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THE POTENTIAL IMPACT OF ELECTRIC VEHICLES ON GLOBAL ENERGY SYSTEMS

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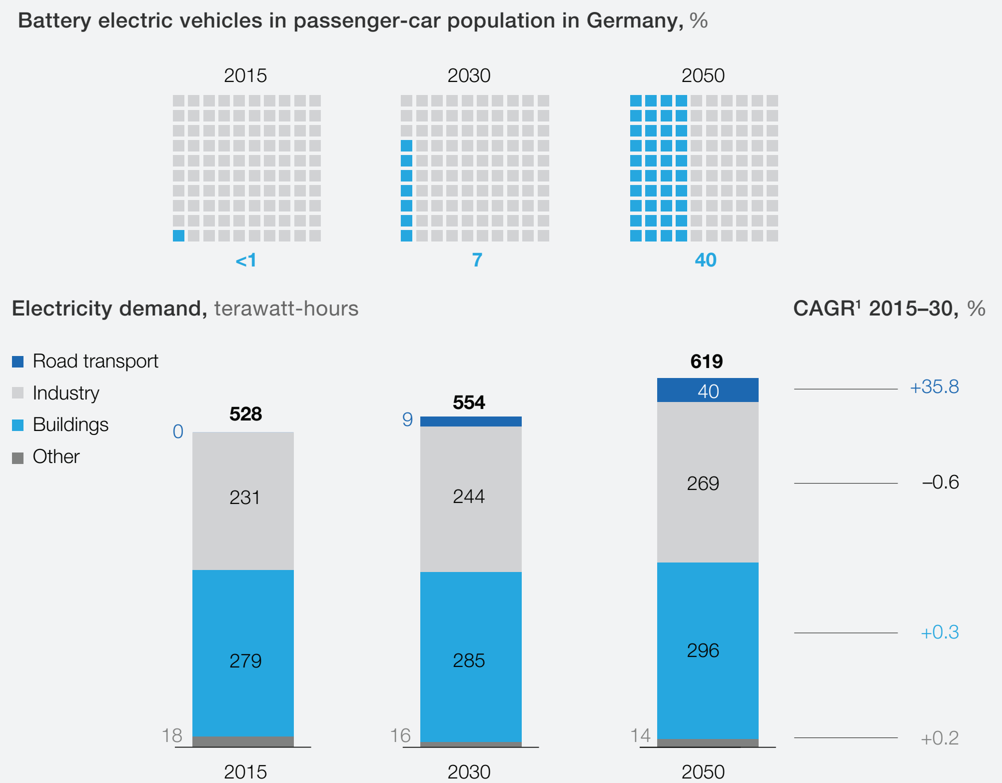
Electric vehicles are unlikely to create a power-demand crisis but could reshape the load curve. Here's how to bend that curve to your advantage.

Could electric vehicles (EVs) soon face a different kind of gridlock? With the electrification of mobility accelerating, energy producers and distributors need to understand the potential impact of EVs on electricity demand (Exhibit 1). The good news: McKinsey analysis suggests the projected growth in e-mobility will not drive substantial increases in total electrical-grid power demand in the near to midterm, thus limiting the need for new electricity-generation capacity during that period.

Exhibit 1

Electric vehicles will likely not drive a large increase in electricity demand.



[1]Compound annual growth rate.

McKinsey&Company | **Source:** Energy Insights by McKinsey Global Energy Perspective, March 2018

Using information from Germany as an example, EV growth is not likely to cause large increases in power demand through 2030; instead, it potentially adds about 1 percent to the total and requires about five extra gigawatts (GW) of generation capacity. That amount could grow to roughly 4 percent by 2050, requiring additional capacity of about 20 GW. Almost all this new-build capacity will likely involve renewables, including wind and solar power, with some gas-powered generation.

Reshaping the electricity load curve

While the uptake in EV sales is unlikely to cause a significant increase in total power demand, it will likely reshape the electricity load curve. The most pronounced effect will be an increase in evening peak loads, as people plug in their EVs when they return home from work or after completing the day's errands. However, at a system level, this effect will represent a relatively small percentage at most. Again, taking Germany as an example, we expect an increase in peak load of approximately 1 percent by 2030 and about 5 percent by 2050—increases that the system can likely absorb.

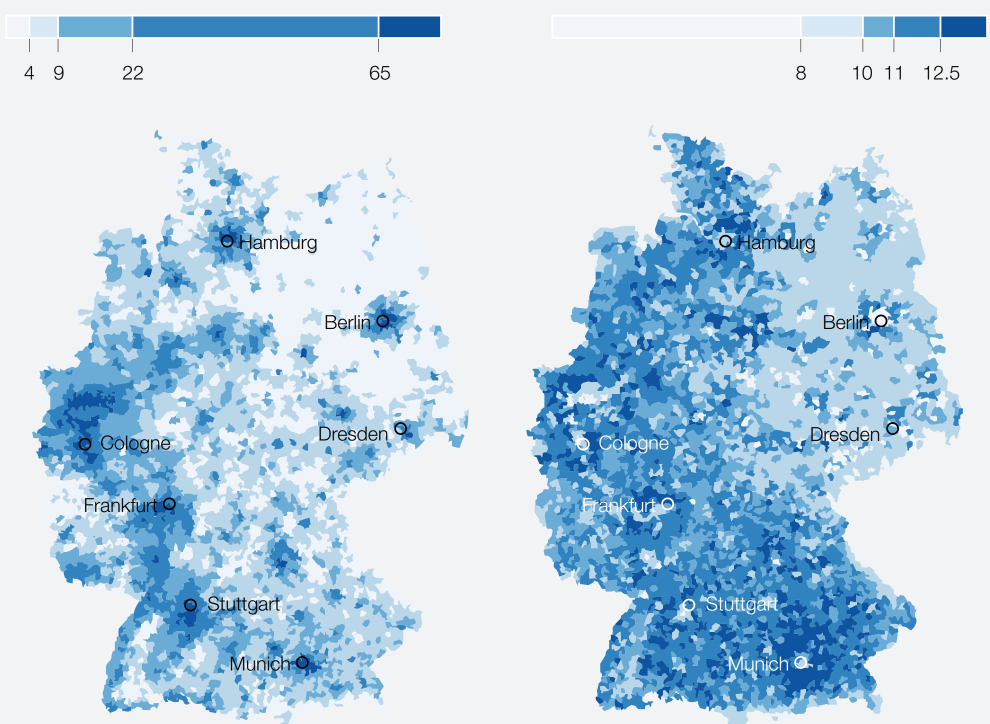
However, the changing load curve will lead to challenges at a local level because the regional spread of EVs will most likely vary—in some cases, significantly. McKinsey's geospatial-analytics forecast of zip-code-level EV penetration shows suburban areas will likely become early EV-adoption hot spots. Therefore, even at still-low nationwide EV-penetration levels, local pockets with significant EV populations will probably emerge (Exhibit 2).

Exhibit 2

We expect a high concentration of electric-vehicle stock in cities and suburban areas.

Electric-vehicle stock in Germany at 10% national penetration, number per square kilometer

Electric-vehicle penetration in Germany at 10% national penetration, % of private passenger cars



McKinsey&Company | **Source:** GfK; Microm; McKinsey analysis

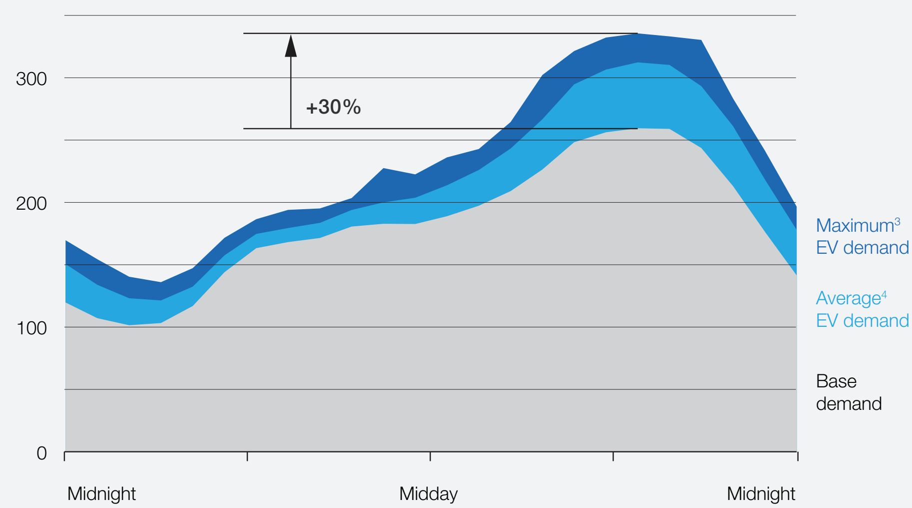
These residential hot spots and other concentration points of EV charging, such as public EV-fast-charging stations and commercial-vehicle depots, will see significant increases in local peak loads. To forecast changes in the load curve in residential areas, McKinsey conducted a Monte Carlo analysis.[1] For a typical residential feeder circuit of 150 homes at 25 percent local EV penetration, the analysis indicated that the local peak load would increase by approximately 30 percent (Exhibit 3).

While significant, the peak-load growth in residential areas is not as dramatic as some assume. That is because while a single EV can easily double peak consumption at the individual-household level, the aggregation across many households (those with and without EVs) reduces the relative increase in peak load at a substation, even considering the effects of high-peak outlier days. Exhibit 3 illustrates both maximum and average peak EV-electricity demand experienced by a typical residential substation, assuming no delayed or "smart" (that is, centrally managed) charging.

Exhibit 3

When local electric-vehicle penetration hits 25 percent, peak circuit loads can grow 30 percent.

Feeder circuit load,[1] 150 homes with 2 vehicles per household,[2] with 25% electric-vehicle (EV) penetration, kilowatts



[1]Load shape for a typical feeder with 150 houses at 8 megawatt-hours per year; example shown for Midwestern US on typical September day.
[2]The average US household owns 2.1 vehicles.
[3]Statistically expected maximum EV demand—"peak day."
[4]Statistically expected average EV demand—"typical day."

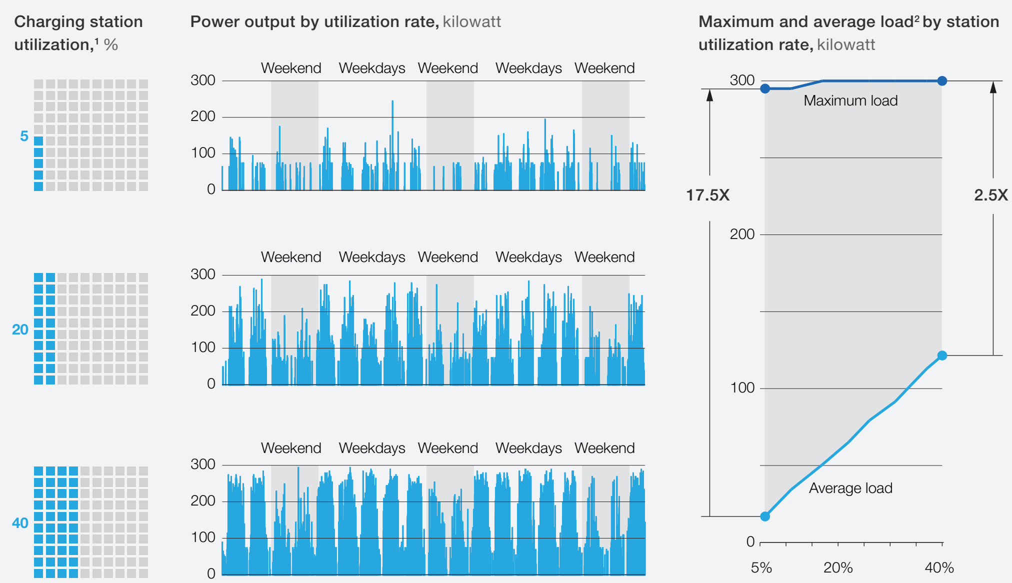
McKinsey&Company | **Source:** OpenEI; McKinsey analysis

1 Monte Carlo analysis is a statistical analysis method in which analysts use repeated sampling along predefined parameters to obtain the statistical properties of a phenomenon.

Beyond peak-load increases, the highly volatile and spiky load profiles of public fast-charging stations will also require additional system balancing. We simulated the load profile of a fast-charging station to explore this situation in greater detail (Exhibit 4). In this case, a single fast-charging station can quickly exceed the peak-load capacity of a typical feeder-circuit transformer.

Exhibit 4

Load profiles for fast-charging stations fluctuate wildly but follow a weekday and weekend rhythm.



[1]Share of time charging station is occupied by a charging electric vehicle.
[2]Fifteen-minute demand charge window.

McKinsey&Company | **Source:** McKinsey analysis

Unmanaged, substation peak-load increases from EV-charging power demand will eventually push local transformers beyond their capacity, requiring upgrades. Combining data on the distribution of EV penetration per zip code from McKinsey's geospatial analysis with data on the current utilization of transformers reveals that capital-expenditure requirements as a function of national-level EV penetration follows an S-curve shape. In other words, while investment needs require very few upgrades at low EV penetrations, they jump rapidly as the number of EVs increases and eventually level off again at high penetration levels. Without corrective action, we estimate that the cumulative grid-investment need could exceed several hundred euros per EV.

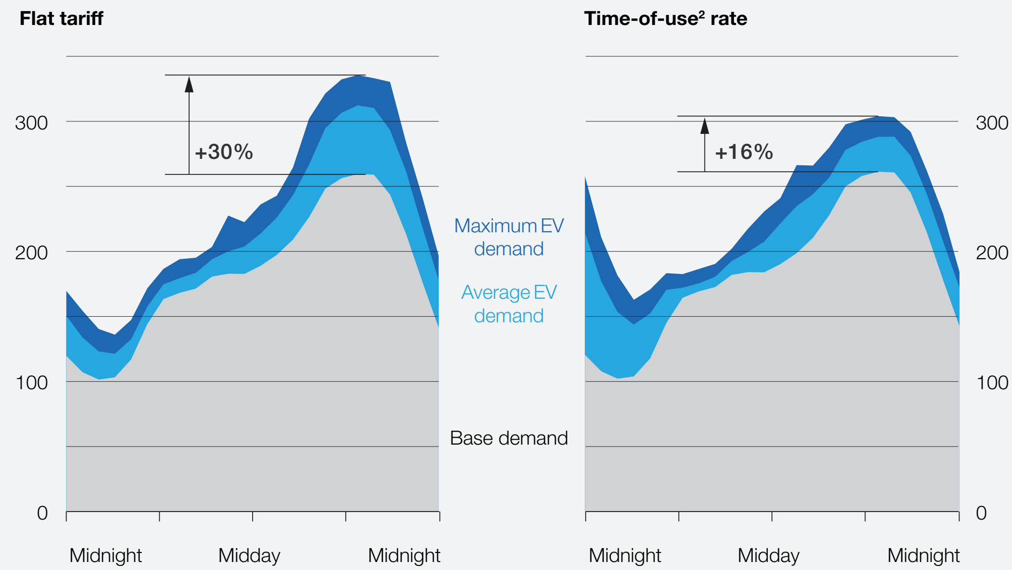
Exploring potential solutions

Energy players have several ways to address this situation. They can influence charging behavior: for example, time-of-use electricity tariffs can give incentive to EV owners to charge after midnight instead of in the early evening. Analysis shows this could halve the increase in peak load (Exhibit 5). Easy to implement and proved in trials, time-of-use rates will require oversight because their use can result in "timer peaks," which occur when many people inadvertently set their chargers to start charging at the same time.

Exhibit 5

Time-of-use rates could halve peak loads.

Feeder circuit load,[1] 150 homes with 2 vehicles per household,[2] with 25% electric-vehicle (EV) penetration, kilowatts



[1]Load shape for a typical feeder with 150 houses at 8 megawatt-hours per year; example shown for Midwestern US on typical September day.
[2]Midnight time-of-use (TOU) rate; 90% of users adopt; users begin charging immediately if TOU benefit is >10 hours from trip end; avg plug power of 3.7 kilowatts, with average trip of 62 km; 50 days used for averaging/percentile.

McKinsey&Company | **Source:** OpenEI; McKinsey analysis

Alternatively, energy players can deploy more local solutions, such as co-locating an energy-storage unit with the transformer that charges the unit during times of low demand. The storage unit then discharges at times of peak demand, thus reducing the peak load. Another option could be using a small combined heat-and-power plant, which could be an attractive solution if the generated heat has local uses (for example, heating a warehouse as it charges a fleet of delivery vans).

As the cost of batteries continues to decline rapidly, using energy storage to smooth load profiles will become increasingly attractive. Other applications include public fast chargers, depot chargers for electric buses and trucks, and residential settings where more EV owners combine rooftop solar panels and home storage. Several factors can drive the business case for installing energy storage. These include shaving peak loads to reduce demand charges (extra fees based on peak loads) and avoid grid upgrades as well as taking advantage of lower power prices at certain times (by charging the battery when energy prices are low). Energy users can also potentially seek compensation for offering flexible services.

While some investments in grid upgrades or alternative solutions will be unavoidable, companies can greatly reduce them by tackling their root causes.

An example involves avoiding peak-load increases altogether by shifting EV-charging loads. Early insights into the charging behavior and the driving and parking patterns of EV owners suggest that for a significant share of the time that EVs remain connected to the grid, they are not actively charging. This share can range from more than 80 percent of the time for private, residential EV charging to some 25 percent for public charging. This situation creates the potential to shift the charging load and thereby optimize charging times and speeds from a system perspective, thus making charging smart.

Intelligently steering charging behavior to create value

Centrally coordinated, intelligent steering of EV-charging behavior could create value in several ways. First, it could allow even more effective peak shaving and thus greatly reduce the grid investments discussed. Second, it could allow a reshaping of the load curve beyond peak shaving to optimize generation cost (shifting demand from peak to base-load generation). And, revving charging up at times of excess solar and wind generation or throttling it down at moments of low renewables production could help to integrate a larger share of renewable power production. Finally, by providing demand-response services, smart charging could offer valuable system-balancing (frequency-response) services.

A next-horizon refinement of this approach involves vehicle-to-grid plans, which not only shift the power demand from EVs but also make it possible for EVs to feed energy back into the grid under certain conditions.

Pilot studies have shown a substantial willingness of EV owners to participate in coordinated smart charging. The total value created can be up to several hundred euros per EV each year, depending on local specifics.

To realize these benefits, energy players must make some up-front investments in smart-charging infrastructure and work to achieve effective collaboration with other stakeholders. But once these aims are established, EVs will no longer pose a cause for concern from an energy-system perspective. Instead, they will become a source of benefit by making the system more cost-effective, resilient, and green.

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The expected increase in EVs on the road creates a challenge for power companies. While EVs will not lead to a substantial increase in power demand by 2030, they will reshape the load curve, thus placing new strains on the grid. The suggestions offered here can help energy players overcome this challenge and effectively integrate growing numbers of EVs on the road, thus creating substantial benefits for the energy system.

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