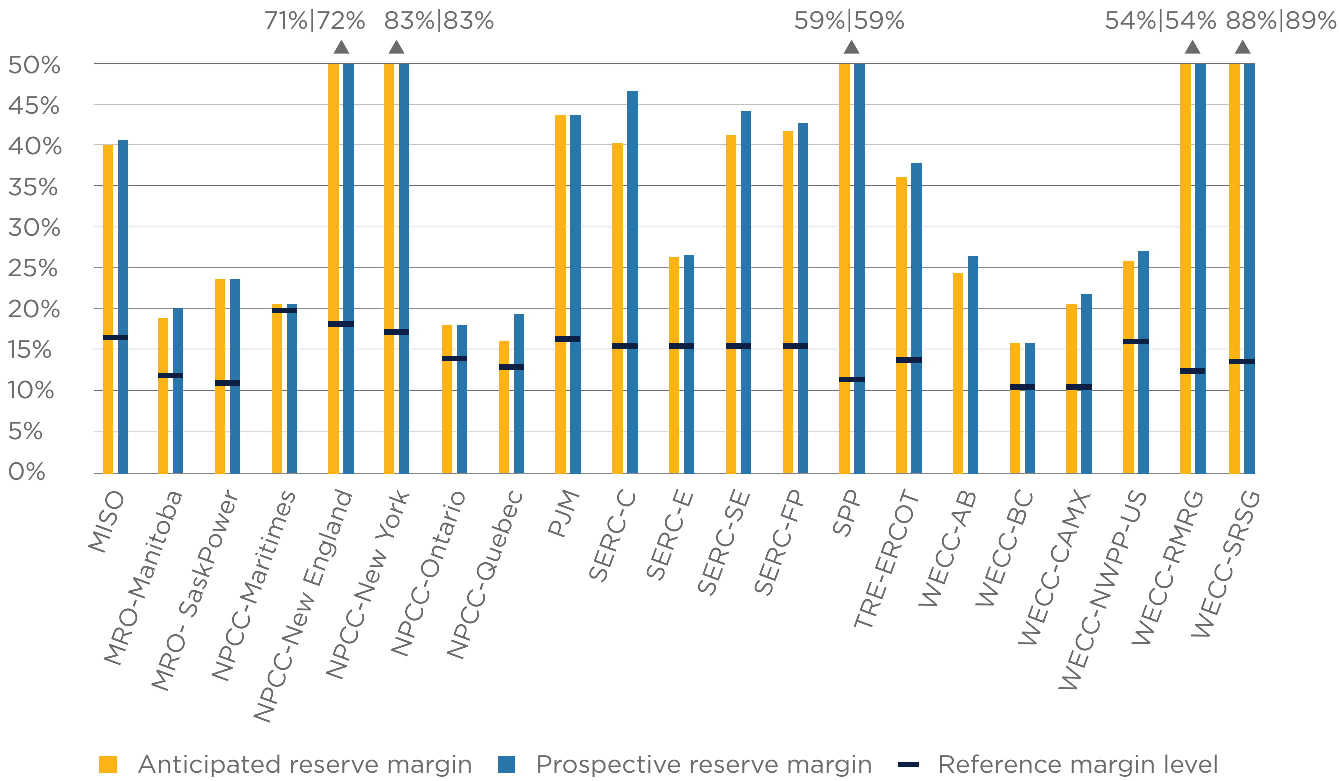
Consequently, much depends on the nature of any potential infrastructure focused stimulus package.[51] Such a package could occur by first quarter 2021, with the resulting investments being made in a two-year period from 2021–2023. A package that includes incentives for small-scale, renewable, behind-the-meter generation coupled with significant energy efficiency measures would further dampen load; one that focuses on accelerating electric vehicle purchases and heating system conversions to electricity could jump start load growth.

6. IMPLICATIONS FOR POLICY MAKERS

The illustrative impacts on load growth and load shape in this paper, if ultimately realized, have several implications for policy makers. Each could be the subject of a paper in its own right. For example, the question of whether the stimulus package following the Great Recession was of sufficient size has direct relevance for design and sizing of stimulus packages following the Great Lockdown; in turn, the size and design of such packages will impact the extent of demand destruction or substitution. The intent of this paper is rather to highlight that permanent demand destruction has implications for a range of policy choices, many of which were under study prior to COVID-19. These policy areas include the following:

- ISOs will need to revise their demand outlooks and, subsequently, the ***capacity mechanism target procurements (for those regions that have them) will need to be adjusted to reflect long-run demand destruction***. In 2019, capacity cost consumers in New England and PJM alone a total of $12.4 billion.[52] Reducing this number could provide meaningful savings to consumers. Total capacity procured is a function of peak load forecasts and target reserve margins. In some regions, substantially less capacity may be required. Even prior to the COVID crisis, reserve margins in many ISOs were robust, as shown in Figure 10. Essentially all ISOs and RTOs except ERCOT have had reserve margins well exceeding their reference margin levels. Increases in distributed energy resources (DERs) may be exacerbating this issue, as ISOs currently have little insight into the quantity and operating regimes of resources connected at the distribution level. ISOs have a natural bias toward using higher load-growth forecasts, as their incentives are asymmetrical: they receive little credit if the lights stay on, but significant criticism when blackouts occur. State regulators, the US Federal Energy Regulatory Commission (FERC), and rate case intervenors will need to carefully scrutinize the peak load forecasts underlying future capacity auctions. Independent Market Monitors (IMMs) should also increase their scrutiny of load forecasts, bearing in mind the potential for permanent demand destruction due to COVID-19.[53]

Figure 10: Winter 2019–2020 reserve margins and reference margin levels



Source: North American Electric Reliability Corporation, 2019 State of Reliability, June 2019.

- ***Static definitions of peak and off-peak hours may need to be revisited.*** As load shapes evolve, the traditional association of peak hours with a set period of time during the day may change. The peak/off-peak designation has always been a crude approximation for the times of day when usage was highest; ultimately, instead of linking pricing to particular set hours, it may be more beneficial to associate commodity and network pricing more dynamically with metrics such as hourly load as a percent of the daily average usage per hour. Static peak/off-peak definitions can be found in a variety of contexts, from design of time of use rates to the definition of hours used in trading blocks. While some observers have highlighted the changing market dynamics caused by behind-the-meter solar in impacting the timing of wholesale market peaks, the combined impact of changing demand patterns along with the increase in solar has yet to be felt. Even where customers are exposed to wholesale prices for energy, network pricing often relies on more static definitions. Regulators should inventory all elements of rate design which rely on static definitions of peak and off-peak hours and develop replacements that are more incentives-compatible. Broader exploration of performance-based ratemaking would also be beneficial.

- Given the uncertainty of future load growth, ***policy makers should avoid establishing procurement targets denominated in megawatts***. While COVID-19 is not the only source of load growth uncertainty, it is exacerbating the problem. Targets for storage, offshore wind, and other directed procurements should be expressed as a percentage of load, with procurements sized accordingly. Regulators in states that continue to have vertically integrated utilities also need to carefully scrutinize utility procurement plans to assure that green initiatives are not used as a means to overcapitalize, and that underutilized existing fossil plants are retired. Failure to refine procurements to reflect future demand uncertainty risks potential stranded costs, including for existing zero-emitting resources, as prematurely procured facilities exacerbate oversupply. Renewables procurement standards are sized as a percentage of load and allow for decentralized procurement using renewable energy credits (RECs), which better aligns the risk of stranded costs between ratepayers and investors. When load declines, all other things being equal, REC prices decline, sending a signal to developers to delay projects. By contrast, state-directed, technology-specific targets with set levels of capacity can be distortionary in the face of declining load. A few recent examples of state procurements expressed in megawatts are shown in Table 8.

Table 8: Recent directed procurements in the northeastern US

Jurisdiction	Year	Selected procurement program
New York	2019	Resources eligible: Offshore wind Target: 1,600 MW
Connecticut	2019	Resources eligible: Offshore wind Procurement target: 400–2,000 MW
Massachusetts	2019	Resources eligible: Offshore wind Procurement target: 800 MW
Rhode Island	2018	Resources eligible: Renewables, including solar, wind, biomass, small hydro, and fuel cells - Procurement target: 400 MW

Sources: NYSERDA; ISO-NE.

- As part of any future stimulus package, ***cash grant programs, such as the 1603 program[54] deployed after the global financial crisis, if used, should be carefully targeted***. Such programs, if not properly designed, may accelerate development of generation that is not immediately needed, increasing the overall cost to the economy of the program unless calibrated to focus on areas of least-cost carbon-emission reduction. This issue also extends to the impact of production tax credits (PTCs) and investment tax credits (ITCs), even in the absence of cash grant programs. Policy makers will face the temptation to extend both PTC and ITC programs beyond their current expiration dates. Because these programs are divorced from any analysis of need or linkage to the value of an expected carbon reduction benefit they are less effective climate policy tools. Changes in demand due to COVID-19 may make them even less so.[55]

- While depressed incomes and historically inexpensive fossil fuel prices may slow adoption of new technologies such as DERs and EVs, ***continued investment in smart-grid components may be among the best uses of potential stimulus funding*** because it enables better use of existing assets while deferring investment in new ones, even if DERs and EVs grow at a slower-than-expected rate. Prior to COVID-19, substantial effort was invested in "grid of the future" studies and redesign of utility remuneration in the face of DERs. Many of these initiatives have paused. However, as uncertainty regarding future load increases, the ability to use existing assets better to defer major capital investment becomes more pressing. Focusing on grid situational awareness, greater transparency regarding distribution system congestion, better data collection and management, consideration of non-wires alternatives where appropriate, and continuing to assess the potential for transactive energy are all potential means of reducing the need for investment that runs the risk of being stranded. Development of smart-charging regimes can significantly reduce the impact of EVs on peak load.[56] Because utilities are less able to invest in new technologies in the face of declining load, targeted stimulus spending on smart-grid projects would assist in maintaining rate stability while reflecting the public good aspects of some elements of such investments. Whereas incentives for more behind-the-meter generation have unintended consequences for grid operators who are required to connect such resources, a focus on a smarter, more dynamic distribution system would help put in place the conditions for less subsidized, small-scale resources to be better optimized.

The above examples are only a small selection of the policies that could be impacted by permanent demand destruction brought on by COVID-19. Demand destruction may also present opportunities to reshape existing systems that have not yet been explored. The potential for permanent demand destruction has not likely been fully examined by policy makers and market institutions. Doing so is necessary to assure that policies are cost-effective and environmentally conscious.

7. APPENDIX – DATA, CALCULATIONS, AND MODELED RESULTS

7.1 Calculations Appendix

7.1.1 Energy Intensity Ratio

Energy intensity ratios are calculated as a function of total load to real total GDP output. Table 9 below shows the outcomes for the economy, and the industrial and commercial sector.

Table 9: Energy intensity ratios

Item	Unit	Variable	Outcome
Pre-recession total load (1998–2007, period average)	TWh	A	3,658
Commercial load	TWh	B	1,207
Industrial load	TWh	C	1,024
Pre-recession total output (1998–2007, period average)	$ Billions	D	13,870
Commercial GDP	$ Billions	E	5,342
Industrial GDP	$ Billions	F	2,943
Energy intensity formula = [Total load/total output]			
Pre-recession energy intensity ratio (1998–2007, period average)	kWh/$1000 GDP	G = A/D*1000	0.26
Commercial ratio	kWh/$1000 GDP	H = B/E*1000	0.23
Industrial ratio	kWh/$1000 GDP	I = C/F*1000	0.35
Post-recession total load (2010–2019, period average)	TWh	J	3,894
Commercial load	TWh	K	1,349
Industrial load	TWh	L	983
Post-recession total output (2010–2019, period average)	$ Billions	M	17,196
Commercial GDP	$ Billions	N	6,343
Industrial GDP	$ Billions	P	3,250
Post-recession energy intensity ratio (2010–2019, period average)	kWh/$1000 GDP	Q = J/M*1000	0.23
Commercial ratio	kWh/$1000 GDP	R = K/N*1000	0.21
Industrial ratio	kWh/$1000 GDP	S = L/P*1000	0.30

Sources: EIA and BEA data.

Notes: GDP in the commercial sector is defined as service-providing facilities and equipment of businesses; Federal, State, and local governments. The industrial sector encompasses the following types of activity: manufacturing (NAICS codes 31-33); agriculture, forestry, fishing, and hunting (NAICS code 11); mining, including oil and gas extraction (NAICS code 21); and construction (NAICS code 23).

7.1.2 Load-to-GDP Increase

Applying the pre-recession load-to-GDP ratio to increase post-recession load growth, we can estimate what load would have been if the ratio had not changed. Data result is shown in Table 10 below.

Table 10: "Missing" load in post-recession period

Item	Unit	Variable	Outcome
Ratio of load growth to real GDP growth	Value	A = Load growth/ GDP growth	
Ratio in pre-recession period (1998–2007)	Value	$A_{Pre\text{-}Recession}$	0.54
Ratio in post-recession period (2010–2019)	Value	$A_{Post\text{-}Recession}$	0.21
Real GDP growth in pre-recession period (1998–2007, period average)	%	B	3.1%
Load growth required to maintain pre-recession ratio	%	$C = A_{Pre\text{-}Recession} * B$	1.66%
Additional post-recession load-growth	%	D = 1+C	101.7%
Average load in post-recession period (2010–2019)	TWh	E	3,893.9
Average load in post-recession period applying additional load growth	TWh	F = E*D	3,958.6
"Missing" load in post-recession period	TWh	F = E-D	64.7

Sources: Analysis using EIA and BEA data.

7.1.3 Residential Load Increase

Applying the difference between pre-recession residential consumption per capita and 2019 residential consumption per capita to the population in 2019, we can estimate the "missing" residential load. This is illustrated in Table 11 below.

Table 11: "Missing" residential load using post-recession usage per capita

Item	Unit	Variable	Outcome
Population growth in pre-recession (1998–2007, period average)	%	A	1.00%
Population growth in post-recession (2010–2019, period average)	%	B	0.68%
Incremental population growth in pre-recession period	%	C = A-B	0.32%
Population in post-recession period	Number	D	319,249,329
Incremental population if pre-recession growth maintained	Number	E = D*C	1,030,928
Post-recession per-capita residential consumption (period average)	kWh/capita	F	4,432
Incremental residential consumption due to additional population	GWh	G = (F*E)/1000000	4,569

Sources: Analysis using EIA, US Census bureau, and BEA data.

7.1.4 Industrial Load Increase

Applying pre-recession industrial share of GDP to 2019 industrial energy intensity, we can estimate the "missing" industrial load. This is illustrated in Table 12 below.

Table 12: "Missing" industrial load using post-recession energy intensity

Item	Unit	Variable	Outcome
GDP in 2019	US$ (Billions)	A	21,427
Industrial load in 2019	TWh	B	952.15
Share of industry GDP in pre-recession (1998–2007, period average)	%	C	20.9
Share of industry GDP in 2019	%	D	17.4
Difference	%	E	3.4
Energy intensity formula = [Total load]/[Total GDP output]			
Industrial sector energy intensity in 2019	kWh/1000$	F = B/A	0.25
Additional load if industrial share of GDP increased to pre-recession levels	TWh	G = (F*E*A)/1,000	0.2

Note: Industry GDP share is defined consistent with EIA definition of industrial sector i.e. "An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses the following types of activity manufacturing (NAICS codes 31-33); agriculture, forestry, fishing and hunting (NAICS code 11); mining, including oil and gas extraction (NAICS code 21); and construction (NAICS code 23)."

Sources: Analysis using EIA, US Census bureau, and BEA data.

7.1.5 Coronavirus Load Reduction Impact Model—Moderate Impact Case

Table 13 illustrates the CLR-IM moderate case impact calculations, as described in Section 4 above.

Table 13: CLR-IM moderate impact case calculations

Item	Unit	Variable	Outcome	Source(s) and explanation
Percentage of office workers assumed to be permanently working from home post-covid	%	A	10.8%	Weighted average of results of survey 317 CFOs in the US on March 30, 2020. CFOs answered the question "what percentage of your workforce will remain permanently remote post-COVID who were not remote before COVID?" • *0% will remain remote: 26% of respondents* • *5% will remain remote: 27% of respondents* • *10% will remain remote: 25% of respondents* • *20% will remain remote: 17% of respondents* • *50% will remain remote: 4% of respondents* • *more than 50% will remain remote: 2% of respondents* *Source: Gartner. Gartner CFO Survey Reveals 74% Intend to Shift Some Employees to Remote Work Permanently. April 3, 2020.*
Current average square footage per employee in office environments	Sqft	B	150	*"What is the average square footage of office space per person?" The Mehigan Company, Inc. Web. March 2016.*
Covid-adjusted average square footage per employee in office spaces	Sqft	B_{covid} = B + (30*50%)	165	Estimates from office designers and architects anticipate that an additional 20–40 sqft is needed per employee to enforce physical distancing requirements. It is assumed that half of existing office areas would need to allocate an extra 30 sqft, while 50% of office areas may already be allocating enough space per employee to enforce social distancing without the need for additional space S *Source: Baird-Remba, R. Designing Offices, Restaurants and Grocery Stores in the Age of Coronavirus. Commercial Observer website. April 18, 2020.*
Percentage increase in office space per employee	%	C = (B_{covid}/B)-1	10.0%	-
Observed change in residential load during covid	%	E	8.9%	Average of observed changes to residential demand based on utilities and monitored electricity usage in homes in over 20 states. *Sources: "COVID-19 is Changing Residential Electricity Demand". Pecan Street. May 15, 2020; "As utilities tackle immediate COVID-19 impacts, analysts stress need to focus beyond the pandemic". Utility Dive. May 20, 2020; "US utilities start to feel pinch in April from COVID-related load declines" S&P Global Market Intelligence. May 8th, 2020*

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Item	Unit	Variable	Outcome	Source(s) and explanation
Percentage of office workers that have transitioned to work from home in March 2020 due to COVID-19	%	F	28.0%	*A survey conducted by YouGov in March 2020 found that 28% of respondents transitioned to work-from-home roles in the US.* *Source: YouGov. Here's how many Americans are working from home during COVID-19. March 19, 2020.*
Ratio of office workers relocating to work from home, to change in residential load	-	G = E/F	0.32	This means that for each 1% of the workforce switching to work from home, residential load is anticipated to increase by 0.32%
Current gross leasable area per capita in the US	Sqft/ capita	GLA	23.5	*Source: Morningstar. Via the New York Times: Why we should be optimistic about retail. April 2018.*
Anticipated gross leasable area per capita in the US post-COVID	Sqft/ capita	GLA_{covid}	16.4	Gross leasable area per capita is anticipated to decline to a level that is equivalent to that of Canada's *Source: Morningstar. Via the New York Times: Why we should be optimistic about retail. April 2018.*
Total current retail area in the US	mill Sqft	$AREA_{retail}$	15,952	*Source: Energy Information Administration. Commercial Buildings Energy Consumption Survey. May 2016.*
Total office area in the US	mill Sqft	$AREA_{office}$	11,330	*Source: Energy Information Administration. Commercial Buildings Energy Consumption Survey. May 2016.*
Retail energy intensity	kWh-yr/ sqft	EI_{retail}	22.95	Average energy intensity for Stand-alone retail and strip malls. *Source: US Department of Energy. Commercial Reference Buildings. Reference Buildings by Climate zone and Representative City"*
Office energy Intensity	kWh-yr/ sqft	EI_{office}	16.77	Average energy intensity for small, medium, and large offices. *Source: US Department of Energy. Commercial Reference Buildings. Reference Buildings by Climate zone and Representative City"*

The results of the calculations are shown in Table 14.

Table 14: CLR-IM moderate impact case results

Item	Unit	Variable	Outcome	Source(s) and explanation
Anticipated post-covid permanent change in residential electricity demand	%	H = G*A	3.4%	Multiplying the ratio of observed change in residential load as a result of work from home orders, by the anticipated percentage of office workers assumed to be permanently from home once offices are re-opened
	TWh	J	1,435	*Total residential electricity consumption, 2019* *Source: Energy Information Administration. Electric Sales, Revenue, and Average Price. (Data from forms EIA-861- schedules 4A, 4B, 4D, EIA-861S and EIA-861U)*
	TWh	Xres= H*J	49.0	*Anticipated change in electricity demand from offices*
Anticipated change in electricity demand from offices	%	D = (1-A)*(1+C) -1	-1.9%	This is equivalent to the anticipated change in total demand for retail space
	TWh	X_{office} = EI_{office} *D* $Area_{office}$ *(10^{-3})	-3.6	-
Anticipated change in electricity demand from retail activities	%	I = (GLA_{covid}/ GLA)-1	-30.2%	This is equivalent to the anticipated change in total demand for retail space
	TWh	Xretail = EI_{retail} *I* $AREA_{retail}$ *(10-3)	-110.6	-
Total demand effect	TWh	ΣX = X_{retail} + X_{office} + X_{res}	-65.2	-

7.1.6 Coronavirus Load Reduction Impact Model—High Impact Case

Similarly, calculations for the CLR-IM High Impact Case are illustrated below.

Table 15: CLR-IM high impact case calculations

Item	Unit	Variable	Outcome	Source(s) and explanation
Percentage of office workers assumed to be permanently working from home post-covid	%	A	25.0%	Weighted average of results of survey 317 CFOs in the US on March 30, 2020. CFOs answered the question "what percentage of your workforce will remain permanently remote post-COVID who were not remote before COVID?" • *0% will remain remote: 26% of respondents* • *5% will remain remote: 27% of respondents* • *10% will remain remote: 25% of respondents* • *20% will remain remote: 17% of respondents* • *50% will remain remote: 4% of respondents* • *more than 50% will remain remote: 2% of respondents* *Source: Gartner. Gartner CFO Survey Reveals 74% Intend to Shift Some Employees to Remote Work Permanently. April 3, 2020.*
Current average square footage per employee in office environments	Sqft	B	150	*"What is the average square footage of office space per person?" The Mehigan Company, Inc. Web. March 2016.*
Covid-adjusted average square footage per employee in office spaces	Sqft	$B_{covid} = B$	150	In this case, a higher proportion of workers remaining at home means no additional space is needed in offices to maintain social distancing
Percentage increase in office space per employee	%	$C = (B_{covid}/B)-1$	0.0%	-
Observed change in residential load during covid	%	E	8.9%	Average of observed changes to residential demand based on utilities and monitored electricity usage in homes in over 20 states. *Sources: "COVID-19 is Changing Residential Electricity Demand". Pecan Street. May 15, 2020; "As utilities tackle immediate COVID-19 impacts, analysts stress need to focus beyond the pandemic". Utility Dive. May 20, 2020; "US utilities start to feel pinch in April from COVID-related load declines" S&P Global Market Intelligence. May 8th, 2020*
Percentage of office workers that have transitioned to work from home in March 2020 due to COVID-19	%	F	28.0%	*A survey conducted by YouGov in March 2020 found that 28% of respondents transitioned to work-from-home roles in the US.* *Source: YouGov. Here's how many Americans are working from home during COVID-19. March 19, 2020.*

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Item	Unit	Variable	Outcome	Source(s) and explanation
Ratio of office workers relocating to work from home, to change in residential load	-	G = E/F	0.32	This means that for each 1% of the workforce switching to work from home, residential load is anticipated to increase by 0.32%
Current gross leasable area per capita in the US	Sqft/ capita	GLA	23.5	*Source: Morningstar. Via the New York Times: Why we should be optimistic about retail. April 2018.*
Anticipated gross leasable area per capita in the US post-COVID	Sqft/ capita	GLA_{covid}	11.1	Gross leasable area per capita is anticipated to decline to a level that is equivalent to that of Canada's *Source: Morningstar. Via the New York Times: Why we should be optimistic about retail. April 2018.*
Total current retail area in the US	mill Sqft	$AREA_{retail}$	15,952	*Source: Energy Information Administration. Commercial Buildings Energy Consumption Survey. May 2016.*
Total office area in the US	mill Sqft	$AREA_{office}$	11,330	*Source: Energy Information Administration. Commercial Buildings Energy Consumption Survey. May 2016.*
Total area of large hotels in the US	mill Sqft	$AREA_{LargeHotel}$	2,717	*Source: Energy Information Administration. Commercial Buildings Energy Consumption Survey. May 2016.*
Retail energy intensity	kWh-yr/ sqft	EI_{retail}	22.95	Average energy intensity for Stand-alone retail and strip malls. *Source: US Department of Energy. Commercial Reference Buildings. Reference Buildings by Climate zone and Representative City"*
Large hotel energy intensity	kWh-yr/ sqft	$EI_{LargeHotel}$	42.6	*Source: US Department of Energy. Commercial Reference Buildings. Reference Buildings by Climate zone and Representative City. <https://www.energy.gov/eere/buildings/commercial-reference-buildings>*
Small hotel energy intensity	kWh-yr/ sqft	$EI_{SmallHotel}$	18.6	*Source: US Department of Energy. Commercial Reference Buildings. Reference Buildings by Climate zone and Representative City. <https://www.energy.gov/eere/buildings/commercial-reference-buildings>*
Anticipated change in large hotel energy intensity	kWh-yr/ sqft	$\Delta EI_{LargeHotel} = -0.5(EI_{LargeHotel} - EI_{SmallHotel})$	-12.0	Large hotels are anticipated to reduce their energy intensity by 12kWh-yr/sqft, as their energy intensity declines to close the gap with small hotels by 50%, as common amenities (gyms, pools, ballrooms etc.) are anticipated to get less use or be shut down
Office energy Intensity	kWh-yr/ sqft	EI_{office}	16.77	*Average energy intensity for small, medium, and large offices.* *Source: US Department of Energy. Commercial Reference Buildings. Reference Buildings by Climate zone and Representative City*

The results of these calculations are shown below.

Table 16: CLR-IM high impact case results

Item	Unit	Variable	Outcome	Source(s) and explanation
Anticipated post-covid permanent change in residential electricity demand	%	H = G*A	7.9%	Multiplying the ratio of observed change in residential load as a result of work from home orders, by the anticipated percentage of office workers assumed to be permanently from home once offices are re-opened
	TWh	J	1,435	*Total residential electricity consumption, 2019* *Source: Energy Information Administration. Electric Sales, Revenue, and Average Price. (Data from forms EIA-861- schedules 4A, 4B, 4D, EIA-861S and EIA-861U)*
	TWh	Xres= H*J	113.5	-
Anticipated change in electricity demand from offices	%	D = (1-A)*(1+C) -1	-25.0%	This is equivalent to the anticipated change in total demand for office space
	TWh	$X_{office} = EI_{office} * D * Area_{office} * (10^{-3})$	-47.5	-
Anticipated change in electricity demand from retail activities	%	I = (GLAcovid/ GLA)-1	-52.8%	This is equivalent to the anticipated change in total demand for retail space
	TWh	Xretail = $EI_{retail} * I * AREA_{retail}$ *(10-3)	-193.2	-
Anticipated change in electricity demand from hotels	TWh	$X_{Hotel} = \Delta EI_{LargeHotel} * A_{LargeHotel} * (10^{-3})$	-32.6	-
Total demand effect	TWh	$\Sigma X = X_{retail} + X_{office} + X_{res}$	-159.8	-

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NOTES

1. In this paper, "load" refers to annual consumption (Wh), while "peak load" refers to maximum load in a particular hour (W).

2. Unemployment rates following the Great Recession peaked at 10 percent in the month of October 2009, rising from 5 percent in January of the same year. In 2020, unemployment rates peaked at 14.7 percent during the month of April, rising from 3.5 percent in the month of February of the same year. Source: US Bureau of Labor Statistics, "Civilian Unemployment Rate, seasonally adjusted", US Department of Labor, https://www.bls.gov/charts/employment-situation/civilian-unemployment-rate.htm.

3. Anouk Honoré, "Economic Recession and Natural Gas Demand in Europe: What Happened in 2008–2010?" Oxford Institute for Energy Studies (2011).

4. Bruno Declercq, Erik Delarue, and William D'haeseleer, "Impact of the economic recession on the European power sector's CO_2 emissions," *Energy Policy* 39.3 (2011): 1677–1686.

5. Huiru Zhao et al., "The impact of financial crisis on electricity demand: A case study of North China." *Energies* 9.4 (2016): 250.

6. Energy Information Administration, *Monthly Energy Review* (March 2020).

7. Ibid.

8. GDP data was obtained from the Bureau of Economic Analysis (BEA), while load growth data was obtained from the US Electricity Information Administration (EIA). Sources: Bureau of Economic Analysis, *National Income and Product Accounts*, Accessed April 2019; Energy Information Administration, *Annual Electric Power Industry Report* (EIA Form 861) October 2019; Energy Information Administration, *Monthly Energy Review*, March 2020.

9. Please see the Appendix for details.

10. Using EIA and BEA data, we observe that services as a share of GDP has increased from 43 percent in 1998 to 46 percent in 2019, and commercial load growth has averaged 1.3 percent over the same period, relative to 0.8 percent for total load growth. Conversely, industry has declined as a share of GDP from 21 percent in 1998 to 18 percent in 2019, while industrial load growth has actually fallen, averaging negative 0.3 percent in the same time period.

11. In the pre-recession period between 1998 and 2007, the energy intensity ratio for the industrial sector decreased from a period average of 0.35 kWh/$ GDP to 0.30 kWh/$ GDP for the post-recession period between 2010 and 2019. For the commercial sector, the pre-recession period average is 0.23 kWh/$ GDP, falling to 0.21 kWh/$/GDP. Economy-wide, the decline is also similar, with a pre-recession period average of 0.26 kWh/$ GDP, falling to a post-recession average of 0.23 kWh/$ GDP (EIA, BEA data).

12. US Census Bureau, *Current Population Survey: Annual Social and Economic Supplement*, https://www.census.gov/programs-surveys/cps.html.

13. Ibid. In the US context, higher population growth would likely also have contributed to higher GDP growth, with corresponding increases in commercial and industrial load, which are excluded here.

14. In several states, increasing behind-the-meter (BTM) generation is impacting both load growth and peak demand occurrence. For instance, in California, the most recent statewide data indicate an estimate of 13.5 TWh of BTM solar in 2018, an increase of 20 percent year-over-year. The state noted that combined with energy efficiency, BTM solar has "had a measurable impact on utility served load and, consequently, on the total system electric generation." Similarly, in New England, the system operator has noted that BTM is a significant driver of declining peak demand: in one day in 2018, BTM solar reduced grid demand by more than 2,300 MW and has resulted in instances of peak load occurring at night (California Energy Commission, *Energy Almanac* [June 2019]; ISO-New England, *2020 Regional Electricity Outlook* [February 2020]).

15. Energy Information Administration, "Electric Power Monthly: Table 3.1.A. Net Generation by Energy Source: Total (All Sectors), 2008–2018," (2019).

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19. EIA, *Electric Power Annual*. Data collected from Form EIA-861, the Annual Electric Power Industry Report, https://www.eia.gov/electricity/data/eia861/.

20. EIA, *Electric Power Annual*, "Table 10.6. Energy Efficiency" October 2019.

21. The increase in net cooling degree days relative to heating degree days may have created additional demand that is not represented in the graphic; this would have the effect of increasing the amount of load decline attributed to residual structural change.

22. US Energy Information Administration, *Annual Energy Outlook 2020, Reference Case, Table 54: Electric Power Projections by Electricity Market Module Region* (January 29, 2020).

23. Energy Information Administration, *Today in Energy: Daily electricity demand impacts from COVID-19 mitigation efforts differ by region* (May 2020).

24. New York ISO Demand Forecasting and Analysis, *Impacts of COVID-19 on NYISO Demand* (April 13, 2020).

25. Research and credit ratings firms, using data reported by utilities, are reporting an anticipated increase in residential demand, in addition to short-term destruction of commercial and industrial demand. These include S&P Global, CreditSights, Morningstar, and the Energy Information Administration (Morningstar, "Looking for Answers in Utilities' Earnings," Morningstar (April 24, 2020), https://www.morningstar.com/articles/979935/looking-for-answers-in-utilities-earnings; S&P Global Market Intelligence, "US utilities expected to see 'muted impact' from COVID-19 in Q1'20 results," S&P (April 23, 2020), https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/us-utilities-expected-to-see-muted-impact-from-Covid-19-in-q1-20-results-58153257.
26. Energy Information Administration, *Commercial Buildings Energy Consumption Survey* (May 2016), https://www.eia.gov/consumption/commercial/data/2012/bc/cfm/b23.php.
27. National Association of Real Estate Investment Trusts, "Estimating the Size of the Commercial Real Estate Market in the US."
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34. Jones Lang Lasalle, "Tenant needs in a post-pandemic world: 2020 Forecast Series," https://www.us.jll.com/en/trends-and-insights/research/2020-first-look-navigating-post-COVID-19.
35. Rebecca Baird-Remba, "Designing Offices, Restaurants and Grocery Stores in the Age of Coronavirus," *Commercial Observer* (April 18, 2020), https://commercialobserver.com/2020/04/coronavirus-design-architecture-offices-grocery-stores-fast-casual-food/.
36. "CBRE Hotels Research: Full demand recovery by late 2022," Hotel Management (May 21, 2020), https://www.hotelmanagement.net/operate/cbre-hotels-research-full-demand-recovery-by-late-2022.

37. Alesandra Dubin, "This is the future of hotel design after coronavirus, according to hospitality architects," *Business Insider* (June 14, 2020), https://www.businessinsider.com/future-of-hotel-design-after-coronavirus-hospitality-architects-2020-6.

38. Based on the weighted average of the result of a survey conducted by Gartner of 317 CFOs on March 30, 2020, which found that 25 percent of CFOs expect 10 percent of employees to remain remote, 17 percent expect 20 percent to remain remote, 4 percent expect 50 percent to remain remote, and 2 percent expect over 50 percent to remain remote. Additionally, a "Survey of Business Uncertainty" conducted in May by the Federal Reserve Bank of Atlanta, Stanford University, and the University of Chicago, found that 10.3 percent of employees will work from home permanently after the coronavirus pandemic, compared to just 3.4 percent of the existing workforce, based on the weighted average of a sample of 280 firms. Moreover, recent studies that identified remote-compatible roles in the US, place them in the range of 37 percent to 38.8 percent. Sources: Jonathan Dingel and Brent Neiman, "How Many Jobs Can Be Done at Home?" (white paper, University of Chicago, Booth School of Business, June 19, 2020;) Yichen Su, "Working from Home During a Pandemic: It's Not for Everyone," Federal Reserve Bank of Dallas, April 7, 2020, https://www.dallasfed.org/research/economics/2020/0407; David E. Altig, et al., "Firms Expect Working from Home to Triple," Federal Reserve Bank of Atlanta, May 28, 2020, https://www.frbatlanta.org/blogs/macroblog/2020/05/28/firms-expect-working-from-home-to-triple; Gartner, "Gartner CFO Survey Reveals 74 percent Intend to Shift Some Employees to Remote Work Permanently," press release, April 3, 2020, https://www.gartner.com/en/newsroom/press-releases/2020-04-03-gartner-cfo-surey-reveals-74-percent-of-organizations-to-shift-some-employees-to-remote-work-permanently2.

39. Based on an average of observed residential demand changes from utilities in over 20 states, and monitored residential use. While factors other than stay-at-home orders may drive residential demand increases, estimates are generally weather-normalized and weather during the period was within historical norms. Sources: "COVID-19 Is Changing Residential Electricity Demand," *Pecan Street* (May 15, 2020); "As utilities tackle immediate COVID-19 impacts, analysts stress need to focus beyond the pandemic," *Utility Dive* (May 20, 2020); "US utilities start to feel pinch in April from COVID-related load declines," *S&P Global Market Intelligence* (May 8, 2020).

40. The calculation assumes an additional 30 square feet per employee is added by some employers to enforce social distancing, somewhat less than designers recommend. This increase in space is assumed to apply to 50 percent of office spaces, as existing offices that are less concentrated may be reconfigured to accommodate social distancing without needing additional area. A such, the current average would increase from 150 square feet per employee to 165 square feet per employee, an increase of 10 percent (Baird-Remba, "Designing Offices").

41. Cowen & Company, "What in the World Is Causing the Retail Meltdown of 2017?" *The Atlantic* (April 2017), https://www.theatlantic.com/business/archive/2017/04/retail-meltdown-of-2017/522384/.

42. Prior to the pandemic, online sales were anticipated to increase from $4.2 trillion to $6.5

trillion by 2023. Sources: eMarketer, *Global Ecommerce 2019*, (June 2019). It is estimated that for each additional $1 billion of annual incremental online sales, 1.25 million square feet of logistics space is needed. Source: D. Egan, "How has e-commerce shaped industrial real estate demand?" *CBRE Research* (2018).

43. Demand from re-shoring of formerly offshore industrial operations could cause a countervailing increase in load, but evidence of this effect is limited to date.

44. A 30.2 percent decline in retail space leads to a decline of 3,421 million square feet. At 22.95 kWh/sqft, consumption would decrease by 78,527 MWh.

45. New combined cycle plants built between 2015 and 2019 that reported data to the EIA averaged an annual capacity factor of 61 percent in 2019 (EIA-923 and EIA-860 data compiled by S&P Global Market Intelligence).

46. Other assumptions for the high-impact case are the same as those specified in the moderate-impact case above.

47. Derek Thompson, "What in the World Is Causing the Retail Meltdown of 2017?" (April 2017), https://www.theatlantic.com/business/archive/2017/04/retail-meltdown-of-2017/522384/.

48. US Energy Information Administration, "Preliminary Monthly Electric Generator Inventory," (May 26, 2020).

49. ERCOT, *COVID-19 Load Impact Analysis: Load Forecasting & Analysis*, (June 9, 2020).

50. CAISO, *COVID-19 Impacts to California ISO Load & Markets: March 17–July 26, 2020*: Market Analysis & Forecasting, (July 31, 2020).

51. According to *The Economist* (May 23, 2020, p.15), approximately one-eighth of stimulus money disbursed after the Great Recession "went into clean energy loans and investments."

52. Total costs for these markets are shown given similarities in market design; costs for capacity in other regions, as well as in vertically integrated states, face upward pressure as well. ISO-NE reported the settlement of $3.40 billion in forward-capacity market payments in 2019; PJM reported $8.98 billion.

53. IMMs have tended to focus more on the contribution of short-term demand forecast error to price volatility, rather than on the upward bias of long-term forecasts. For example, NYISO's 2019 state of the market report briefly assesses the contribution of load forecast errors to price spikes; MISO's 2018 state of the market report analytic appendix allocates half a page to load forecasting errors; PJM's Market Monitoring Unit, in its 2019 state of the market report, recommended making changes to load and supply forecasts. Sources: Potomac Economics, *2019 State of the Market Report for the New York ISO Markets* (May 2020); Potomac Economics, *2019 State of the Market Report for the MISO Electricity Market—Analytic Appendix*, (July 2019); Monitoring Analytics, LLC, *State of the Market Report for PJM*, (August 8, 2019).

54. The 1603 Program: Payments for Specified Energy Property in Lieu of Tax Credits (referred to as "Section 1603") program was created as part of the American Recovery and Reinvestment Tax Act of 2009. Eligible participants received payments in lieu of investment tax credits from the Department of Treasury. Its purpose was to reimburse eligible applicants for a portion of the cost of installing the specified energy property, which were defined as solar, wind, geothermal, biomass, fuel cells, hydropower, combined heat and power, landfill gas, municipal solid waste, and microturbine property. In most cases, the value of an award was equivalent to 30 percent of the project's total eligible cost basis. By the end of the program, over 34 GW of projects had been funded, comprising over 21.6 GW of wind projects and 9.1 GW of utility-scale solar. Source: Department of Treasury, *Final Overview of the §1603 Program*, (March 1, 2018).

55. Program designs like the NY-SUN and Massachusetts SMART initiatives, which establish tranches of capacity with compensation which steps down after each tranche is filled, would be one way to better calibrate the incentives, if nationwide carbon pricing remains unattainable.

56. A number of recent studies have demonstrated that electric vehicles coupled with smart charging technology are able to show limited impact and even reductions to peak load, as well as reduce curtailment and allow integration of solar PV. In one study that modeled the impact of 100 percent EV penetration in Germany and Scandinavia in 2050, the researchers demonstrated that application of vehicle-to-grid (V2G) smart charging technologies lowered peak demand by 7 percent and smoothed the net load curve. A more conservative analysis performed by 50Hertz, one of the system operators in Germany, concluded that growth of EVs will result in peak demand impact of 8 percent by 2035 with implementation of smart charging. Sources: IRENA, *Innovation landscape brief: Electric-vehicle smart charging*, International Renewable Energy Agency (Abu Dhabi 2019); B. Schucht; M. Taljegard, *The impact of an electrification of road transportation on the electricity system*, Gothenburg, Sweden: Chalmers University of Technology (2017.)

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