World Economic Forum

The Future of Electricity
New Technologies Transforming the Grid Edge

In collaboration with Bain & Company

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Contents

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Preface

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A reliable, economically competitive and environmentally sustainable electricity system is the cornerstone of a modern society. The Fourth Industrial Revolution builds on the digital revolution and combines multiple technologies that are leading to unprecedented paradigm shifts in the economy, business, society, and for individuals. It involves the transformation of entire systems. The electricity landscape is a prime example of the Fourth Industrial Revolution as it undergoes transformation, becoming more complex than ever before, with rapidly evolving technologies, emerging innovative business models and shifting regulatory landscapes.

Building on the World Economic Forum's previous work on the Future of Electricity and the Digital Transformation of Industries platforms, we have examined three major trends affecting the electricity grid: electrification, decentralization and digitalization. Our recommendations aim to accelerate the deployment of these grid edge technologies and the economic and societal benefits they bring.

Towards those goals, this report identifies critical actions for public- and private-sector participants to hasten the deployment and integration of grid edge technologies, to increase sustainability, customer choice, reliability, security and asset utilization. These recommendations support the Forum's efforts to understand and shape industry transformation across all sectors through global System Initiatives.

The trends and recommendations described in this report were discussed at the World Economic Forum Annual Meeting 2017 in Davos-Klosters, Switzerland, in a high-level roundtable that included policy-makers, technology innovators and pioneers, automakers and representatives from industry – utilities, renewable developers and equipment manufacturers. The Forum intends to collaborate with countries and policy-makers around the world to examine the promotion of grid edge technologies in various markets.

This report seeks to present a holistic view of the evolving electricity landscape, and the recommendations target the system level rather than individual entities. We trust this platform will help accelerate the integration of grid edge technologies for the benefit of society.

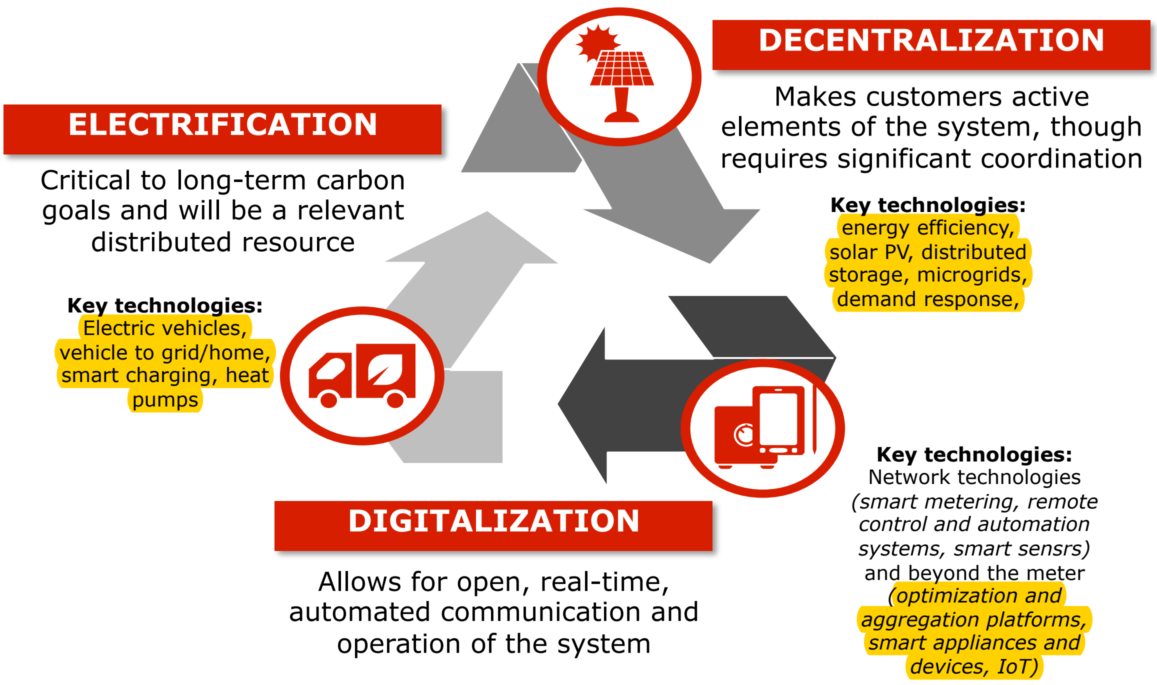
Overview

The electricity system is in the midst of a transformation, as technology and innovation disrupt traditional models from generation to beyond the meter. Three trends in particular are converging to produce game-changing disruptions:

- **Electrification** of large sectors of the economy such as transport and heating
- **Decentralization**, spurred by the sharp decrease in costs of distributed energy resources (DERs) like distributed storage, distributed generation, demand flexibility and energy efficiency
- **Digitalization** of both the grid, with smart metering, smart sensors, automation and other digital network technologies, and beyond the meter, with the advent of the Internet of Things (IoT) and a surge of power-consuming connected devices

These three trends act in a virtuous cycle, enabling, amplifying and reinforcing developments beyond their individual contributions (see Figure 1). Electrification is critical for long-term carbon reduction goals and will represent an increasingly relevant share of renewable energy. Decentralization makes customers active elements of the system and requires significant coordination. Digitalization supports both the other trends by enabling more control, including automatic, real-time optimization of consumption and production and interaction with customers.

Figure 1: Three trends of the grid edge transformation



Three factors fuel the potential for disruption by these grid edge technologies:

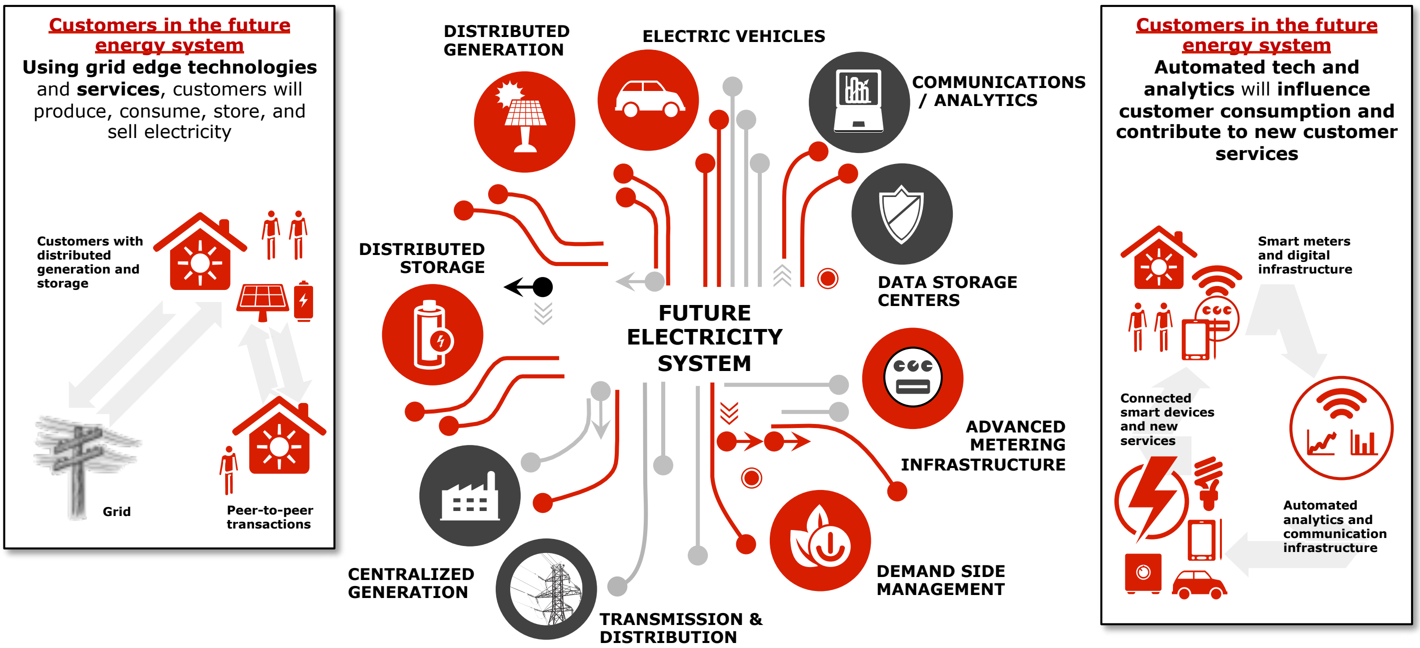
1. Their exponentially decreasing costs and continuous technical enhancements
2. Their enabling role for innovative business models, built around empowered customers
3. The sizeable improvement to the asset utilization rate of the electricity system, which is typically below 60% in the United States; electric vehicles alone could add several percentage points to system asset utilization (as noted below)

Together, these grid edge trends pave the way towards a system where traditional boundaries between producers, distributors and customers are blurred, increasing the complexity of system governance. Customer preferences and expectations are shifting towards fewer carbon emissions, greater choice, real-time interaction and sharing, always-on connection, higher transparency, experiences and learning opportunities through services more than products, better reliability and security.

Drawing parallels to the media industry and the internet revolution, it is possible to expect that customers will participate differently from before. The role of the grid is evolving beyond supplying electricity and becoming a platform that also maximizes value of distributed energy resources. Revenue models will see a smaller share of income derived from centrally generated electrons, but could be compensated by revenue from new distribution and retail services. Individual customers will be able to select the technologies of their choice, connect them to the grid and eventually transact with other distributed and centralized resources.

This smarter, more decentralized, yet more connected electricity system could increase reliability, security, environmental sustainability, asset utilization and open new opportunities for services and business (see Figure 2).

Figure 2: The future energy system will provide additional roles for the grid and incorporate many customer technologies

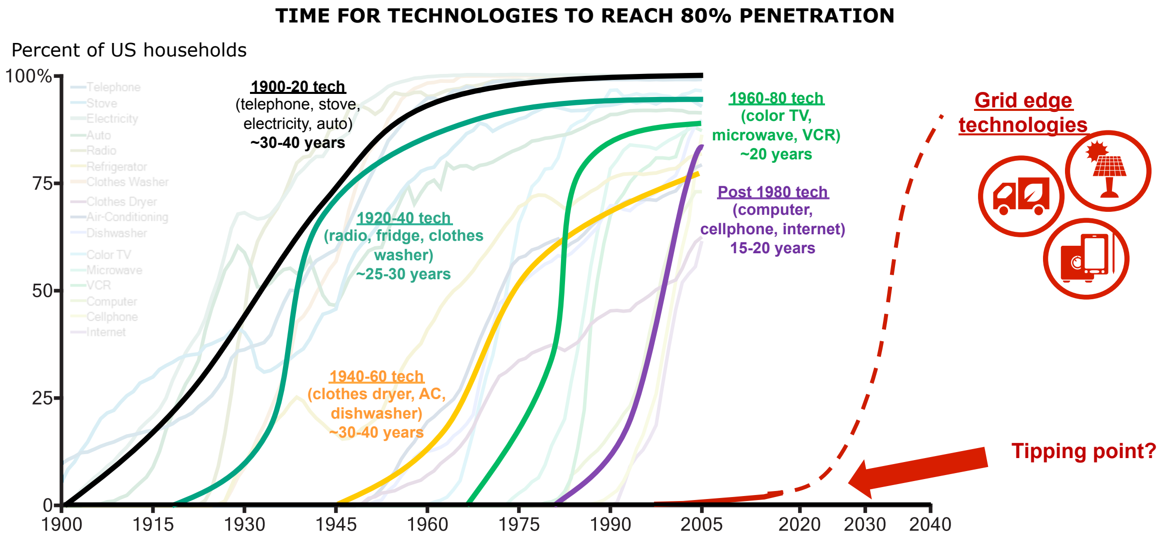


By increasing the efficiency of the overall system, optimizing capital allocation and creating new services for customers, grid edge technologies can unlock significant economic value for the industry, customers and society. Previous analysis by the World Economic Forum has pointed to more than $2.4 trillion of value from the transformation of electricity over the next 10 years. Society will benefit from a cleaner generation mix, net creation of new jobs related to the deployment of these technologies and a larger choice for consumers. Grid edge technologies can also improve social equity by creating value for low-income segments of population. Under the right regulatory model and targeted innovative business models, low-income households could participate and benefit from the value created by grid edge technologies.

Worldwide, several grid edge regulatory innovations showcase the change taking place, including New York's Reforming Energy Vision initiative, Jeju Island's Carbon Free Island initiative, the UK's RIIO regulation and the European Commission's Energy Winter Package. There is also change in the private sector, with new cross-sectoral partnerships to deliver the enabling infrastructure and company reorganizations to develop new business models.

The adoption rate of these grid edge technologies is likely to follow the typical S-curve seen with previous technologies such as TVs, white good appliances and the internet (see Figure 3). It has always been difficult to accurately forecast when technologies reach their tipping point and spread at an exponential pace. However, in the past few decades the time to reach the point of mass adoption has decreased to about 15 to 20 years.

Figure 3: Grid edge technologies will likely follow an adoption S-curve similar to other innovative products



Source: World Economic Forum and New York Times

It is worth noting that the system faces a great risk of value destruction if it fails to capture the benefits of distributed energy resources, which could result in stranded network assets and eventually customer defection from the grid. This risk represents one more reason to identify and take the most effective action to accelerate the transition and make it cost-effective. The Forum believes this transformation is inevitable and that status quo is not an option. The key issues are, therefore, how the public and private sectors can successfully deal with it and shape it.

An efficient transition towards this new electricity system faces four main challenges. First, electricity is still largely perceived only as a commodity, making customer engagement in new technologies a costly and difficult endeavour. Second, the current regulatory paradigm hinders distributed resources from providing their full value to the system. Third, uncertainty around rules prevents key stakeholders from deploying enabling infrastructure that could complement the grid as the backbone of the future electricity system. Finally, some segments resist a cultural change towards a different allocation of roles and new business models.

The Forum's recommendations, formed after assessing practical examples and best practices in mature markets, fall into four categories:

1. **Redesign the regulatory paradigm.** Change the rules of the game, advancing and reforming regulation to enable new roles for distribution network operators, innovation and full integration of distributed energy resources
2. **Deploy enabling infrastructure.** Ensure timely deployment of the infrastructure to enable new business models and the future energy system
3. **Redefine customer experience.** Incorporate the new reality of a digital, customer-empowered, interactive electricity system
4. **Embrace new business models.** Pursue new revenue sources from innovative distribution and retail services, and develop business models to adapt to the Fourth Industrial Revolution

Grid edge technologies offer the potential for an exciting transformation of the electricity industry, one that creates more choice for customers, greater efficiency, more efficient decarbonization, and better economics for stakeholders across the value chain. By following the recommendations in this report, policy-makers, regulators and private enterprise can work together to secure the positive changes they offer to electricity markets worldwide.

Grid Edge Challenges and Opportunities

The three technology trends bringing disruption to the electricity industry – electrification, decentralization and digitization – will affect grid and behind-the-meter economics differently depending on their trajectory of adoption. To gain a better understanding of which mechanisms will affect the adoption curve and which tools (including policies and regulations) will accelerate adoption, each of these technology trends is examined in detail below.

1. Electrification

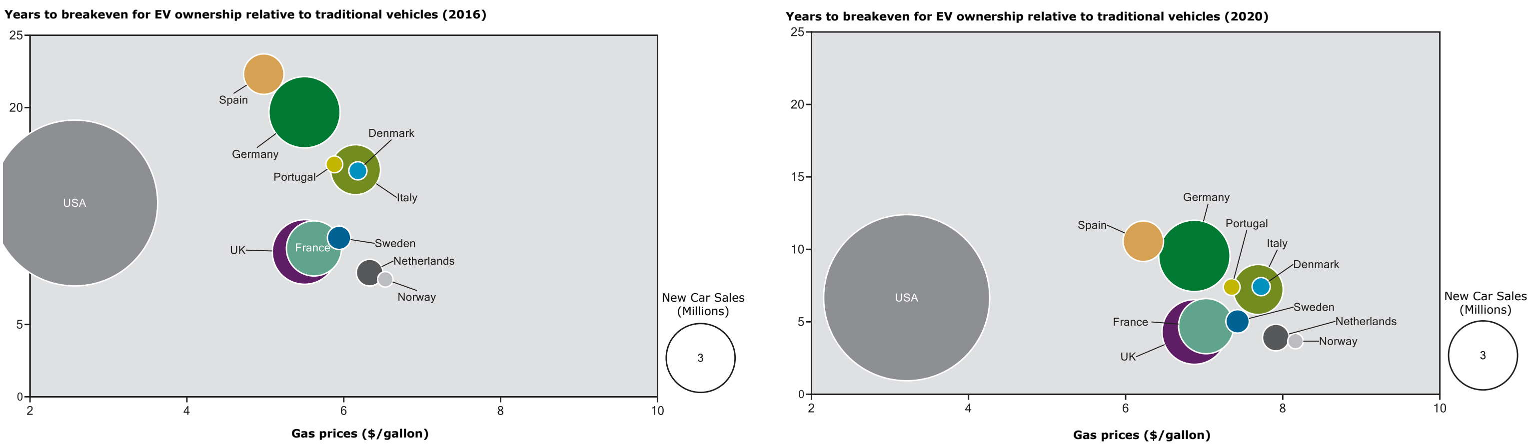
As generation shifts to more renewable sources, electrification creates further environmental benefits by shifting many end uses of electricity (e.g. transportation and heating) away from fossil fuel sources, and in many cases electrification increases energy efficiency. In OECD markets, the most promising electrification opportunities are in those segments that are among the largest polluters: transportation, commercial/industrial applications and residential heating. In the United States, of the 5 billion tons of CO2 emissions in 2015, transportation was the largest segment (1.9 billion tons), followed by commercial/industrial processes and manufacturing (1.4 billion tons) and residential heating and appliances (1 billion tons). Light-duty vehicles (cars, small trucks), at 1 billion tons, accounts for slightly more than half (55%) of the transportation segment, making this a critical area for decarbonization and the current focus area for the initiative. Similarly, in the United Kingdom, transport accounts for about 30% of the country's total carbon emissions (422 million tons in 2014), where passenger cars and light-duty vehicles account for the majority of the transport segment.

Electrification of transport

Electric vehicle (EV) technology has evolved rapidly over the past five years. Range has improved from less than 100 miles (161 km) up to 300 miles (483 km) for some models, addressing a prime convenience issue compared to traditional vehicles with internal-combustion engines (ICEs). The cost of batteries has declined from about $1,000 per kilowatt-hour (kWh) in 2010 to below $300 in 2015, dramatically lowering the cost of EVs and enabling lower-cost models such as the Nissan Leaf or the Tesla Model 3. These price drops have closed the gap with more traditional ICE cars, and buyers can choose from more available models and styles every year. As a result, 2015 was the year where over one million EVs globally were on the road.

Today, electric vehicles in the largest markets benefit from direct subsidies, for example, in the form of tax credits that partially offset higher purchase costs. By 2020, EVs will be economical without subsidies in many countries – reaching three- to five-year breakeven periods compared to an investment in a traditional car or truck (see Figure 4). This improvement is due primarily to the declining costs of batteries, which account for most of the cost differential of electric vehicles today. Battery costs are expected to decrease to below $200 per kWh by 2020 (see Figure 5).

Figure 4. By 2020, with decreasing battery costs, improvement in EV utilization, and rising gas and electricity prices, the number of years to breakeven for EV ownership relative to traditional cars will drop in many markets.



Source: World Economic Forum

Challenges

Even as EVs are expected to become economically competitive, several infrastructure challenges could limit successful adoption of EVs. First among these is the paucity of charging stations, which lag far behind the number of gasoline stations. Today, slow charging stations cost about $1,200 for a residential charger, $4,000 for a commercial garage charger and $6,000 for a curbside charger. Reallocating EV subsidies from vehicles to charging stations over the next five years could enable the deployment of two to eight times as many charging stations compared to the number of EVs subsidized. Public infrastructure is also lagging behind mostly due to uncertainty related to the model of deployment, including costs, ownership and technical requirements. High-power charging infrastructure (greater than 150kW) positioned along highways would be a good choice for this public infrastructure.

Vehicle charging may also present new challenges if the deployment of charging technology and pricing signals fails to enable flexible and smart charging. For example, if all of California's EVs by 2020 were charged during peak hours, it could increase peak load by 13%, requiring significant new investments in peak generation assets and reduced overall utilization of generation assets.

Opportunities

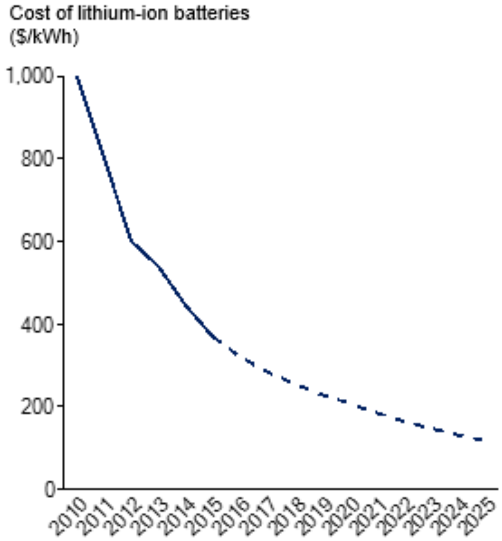
Adoption of EVs will increase electricity consumption, and offer a great opportunity to optimize utilization of the grid. This could be accomplished if recharging technology, together with proper pricing and smart and flexible charging, are deployed – e.g. car owners charge their EVs at times when grid utilization is low (at night) or when supply is very high (windy and sunny afternoons, when renewables are highly productive). In addition, vehicle-to-home/vehicle-to-grid (V2G) technology could be an enabler – where electricity of the batteries can be injected back to the home or grid. In 2015, EVs in California represented about 0.3% of total load, drawing 650 gigawatt hours (GWh). If California reaches its goal of 1.5 million zero-emission vehicles by 2025, they could account for 2% to 3% of the total load in that state, depending on the mix of vehicles. This percentage will continue to climb if EV adoption follows forecast growth. Analysis by the World Economic Forum has shown that this increase in EVs could result in increased system asset utilization by several percentage points.

In broadly cited estimates, in which EV adoption relies on individual customer purchases, EVs will represent a growing and significant portion of new car sales globally: 25% by 2030 and 35% by 2040 (see Figure 6). Sales at this level would mean that EVs could make up 5% to 10% of total vehicle stock by 2030, in line with International Energy Agency (IEA) estimates to reach the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement targets of deploying 100 million electric cars by 2030.

However, under other scenarios, EV adoption could advance even faster. Autonomous driving technology may be one of the biggest accelerators of EV adoption, along with declining battery costs. Electric vehicles also strengthen the economic case for autonomous mobility services such as self-driving taxis, as they offer cost and convenience advantages over conventional vehicles. This technology creates value in several new ways. First, it will allow commuters to focus on working, reading, entertainment or even sleeping rather than driving. Second, autonomous vehicles lend themselves more readily to car sharing when not in use by their owners. This new revenue stream can make the investment in a new car more attractive. A shared car's higher utilization makes a strong case for it to be electric, given their lower operating costs per mile. Ultimately, autonomous technology may encourage a transition to "transportation as a service", where individual customers buy fewer cars and companies own large fleets of electric, autonomous vehicles.

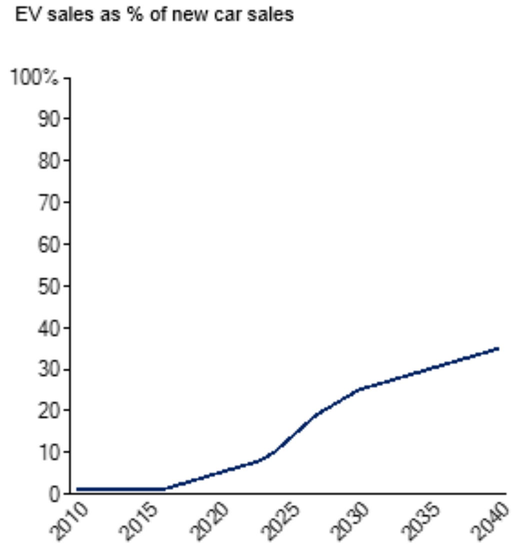
Although the economics of electric vehicles are well suited to fleets of autonomous cars, regulations and laws will have to evolve to allow and encourage these driverless vehicles. Major auto manufacturers project that fully autonomous vehicles will be available in the next 4 to 5 years, especially if fleet companies such as Uber and Lyft invest heavily in the space. If the private sector invests in autonomous technology, EV numbers will probably increase dramatically beyond the projections that rely on individual customer decisions and replacement cycles. This would also have environmental benefits, improving health and air quality in many cities. In addition, the electrification of private and public transportation fleets could further stimulate an introduction of light-duty electric vehicles.

Figure 5. Declining cost of batteries, from $1,000 per kWh in 2010 to $300 kWh in 2016, has helped encourage adoption of EVs and storage



Source: Bloomberg

Figure 6. Forecasts of EV adoption show them making up about 25% of new car sales by 2030 and 35% by 2040

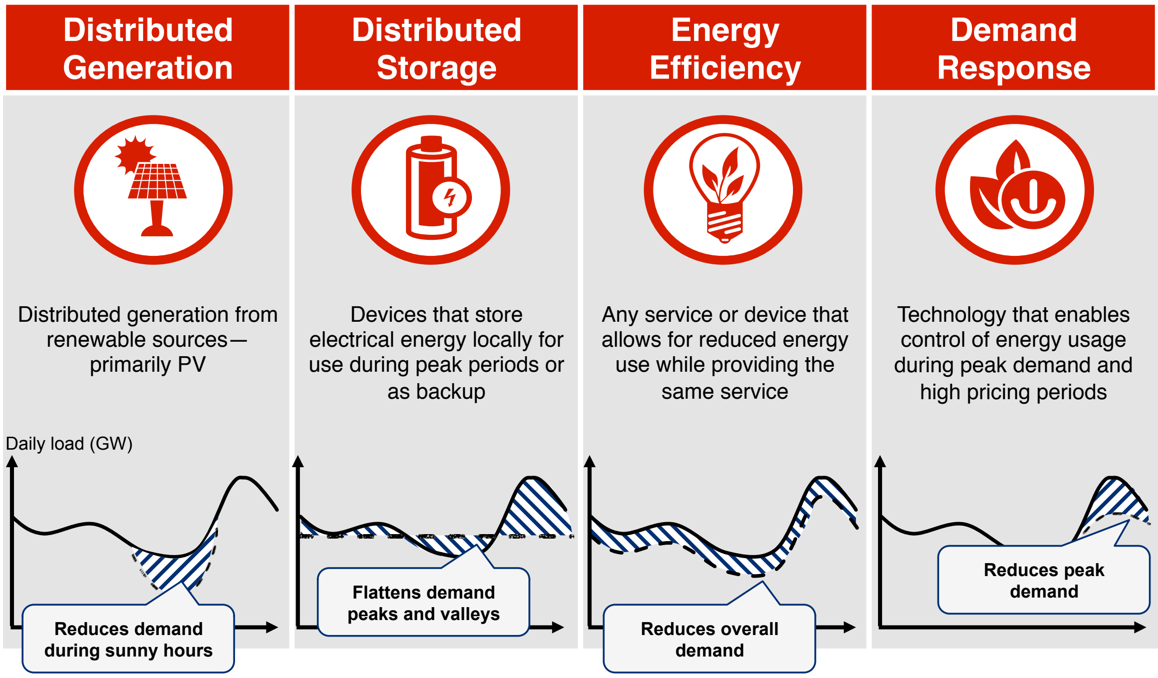


Source: Bloomberg

2. Decentralization

Decentralization refers to several technologies with different implications for the grid:

- **Distributed generation from renewable sources** (primarily photovoltaic solar) reduces demand during sunny hours of the day.
- **Distributed storage** collects electrical energy locally for use during peak periods or as backup, flattening demand peaks and valleys.
- **Energy efficiency** allows for reduced energy use while providing the same service, reducing overall demand.
- **Demand response** enables control of energy use during peak demand and high pricing periods, reducing peak demand.



Distributed generation
Incentive programmes to encourage distributed generation in the form of rooftop solar photovoltaic technologies have been extremely effective in many cases, and customers have embraced them in many countries. Deployment of solar PV panels has increased dramatically in recent years with global installed capacity reaching 260 GWp (gigawatt-peak) in 2015 and expected to surpass 700 GWp by 2020. This growth has brought down the installed price of residential solar PV from about $7 per watt in 2009 to $3 per watt in 2015 in the US (and less than $3 in parts of Europe, such as Germany). New technologies, such as rooftop solar tiles and building integrated PV (BIPV), are now becoming available, broadening the future potential of distributed generation.

Challenges
The conventional electricity system regulatory structure was designed around a limited number of large-scale centralized generation assets connected to a grid that carried electricity in one direction, to customers, and divided the one-way flow of power into siloes of various roles across the value chain. With distributed generation, distribution grids become active and see power flowing in both directions, with a higher number of active customers to manage and a change in the load profile by reducing demand from the central generation. The requirements that allow management of the flow of electricity in real time, including revised roles of network operators and proper network technology, are yet to be fully developed in most of the countries, along with solid schemes for valuing distributed generation services.

Opportunities
Distributed generation can benefit customers and the system in several valuable ways. For customers, solar can be an attractive and economical option, especially in sunny areas where they generate more electricity. For the system overall and for utilities, distributed generation can supply electricity directly to some percentage of customers, and depending on the status of the grid infrastructure, allows deferral of capital investments to maintain and upgrade grids and related services when these are less economical.

In some cases, distributed generation may be the most affordable and expedient way to support load growth, particularly where it would be too expensive or time consuming or difficult to add new infrastructure. In Southern California, for example, the closure of the San Onofre Nuclear Generating Station and the resulting shortage of centralized capacity created a need for more electricity in a stressed area of the grid in West Los Angeles. As a result, hundreds of megawatts were procured from distributed resources, amounting to about 10% of load capacity requirements. In Hawaii, high land prices and a very mountainous terrain, combined with sunny skies, make distributed generation a pragmatic solution. The technologies can also play a part in rural microgrids, which would be especially important in areas lacking access to electricity.

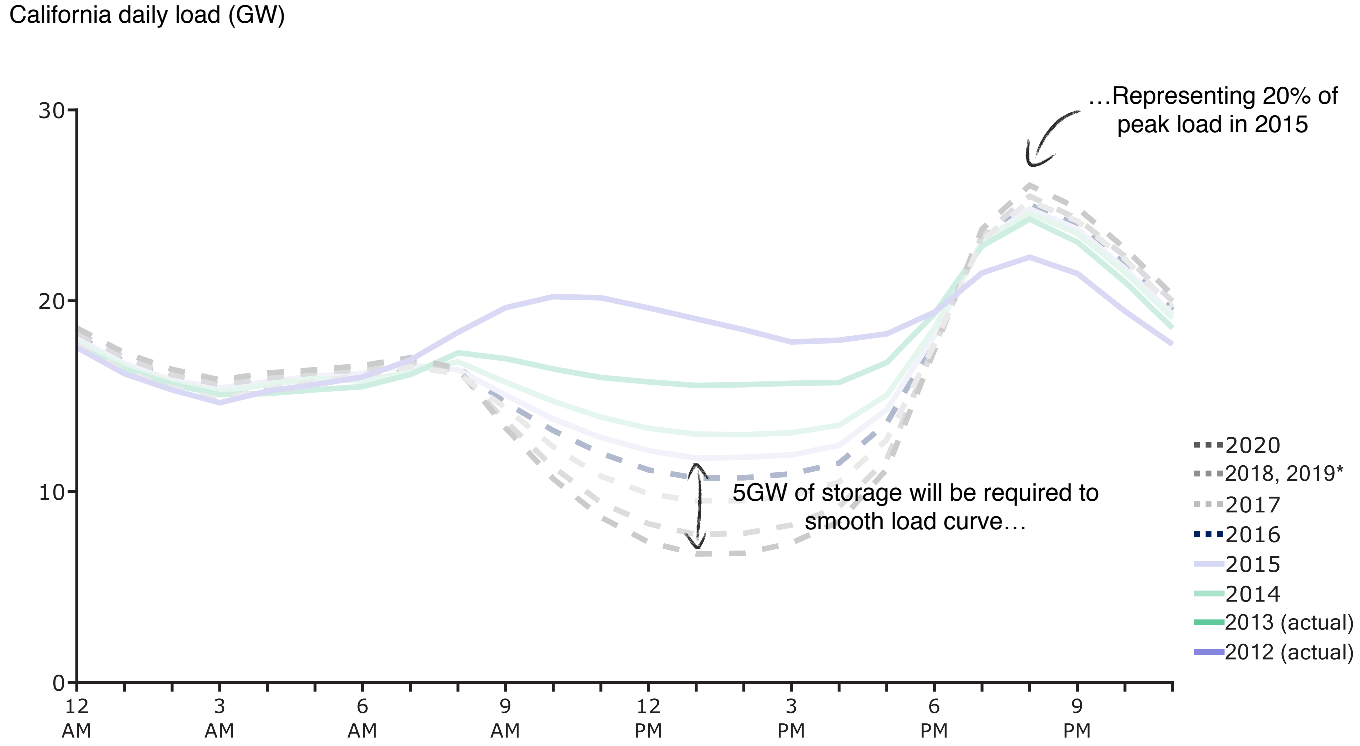
Distributed storage
As more renewables come online, the need for storage will become increasingly acute. Without storage, when too much electricity enters the grid on sunny days and windy afternoons or days with reduced demand, supply exceeds demand and negative pricing occurs – as it did more than 7,700 times in California in 2015. Forecasts estimate this imbalance will grow over the next few years as more electricity enters the grid from renewable sources, intensifying the “load duck curve” (see Figure 7). Storage adds flexibility to the system, allowing those electrons to be stored and discharged later when they are needed – for example in evening hours or during times of peak demand. Thus, storage offers a way to flatten out the peaks and valleys of supply and prevent disruptive economics.

Today, utility-scale storage (in front of the meter) accounts for the majority of installed storage capacity, providing numerous system functions, and is also proving an effective way to complement peaker plants. Behind-the-meter storage allows customers to store the electricity generated by their rooftop solar panels and use it later when needed – for example, after the sun sets. Some estimates indicate that almost half of the annual deployments of energy storage by 2020 will be non-utility-scale storage.

Projections estimate that demand for energy storage, excluding pumped hydro, will increase from 400 MWh globally in 2015 to nearly 50 GWh in 2025. Lithium ion batteries will make up most of the market, and those are likely to become more economical as vast quantities are developed and deployed for use in electric vehicles, a market where the demand for these batteries could reach 293 GWh by 2025.

Storage is becoming cheaper as a result of advances in battery technologies and is achieving higher capacities that will allow for larger scale deployment. With current projections, utility-scale storage could be a viable alternative to peaker plants by 2023. As battery costs decline, the cost of storage could reach parity with grid power in the late 2020s – an inflection point after which grid operators will be able to offer the flexibility of peaker plants by tapping the stored output of renewables.

Figure 7. As renewable generation increases, the disconnect between supply and demand – shown here as the "load duck curve"-- is expected to worsen in California. The state needs about 5 GW of storage to smooth the load curve



*Note: *CAISO forecast of 2018/2019 duck curve is nearly identical. Represents March 31.*
Source: CAISO

Challenges
Structural barriers include the lack of price signals to encourage distributed storage, no clear definition of storage as an asset and poor integration with current planning processes. Effective storage depends on storing and discharging electrons at optimal times, and that in turn depends on clear and automatic pricing signals sent to smart storage systems. Currently, most electric systems lack such real-time pricing signals at the customer level.

At the grid level, ownership structures and potential returns have not been consistently and clearly designed, and this uncertainty delays potential investments in grid assets. Storage can also provide a solution to some local congestion challenges at the distribution level and therefore defer or avoid potential upgrades in grid infrastructure. However, storage is typically not included in system planning processes and thus its impact cannot be fully realized.

Opportunities
Storage will help decarbonize generation by smoothing out the supply curve and paving the way for more renewable generation. The use of storage in commercial and industrial environments has boomed in recent years. However, storage achieves its greatest value at the system level when it is connected to the grid and a full set of services can be realized at various levels, such as network management services (frequency regulation, voltage support), utility services (resource adequacy, congestion relief) and customer services (backup power, demand charge reduction). Coupled with price signals, it can provide additional benefits in the form of rate arbitrage and deferred capital investment necessary to upgrade the grid. Some providers of distributed energy storage are combining big data, predictive analytics and advanced energy storage to reduce electricity costs for customers and simultaneously aggregate these assets to provide capacity to the grid when demand is peaking.

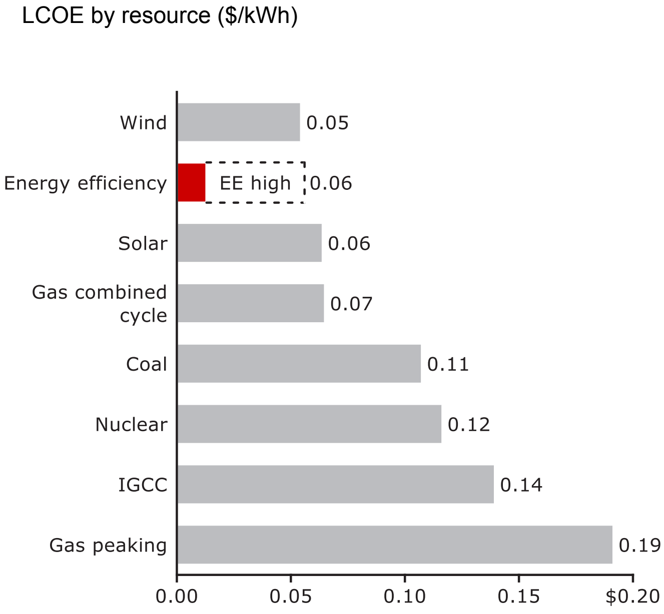
Energy efficiency
Product innovation and energy efficiency programmes have combined to make most consumer and industrial power products dramatically more efficient than they were just a few years ago. In IEA countries, investments in efficiency since 1990 have helped to avoid electric consumption equivalent to about 5 million homes each year. Energy consumption for lighting has fallen more than 75% as compact fluorescents and LEDs replace incandescent lamps. In the US, products with the EPA's Energy Star label certifying their efficiency make up 46% of new refrigerators, 84% of new dishwashers, 93% of new LCD monitors, 53% of new computers and 67% of new compact fluorescent lamps.

Challenges
Despite this apparent success, adoption of energy efficient products remains challenged by long replacement cycles for appliances and equipment (nine or more years) and largely based on technological innovation and incentives. It will take more than 25 years to replace the refrigerators in the US with more efficient ones, as nearly half of new refrigerators are energy efficient and replacement cycles take about 13 years.

Standards and mandates have proven effective in speeding up replacement cycles, but not all energy efficiency programmes have been equally successful. Some have seen limited adoption and impact, especially downstream programmes that rely on residential customer adoption. For example, Green Deal in the UK, which provided loans to fund energy efficiency improvements, saw less than 1% of loan up-take in the first 16 months and funding was later stopped. Top-down programs have been more effective, such as Energy Star and programs that encourage LED lighting.

Opportunities
Despite the limitations, energy efficiency products and programmes are worth pursuing because they are often the lowest cost way to meet resource needs. Avoiding a kilowatt-hour of demand is typically cheaper than supplying that demand by any other available resource. With an average price of about 2 to 3 cents per kWh including participant costs, energy efficiency is a cost-effective resource and is significantly less expensive than investing in additional generation (see Figure 8). The IEA estimates that every dollar spent on energy efficiency avoids more than $2 in supply investments.

Figure 8. Energy efficiency costs less than investing in additional generation (uses average unsubsidized levelized cost of energy for each generation resource)



- Energy efficiency is **cheaper than investing in additional generation**
- A range of studies tags the **average price of EE around ~2 cents per kWh**
- Participant costs of EE programs **may add ~40%** (e.g., customer installation costs)
- Average cost of **generating power from new sources can be many times that amount**

Source: Lazard "Levelized Cost of Energy Analysis 9.0", ACEEE "Best Value for America's Energy Dollar", LBL "The Total Cost of Saving Electricity",
Greentech Media

Demand response

Demand response creates flexibility by providing price and volume signals and sometimes financial incentives to adjust the level of demand and generation resources (consumption, distributed generation and storage) at strategic times of the day.

As such, it is a critical resource for a cost-effective transition to a low-carbon electricity system. Energy policies around the world increasingly acknowledge the importance of demand response and are beginning to solve the challenges that hinder its full uptake. As more distributed energy resources (DERs) come online, demand-response programmes may become even more flexible and by some estimates could reduce necessary annual investments in US grid infrastructure by 10%. Many programmes have targeted commercial and industrial customers since the residential sector can be more difficult due to a range of factors, including high acquisition costs for individuals and the limited range of flexibility available to them. However, new smarter devices, such as pre-cooling air conditioners, smart refrigerators and shallow lighting that can respond to automated price signals, as well as the progress of digitalization that is enhancing the technical capabilities of aggregation, are helping make demand response programmes easier even for residential customers.

Public and private efforts demonstrating these newer technologies are proving successful. In Gotland, Sweden, several hundred electricity customers participated in a programme that integrated price signals (for example, lower prices at off-peak times) with a smartphone app that allowed them to choose between four pre-set levels. At the start of the programme, 23% of total electricity consumption occurred during the five most expensive hours; this dropped to 19% and 20% in the first and second year of the programme. Additionally, companies have begun to offer more advanced demand-response programmes. Opower's programme alerts customers about peak times through text or email messages. Enernoc offers a turnkey demand-response programme to utilities and grid operators, as well as commercial and industrial companies.

Challenges

Three main challenges have hindered the uptake of demand response: lack of market integration (including market access, definition of standardized processes for measurement, verification and settlement, unclear role or not allowed independent aggregation), absence of price signals and inconvenience.

Opportunities

Demand flexibility creates value for customers and the grid by shrinking customer bills (by as much as 40%), reducing peak demand and shifting consumption to lower price, off-peak hours. Demand flexibility also can help providers, in some cases, to avoid or defer investments in central generation, transmission and distribution, and peaker plants. The global demand response market is estimated to be 68.8 gigawatts by 2018 – capacity will be able to be time shifted.

3. Digitalization

Digital technologies increasingly allow devices across the grid to communicate and provide data useful for customers and for grid management and operation. Smart meters, new smart/IoT sensors, network remote control and automation systems, and digital platforms that focus on optimization and aggregation, allow for real-time operation of the network and its connected resources and collect network data to improve situational awareness and utility services.

Data from smart devices and distributed resources in general will be critical to new business models and to facilitate customer engagement and adoption of grid edge technologies. Properly shared and detailed, data has the potential to improve customer experience on several dimensions, such as improving customer service through better access to more information and by enabling automated operations that will help customers flexibly manage their electricity demand and optimize costs.

Though market penetration of smart, IoT-enabled devices, including refrigerators, microwaves and dishwashers, is currently low at 3% to 5% of major customer appliances, this share is forecasted to dramatically grow, with the number of sensors in power consuming devices multiplying by six by 2020. As more areas of the value chain become digitalized – encouraged by declining costs of technology – and connected with data-generating devices, the extent and quality of the grid and data increase, and the potential use cases for what can be accomplished through analysing this data becomes increasingly interesting and valuable

Challenges

Deployment of digital technologies in the network can be hindered by outdated regulation, when the remuneration model creates a bias towards capital investments in network infrastructure at the expense of potentially cost-effective alternatives in digitalization and exploitation of distributed resources. As digitalization continues and more digital devices are deployed, communication among them will be vital. Broadband communication infrastructure supporting a broad set of services – both network and customers services – is the backbone enabling digitalization. A lack of technology standards may hinder the development of this communication infrastructure and could slow innovation in the space.

Three additional challenges for digitalization include legal infrastructure, dynamic pricing, and device premiums and replacement cycles. First, the lack of a clear legal structure around customer and distributed resources data limits growth in this area. Only a few regulatory regions (e.g. California, Illinois and Texas in the US) have well-defined rules about who can access, own and share utility customer data. Second, the lack of a dynamic pricing model, which would help the business case around the adoption of smart devices, is another hindrance. Third, high purchase premiums and long replacement cycles for these appliances are prolonging their mass adoption.

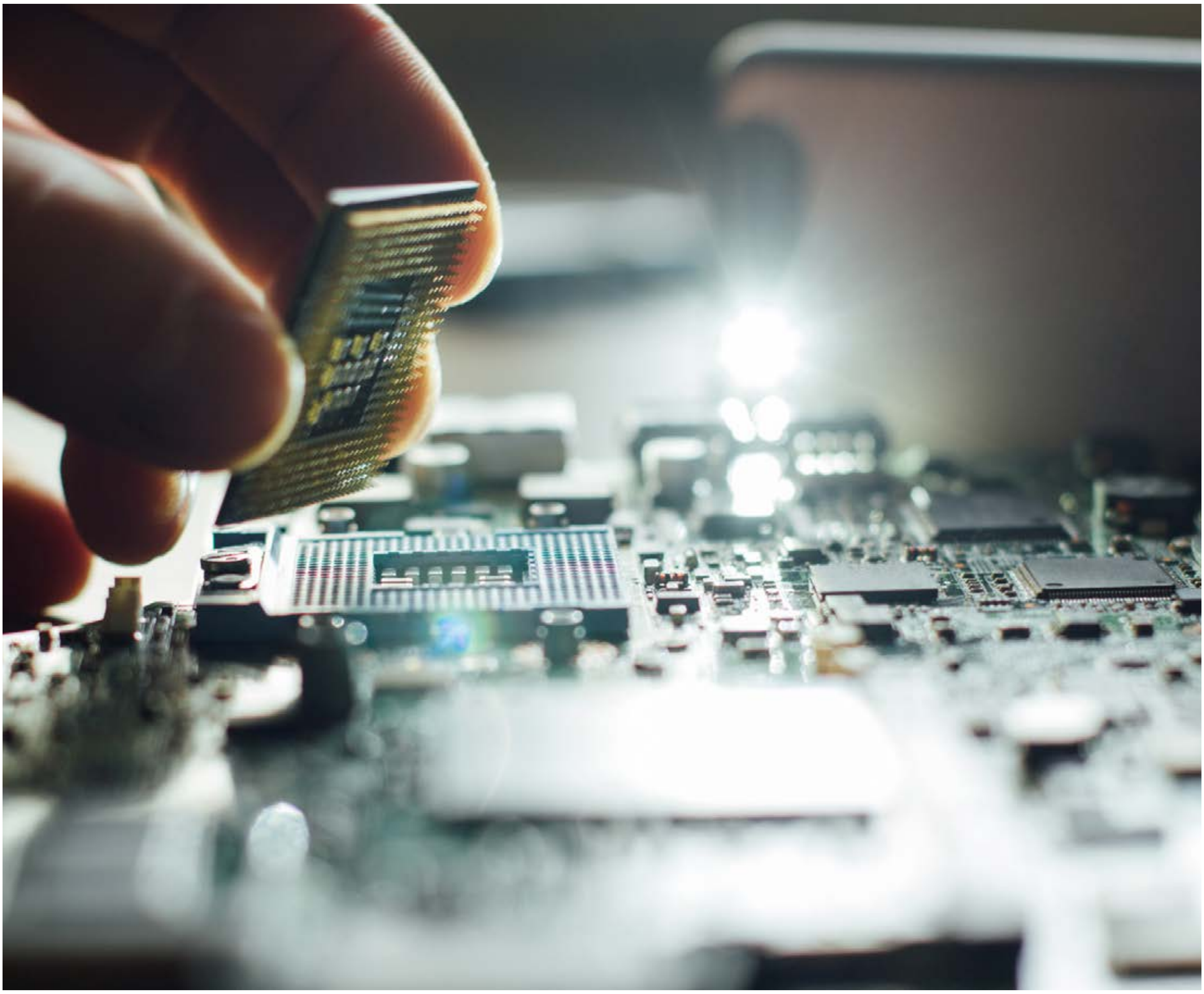
The capability to exploit data (for automated outage detection, locational targeting for DERs, or improved demand forecasting) may be a challenge, as the utility industry is not well positioned to make the most of it. The economics of the industry lack incentives for research in data innovation, and external players (such as SaaS grid platforms) are often barred from accessing the full integrated data sets they may need.

Opportunities

The increasing deployment of advanced metering infrastructure presents clear opportunities for improving quality of service, low voltage network observability and data gathering (this data offers opportunities for automated outage detection, locational targeting for DERs and energy efficiency, more detailed demand forecasting). Some utilities are taking major steps in this direction, deploying millions of smart meters in the US and Europe.

Network digitalization is a clear opportunity for cost effective development and management of the electricity system, with proven returns in quality of service improvement (duration and frequency of outages, time of service) and in the cost to serve. There are numerous technical advantages of smart grid and smart meters. Some utilities are already realizing significant value by using data to improve operations, design new products and services, and improve customer relationships. Florida Power and Light uses grid data to monitor the status of their grid and operations. FPL says its use of data, particularly from its installed base of smart meters, has contributed to $30 million in operational savings in 2014.

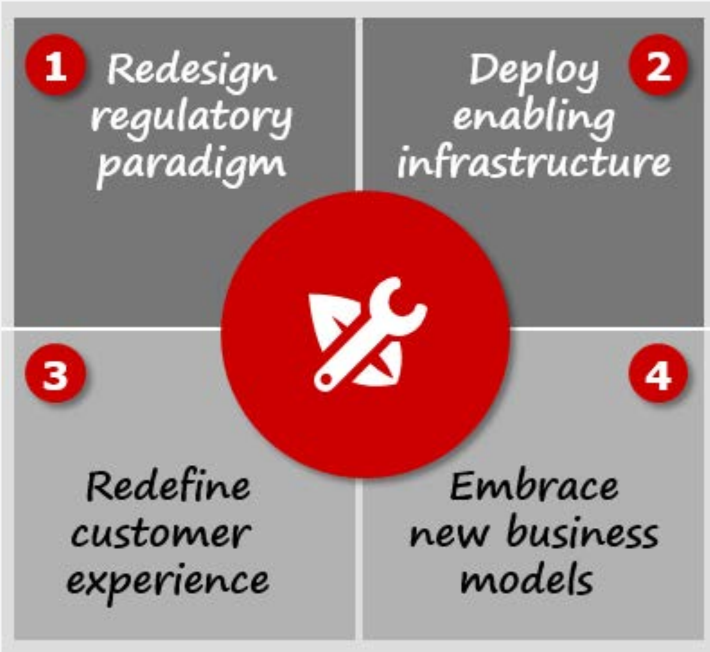
On the customer side, as the cost of sensors decreases, opportunities for the use of smarter customer technologies expands. Smart devices are a critical enabler of the grid edge technologies, and the data from them will help inform innovative new products and services – which in turn will help speed further adoption.



Grid Edge Actionable Framework

Regulation, infrastructure, customer engagement and new business models are the keys to unlocking significant opportunities and deal with the challenges of this transformation. Towards that goal, the World Economic Forum has gathered and analysed practical examples and best practices of grid edge innovations across mature electricity markets, interviewed several experts and leaders, and ran a series of workshops in the United States (mainly focused on the New York REV experience), the United Kingdom (mainly focused on RIIO) and South Korea (mainly focused on the transport electrification plan in Jeju Island).

This section identifies recommendations for both public and private sectors. Parties within the public and private sectors will need to contribute to successfully accelerate adoption of grid edge technologies, as neither can do it alone.



Principle 1	Principle 2
Redesign regulatory paradigm	**Deploy enabling infrastructure**
Change the rules of the game, advancing and reforming regulation to enable new roles for distribution network operators, innovation and full integration of distributed energy resources	Ensure timely deployment of the infrastructure to enable new business models and the future energy system
Principle 3	Principle 4
Redefine customer experience	**Embrace new business models**
Incorporate the new reality of a digital, customer-empowered, interactive electricity system facilitating customer engagement by making the experience easier, convenient and economical	Pursue new revenue sources from innovative distribution and retail services, and develop business models to adapt to the Fourth Industrial Revolution

The recommendations in this actionable framework aim to identify market priorities and regulatory incentives in order to hasten the adoption of grid edge technologies. By encouraging the supporting infrastructure, simplifying customer engagement, and encouraging collaboration and openness, the framework acts a practical guide for action by policy-makers, regulators and executives from electricity system participants.

Principle 1 – Redesign the regulatory paradigm

Change the rules of the game, advancing and reforming regulation to enable new roles for distribution network operators, innovation and full integration of distributed energy resources

Key dimensions to be addressed when redesigning the regulatory paradigm:

– Evolve the revenue model
– Integrate DERs into markets and monetize their services
– Modernize system planning
– Use price signals by redesigning rate structures

Evolve the revenue model

The revenue model should evolve around two main principles: outcomes-based regulation and a total expenditure approach. Together they can stimulate innovation and efficiency, digitalization and exploitation of distributed resources.

The first approach implies that policies reward players for reaching policy goals (such as energy efficiency, peak shaving, data sharing), instead of picking specific technologies. The second approach removes the incentive for utilities to invest only in additional network infrastructure and encourages them to invest also in non-wire alternatives, including network digitalization or procurement of services from distributed energy resources.

One good example on how to evolve the revenue model is the UK's RIIO (revenue = incentives + innovation + outputs) programme, which requires transmission and distribution operators to submit revenue proposals tied to specific performance metrics along with introducing the totex[1] model. With totex, companies in the UK are considering innovative solutions such as demand-side response or batteries as alternatives to building more capacity. Moreover, they are shifting towards purchasing services (for instance IT cloud-based solutions) rather than the traditional model of owning assets. Network companies that try innovative approaches to the goals set by policy can exceed the baseline return on regulatory equity.

Another example of this would be the Brooklyn-Queens Demand Management (BQDM) project in New York, where distributed energy resources are being utilized to support project load growth, instead of building new network infrastructure. Recognizing that the utility had replaced capital investment with operating expenses to achieve the same goal, the New York Public Service Commission authorized a return on total program me expenditures, as well as performance incentives tied to goals on customer savings. Through solar, batteries and energy efficiency, the BQDM programme enabled Consolidated Edison to defer $1.2 billion of upgrades of electrical substations in Brooklyn, while it led to an estimated net benefit of almost $9.2 million to customers.

[1] Totex, or total expenditure, includes both capital and operating expenses. It represents an attempt to consider the total cost of an asset over its life-time, and thus move away from incentives towards capex only.

Integrate DERs into markets and monetize their services

To ensure that distributed energy resources can play a role alongside large-scale centralized generation, and that their value is optimized, policy-makers should ensure the resources have access to energy markets. Doing so requires that they are clearly defined in terms of their role, asset type and ownership. Adequate market design is to be enabled, allowing independent aggregation, network operators to procure services from distributed resources, time and location-based valuing of distributed resources and improved connection speed and economics. Market mechanisms paired with regulatory incentives should reward distributed resources where it is most valuable for the system. Locational value of DERs – where it would have greatest grid value – can be assessed by combining pricing data and data from substation locations.

Recent efforts to integrate DERs into markets include California's Demand Response Auction Mechanism, a pilot programme mandated by the state's Public Utilities Commission. California's DRAM allows demand-side assets to be bid into the wholesale market, with a focus on energy efficiency, distribution resource plans and demand-response rules. For demand response, this includes participation in energy markets in increments of 100 kW and bidding increments of 500 kW in a real-time Reliability Demand Response Resource programme. California DRAM was successful in meeting targets through 120 MW contracts issued with companies offering demand response, behind the meter batteries, residential and commercial and industrial load control, and plug-in EVs. CAISO, the California Independent System Operator, is also helping to drive the transition forward by evolving their systems to accommodate smaller bidders and more real-time availability of resources.

A key dimension for the market design for DERs is to facilitate the possibility of aggregation of resources by third party service providers, and access to wholesale markets under fair conditions. An example of market design integrating DERs comes from France, which is consistently one of the largest demand-response markets in Europe, and allows for aggregated demand response by opening both ancillary services and wholesale markets to demand-response and independent aggregators. This is done through standardized processes allowing the aggregator or customer direct access to the market without retailer involvement. Full integration also requires allowing distribution network operators to procure services from distributed resources to solve issues in specific locations of the network (e.g. voltage and power flow control).

New York provides another approach with the Distribution Service Platform Provider (DSPP) introduced with the Reforming Energy Vision programme. The platform provider, typically a utility, is given the responsibility by the Public Services Commission to modernize its distribution system and create a flexible platform, incorporating DERs as necessary to meet system needs. This includes planning and accommodating generation and demand-response resources at the customer site.

All options imply careful allocation of the ownership of distributed resources, to mitigate as much as possible any risk of conflicting interests between the development of the system and its management.

In terms of connections procedures, government-funded trials in the UK have demonstrated how to reduce connection costs by up to 90% and connection time by about seven months. This allows for faster and cheaper connections, supporting flexible management of energy flows and utilizing data such as real-time network hosting capacity. Success at this level requires a digitized grid with active network management.

Modernize system planning
The introduction of DERs at scale will increase the complexity of system governance, and system planning needs to be modernized around three main dimensions: the role of distribution network operators, the need to overcome regulatory siloes (regions/countries/cities, industries, sectors) and the need for regulation that can reassure investors while keeping the pace of technology evolution.

A larger number of resources at the customer side, providing a range of services to the grid (including energy, capacity, voltage control and frequency response) and likely willing to make transactions with other distributed resources, will result in the need of a digitized network that can enable real time management of those resources, as well as support to qualification, verification and settlement of the DER-related services. This also demands the need for a system operation role at the distribution level, and regulation to enable distribution system operators to shift from network operator to platform providers. Countries will have to decide on the appropriate way to incorporate this new distribution system operation function in their overall system design. They will also have to tackle issues around the coordination with transmission operators, asset ownership, avoidance of conflicts of interest between the network and system operators, and the operating model for distributed resources. In the UK, National Grid has moved to separate their functions of system operation and the development and ownership of assets after calls from regulators and policy-makers.

In this context of blurring boundaries and evolving roles, it is important that regulators siloes are addressed and overcome through integrated plans. Possible siloes can be identified at several levels:

– **Siloes along the value chain** (e.g. between transmission system operators and distribution system operators). As long as the distribution network is transformed by the increasing number of DERs and the role of network operators evolves, the need for coordination and data and information exchange between TSOs and DSOs increases. Breaking siloes is fundamental to ensure secure and safe operation of the network, performing tasks such as congestion management, balancing, use of flexibility, real-time monitoring and control and network planning.

– **Siloes among technologies** (e.g. EVs and storage). Grid edge technologies act in a virtuous circle. Maximization of their value can be achieved if they can all contribute to achieve policy goals. Thus, rather than promoting specific technologies, regulation should set policy goals and reward for their achievement.

– **Siloes between industries** (e.g. IT/telecommunications and energy or transport and energy). As the convergence of information and telecommunication technologies within electricity network operations continues, the technology roadmaps of various sectors should intersect, and regulatory entities should be at the forefront. This includes, for example, the convergence of the automotive and electricity sectors.

– **Siloes at geographical level**. City governance, fostered by a strong urbanization trend, will play an increasingly relevant role in the deployment of grid edge technologies. Coordination with national and regional policies will be critical to ensure efficient deployment. For example, the roll-out of EV charging stations will need the involvement of local stakeholders, urban planners, distribution operators and central regulators. From a broader perspective, improved regional integration (specifically, across states in the US or countries in the EU) could be a key factor in balancing intermittent and distributed resources. This would require a harmonization of policies, especially with respect to power generation.

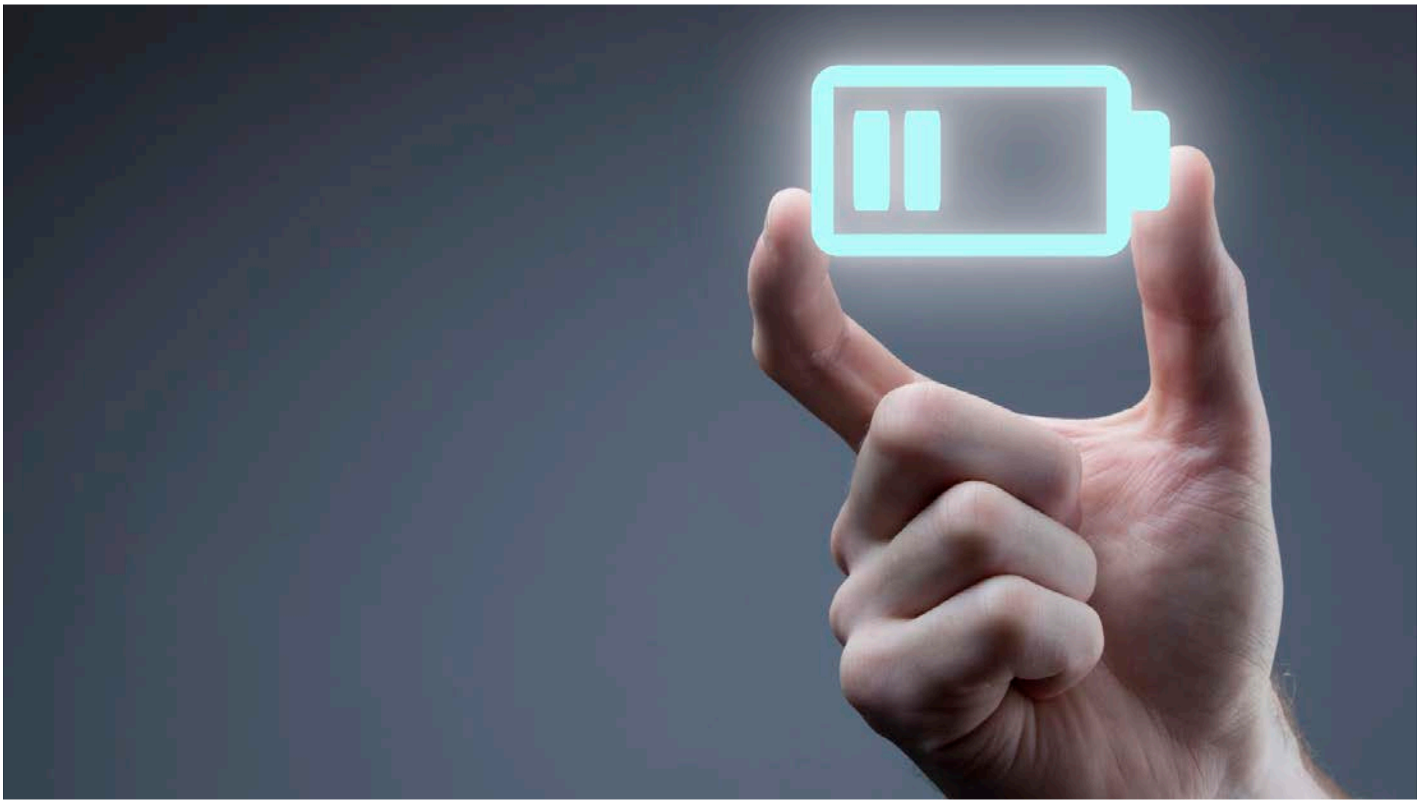
All this requires integrated plans that are most beneficial when combining technologies and data from diverse industries – for example between the automotive and electricity sectors, to support EVs. The EV test bed on South Korea's Jeju Island is a good example of an attempt to create an integrated roadmap, and a new industrial ecosystem. It combines technologies and players of the broad electricity system (technologies including microgrids, renewable energy sources, EVs and batteries, and several industries such as utilities, technology manufacturers, telecommunications and automotive). Synergies from these plans are leading to a faster expansion of technologies and more innovative business models than if they had been introduced individually.

Finally, the rapid pace of technology evolution requires regulators to have the key qualities of pro-activeness, adaptability and stability. These qualities would materialize in longer regulatory periods and flexible review cycles. A long-term approach reassures investors, facilitating their investment decisions. This approach must be accompanied by periodic reviews, to adjust to changing market dynamics, new technologies and changed costs. Consistency in regulatory principles, policies and processes will provide stability, while flexible and shorter review cycles provide the proactivity and adaptability. The policies should limit the scope of these reviews to avoid overcomplicating the process. RIIO regulation in the UK and Italy's Authority for Electricity Gas and Water (AEEGSI) are two examples of attempts in this direction. In RIIO, a regulatory term of eight years includes a mid-period review, the scope of which is restricted to specific changes on the ground – such as changes in outputs due to government policy changes or the introduction of new outputs necessary to meet customer needs. In Italy, the regulatory period was extended to eight years and divided into two sub-periods of four years each, to balance the objective of stability with the need to reform the regulatory paradigm. The first sub-period will be similar to the previous system in terms of tariff components, while the second sub-period shifts to the new totex paradigm, combined with incentives and output-based incentive schemes.

Use price signals by redesigning rate structures
Time-sensitive dynamic pricing is an essential component of a decentralized energy system, as it provides an economic signal for customers to interact with the grid. Dynamic pricing encourages customers to reduce electricity consumption during high-cost periods, reducing utility system costs. As customers install more distributed resources (such as storage or distributed generation), cost-reflective and time-sensitive dynamic pricing will enable the development of more sophisticated value services comprising different distributed resources.

Price signals can trigger changes in customers' consumption patterns, leading to a reduced peak and total consumption as it encourages customers to reduce electricity consumption during high-cost periods, reducing utility system costs. There are a few essential components of this rate design restructuring. First, price differences between peak and non-peak hours need to be large enough to make customers care and react to the price signals (only if the value differential is sufficiently large). In addition, the enrolment method (opt-in vs opt-out) and the enabling technology (automation vs manual operation) are critical factors improving the efficacy of variable rates.

Experience shows time-varying rates can reduce total energy consumption up to 10% and reduce peak load up to 50%. Many utilities in California in 2016 have started to offer various rates in order to reduce the load "duck curve" – offering hourly dynamic pricing with day-ahead prices and lower rates during certain periods of the day. In Spain, time-of-use rates are published a day ahead and then allowed to vary over the hours of the day to reflect electricity conditions – with about a 20% difference between the lowest and highest daily rates. Digital meters, expected to be deployed to all customer by 2018, are needed to measure hourly consumption.



Principle 2 – Deploy enabling infrastructure

Ensure timely deployment of the infrastructure to enable new business models and the future energy system

Several actions can be taken to ensure that the necessary infrastructure is in place to enable new business models and the future energy system, including the following:

– Define the model to deploy enabling infrastructure that is flexible, open and interoperable
– Ensure customers and third parties can benefit from data generated by DERs and the digital grid

Define the model to deploy enabling infrastructure that is flexible, open, and interoperable

The model of deployment of enabling infrastructure encompasses three main dimensions:

– Defining what is considered enabling infrastructure (for example, recharging stations, broad-band telecom and smart meters)
– Removing uncertainty by deciding rules on ownership and cost-recovery of enabling infrastructure – targeting a market-based approach whenever sensible
– Convening open standards and requiring interoperability for DERs and communication infrastructure to ensure multiple services can be combined

New infrastructure is critical to accelerate the roll-out of DERs, increase customer convenience and capture the full value of grid edge technologies such as storage, demand response and EVs. Charging stations for electric vehicles, smart meters, broadband communication infrastructure, and network remote control and automation systems (network digitization) are all fundamental enablers to services associated with DERs.

The public and private sectors in coordination have the potential to jump-start adoption and can be encouraged through innovative business models or test-beds set up by regulators such as the EV test-bed on Jeju Island, South Korea. In another example, Norway has spurred EV adoption by creating an ecosystem of subsidies, including charging stations, parking benefits and other benefits with zero marginal costs, such as the free use of carpool lanes by EVs.

Defining clear ownership, the cost recovery and the model of deployment are critical to quicken infrastructure deployment. This might prove problematic as the benefits of the enabling infrastructure are spread to various stakeholders while the costs are typically borne by one party. For instance, countries have adopted different models for the roll-out of smart meters. Italy, Spain and others have chosen to allow the distribution company to own the installed smart meters and to pass its cost to customers through the rate, while in the UK the smart meter is owned by the customer that decides to purchase it from retailers. The grid-related approach has seen a faster roll-out and cost synergies from the mass deployment.

Another example of the ongoing discussion of infrastructure ownership is PG&E's proposed deployment of 7,500 charging stations in northern California. In this model, public utilities could deploy charging stations and pass costs through to ratepayers. Another model is Tesla's national network, where a private company deploys charging stations where there is a business case – in this case, to support and encourage sales of their electric cars.

In some cases, there currently might not be any clear business case for the private sector to invest in physical infrastructure such as charging stations, where initial failures of private companies have led to limited interest by others to invest. In contrast, the regulated business model where a return could be earned based on these new rate base assets do provide a clear business case and interest by utilities. In such cases, to accelerate deployment the regulatory model would need to support regulated utilities to deploy the infrastructure where private companies will not. In addition, industry collaboration or public-private partnerships can offer viable alternatives. For example, a group of competing EV manufacturers has recently unveiled a plan to invest over €1 billion in building an ultrafast charging network in Europe.

Large-scale deployment of grid-edge technologies will require interoperability and compatibility between technologies to ensure that the combination of multiple services and "plug and play" is possible, which can be ensured through open technology standards and interoperability. The public sector should convene private sector participants to define these open standards, which will ensure standardization but still allow for flexibility and innovation in this space. A well-cited example is the open standards set in the telecom industry, resulting in devices that are easily and automatically able to operate between various networks globally. In addition, the discussion by some companies regarding creating closed loop or open system charging infrastructure also falls under this area. The utility and technology industries have taken steps in this direction, with initiatives such as those addressing smart metering communication protocols (for example, Meters and More and PRIME).

Ensure customers and third parties can benefit from data generated by distributed energy resources and digital grid

Smart meters, sensors, remote control and automation systems, DERs and connected devices are all generating large amounts of new data. Sharing this data will be essential to realize greater value from these technologies, but policy-makers and regulators will have to define the rules for who can own, access and share data. Some regulatory areas, including California, Colorado, Illinois and Texas, have already adopted data privacy rules that set standards on how usage data can be shared with third parties. A proposal in New York would allow utilities to sell customer data, and includes security provisions to keep that data safe.

The Green Button initiative from the US Department of Energy provides 60 million utility customers in the US with easy and secure access to their energy usage information, which they can then have analysed by other online services to better understand their energy use. Several data-sharing models are under consideration across regions. Data hubs store the data with a central authority that manages access by interested parties. In the Nordic countries, for example, this data hub manager can be the transmission system operator (TSO).

Another model takes a decentralized approach with communication standards that allow various network operators to collect and distribute data to eligible partners. This model is frequently used in projects in Germany and elsewhere in the EU. Blockchain registries also hold some promise for data sharing, although a detailed model has yet to be worked out.

Principle 3 – Redefine customer experience

Incorporate the new reality of a digital, customer-empowered, interactive electricity system facilitating customer engagement by making the experience easier, convenient and economical

Services enabled by grid edge technologies have often been weak in engaging customers. This might be due to several reasons – that most customers see electricity as an undifferentiated commodity, spending in average less than 10 minutes reviewing their monthly bill. Or that attempts to bundle new services to the conventional selling of electricity have often not incorporated emerging customer attitudes and innovative business models, and have faced difficulties.

For example, in Nevada utilities had difficulty signing customers up for time-of-use rates, even though the utilities guaranteed a refund at the end of the first year if those rates proved higher than traditional volumetric rates. Even with this guarantee, adoption of the time-of-use rates was very limited because customers were unwilling to deal with the inconvenience of monitoring and adjusting their electricity use – for example, by reducing air conditioning during hot summer months.

Digitalization is transforming the way customers interact with their service suppliers. Within the context of the Fourth Industrial Revolution, customer expectations are shifting, and companies seeking a competitive advantage are creating better experiences to meet those expectations. Emerging social concepts like the sharing economy, coupled with the rise of distributed technologies, foster the development of customer-centred services such as community solar or energy trading virtual marketplaces.

Three ways to redefine the customer experience and simplify customer engagement are to:

- Create a seamless customer experience by overcoming the complexity
- Shift the customer experience by combining multiple services
- Recognize sophisticated customer segmentations and tailor offers accordingly

Create a seamless customer experience by overcoming complexity

Complexity will hinder adoption in any industry, especially in this industry where customers may not fully understand the technology behind the products and services. Successful products make it easy for customers to engage, offering simple customer interfaces that incorporate automation, self-learning and multi-device applications. Customers want experiences that are fast, intuitive, simple and effortless, and smooth and consistent. Nest's thermostat, for example, learns customer schedules and automatically adapts and programmes itself. Nest indicates savings of 8 billion kWh for its customers since 2011, and this is likely to increase with its next generation.

Another example of this kind of initiative comes from the UK, where a new service enables customers to buy gas and electricity in advance and monitor their usage – purchasing fuel in packages from one to 180 days at a set price. If customers do not need to use power for a period of time, the days where no gas or electricity is used will not be taken out of the package.

Customer choice is important, but opt-in schemes create obstacles for new technologies. Opt-in programmes that encouraged customers to buy their own smart thermostats or join time-of-use programmes have seen lower participation rates; making participation the default while allowing for opt-out provides customers with the same options while facilitating adoption. In Sacramento, California, a pilot programme of the Municipal Utility District found that when customers were defaulted into time-of-use rates, 90% of them stayed on the programme. In an opt-in programme, only 15% to 20% of customers agreed to sign up for the new rates. Regulators across California now consider participation the default option.

Embedding standards and incorporating smart capabilities in household appliances and grid edge technologies in new buildings have also proven useful ways to speed up adoption. Incorporating smart capabilities is an effective way to future-proof buildings by incorporating technologies such as electricity storage into each new building and building-integrated photovoltaics (BIPV).

Shift the customer experience by combining multiple services

Combining products and services can be an effective way to encourage adoption. Energy providers can engage customers who are looking for more than a single product, by connecting different lines of services. Commercial and industrial customers often want multisystem integration that incorporates energy storage systems into their operations. Residential customers may be more interested in "beyond-the-electron" services such as home security, which have proven successful. For some customers EVs can be a gateway to a new relationship with the electricity system, spurring the uptake of other products like electricity storage (in the form of large home batteries). For other customers, bundling energy management technologies with car, media and entertainment services (for example, in connected homes) can create new value. Different customers will engage with different technologies, and technology that can act as a gateway to push adoption can be different by customer.

Recognize sophisticated customer segmentations and tailor offers accordingly

In a digital and increasingly interconnected world, customers want services that are highly customized to their needs. Customers are looking for personalized interactions and experiences that create value according to their expectations – and those expectations will differ among residential, commercial and industrial customers, who use electricity differently.

Traditional approaches to demographic segmentation are shifting to targeting through digital criteria, where potential customers could be identified based on their willingness to share data and interact. Moreover, changes happening at the grid edge are resulting in new definitions of customer segments, beyond the traditional distinctions of size, load factor, and residential vs commercial and industrial. It will be especially important to incorporate new and shifting customer attitudes towards being digital, adopting electric transport or heating and distributed resources such as PVs or batteries.

Customers will combine different technologies and by doing so will create opportunities for new and sophisticated segmentation. Traditionally, the electric industry treated customers in a one-size-fits-all fashion and was not able to segment customers based on their needs, as is common in other industries. New technologies provide the ability to focus on different aspects of electricity – such as reliability or a clean supply of electricity, free of voltage spikes of drops. New segmentation models will find ways to maximize the value of each of these attributes, according to the customer's preferences. Today, smart technologies allow utilities and other players in the electricity system to recognize new segments and tailor offers to them.

The increasing volume of customer-related data generated by distributed resources and end-user infrastructure offers significant opportunities to personalize services for energy customers. Personalization of energy services for residential customers might come in various ways, such as customizable energy bills, real-time data on energy consumption, or new customized and adapted services.

Principle 4 – Embrace new business models

Pursue new revenue sources from innovative distribution and retail services, and develop business models to adapt to the Fourth Industrial Revolution

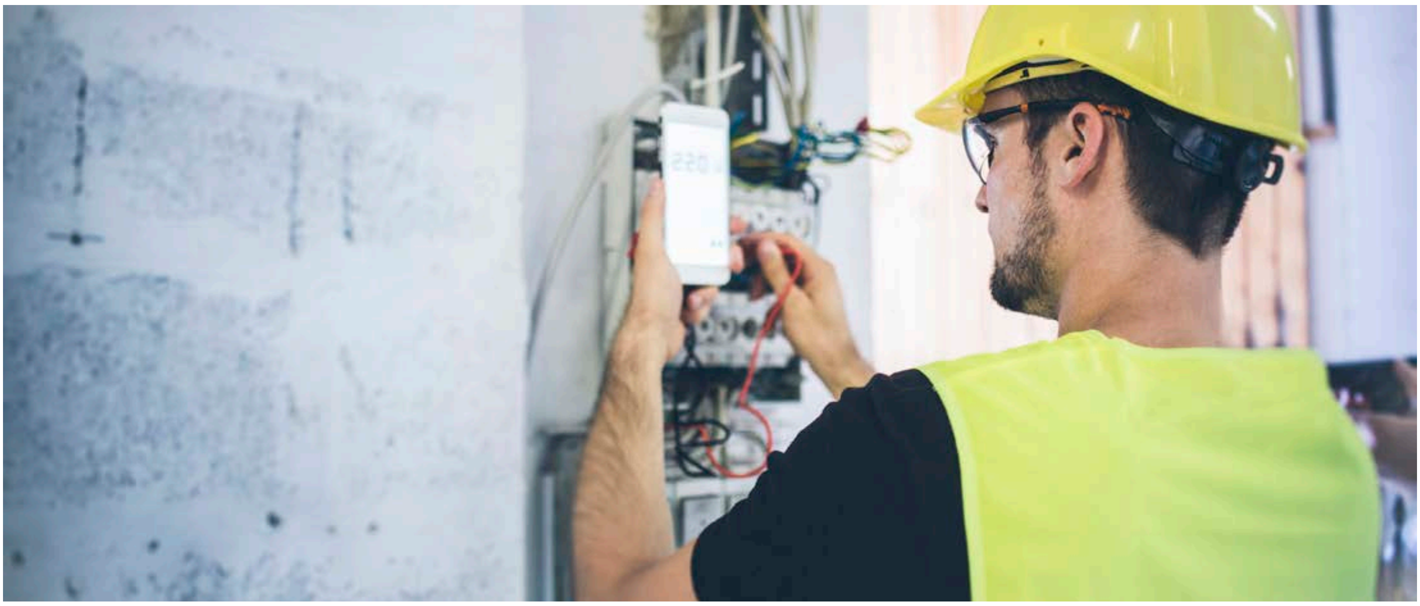
Utilities and other organizations in the electricity system will pursue new revenue sources from innovative distribution and retail services, and develop business models to adapt to the Fourth Industrial Revolution. Players in the system will increasingly:

– Shift business models towards alternative and complementary services
– Equip organizations with the new capabilities required in the grid edge world
– Develop innovative financing schemes

Shift business models towards alternative and complementary services

Integrating and exploiting distributed energy resources in the electricity system will open up new revenue streams, at both the distribution and retail levels. Distribution network operators could offer new services, including the qualification, verification and settlement of distributed energy resources – compliance obligations that are required and similar to traditional generators. At the retail level, a full set of services related to distributed resources management, provision, operation and installation is possible.

Business models are shifting from asset-intensive services to provider platforms. For network operators, distributed resources and digitalization create promising alternatives to building more network infrastructure. The network becomes a platform that maximizes the value of distributed resources and enables them to exchange services with others across the grid. The network as a platform also enables other market players to offer services without owning expensive assets.



Cross-sector partnerships will be critical to success as technologies converge and boundaries blur. In Europe, automakers and utilities are partnering to develop new business models, such as the development of energy storage facilities that rely on used EV battery modules, or ancillary services provided by vehicle-to-grid (V2G) technology. Partnerships could also be used to hasten the development of innovative business models that incent the electrification of private sector fleets.

Business model innovation could expand the market size by bringing new solutions to low-income households. Companies can identify new sources of value and revenue, for example by leveraging aggregated community resources, or realizing the value of demand-response problems and the load flexibility they enable.

Equip organizations with the new capabilities required in the grid edge world

Organizations need to prepare for the revolution in grid technologies by building up capabilities that allow them to glean insights from data and provide new services that embrace digital capabilities.

Three examples of emerging business opportunities attracting cross-sector partnerships are storage-as-a-service (which can be attractive for commercial and industrial customers), transportation-as-a-service (which can improve fleet utilization with the advent of autonomous driving) and blockchain technology. All three support the shift from asset-intensive business models to service provider platforms. Their business models require a new set of digital capabilities and internal operating models that embrace the digital transformation.

However, these new business models also carry liabilities that could impede their development. The success of transportation-as-a-service, for example, will depend on new rules that assign responsibility for crashes to either the manufacturer or someone else. Volvo says it will accept responsibility for crashes caused by errors in its self-driving systems, while Tesla has not gone as far. If these new issues are not addressed, traditional business models will not be disrupted. Organizations will need new capabilities, including digital and data analytics capabilities, in order to address the issues at hand.

Develop innovative financing schemes

Financing in the electricity sector has not evolved as quickly as grid edge technologies, as it has remained focused mostly on large power infrastructure projects. Distributed energy projects are smaller and more numerous. In spite of significant incentives and subsidies by governments, investments by US venture capital firms in new and clean energy technologies fell from $5.7 billion in 2011 to $2.2 billion in 2016.

The shift brings up numerous questions that will need to be answered. What are the implications on the risk and return profile of investments in energy assets in the future? Should small grid edge transactions be aggregated to facilitate financing? Will new energy assets have access to low cost institutional capital? New financing approaches that answer these questions will need to be developed, to support the adoption of new technologies.

Redefine customer experience

Incorporate the new reality of a digital, customer-empowered, transactive electricity system

- **Create a seamless customer experience**
  - Hide the complexity through automation, self-learning, and multi-device applications
  - Make participation the default option and embed standards into smart appliances and new buildings
- **Shift customer experience by combining multiple services**
  - Combine multiple energy services and develop beyond-the-electron propositions
  - EVs as gateway to a new relationship with the electricity system
- **Recognize sophisticated customer segmentations**
  - Tailor offers based on customer preferences towards digital, electric and distributed resources

Embrace new business models

Pursue new revenue sources from innovative distribution and retail services

- **Shift business model towards alternative and complimentary services**
  - Grow alternative revenue streams by providing innovative distribution and retail services associated to distributed energy resources
  - Shift from asset intensive business model to service provider platform
  - Consider cross-sector partnerships as a critical success factor
- **Equip organization with the new capabilities required in the grid edge world**
  - Operating models and partnerships that embrace digital and data analytics capabilities
- **Develop innovative financing schemes**

Redesign regulatory paradigm

Change the rules of the game, enabling new roles for network operators, innovation and full integration of distributed resources

- **Evolve the revenue model**
  - Promote innovation & efficiency through outcomes-based regulation
  - Remove bias towards capital expenditures by allowing non-wires alternatives to compete
- **Integrate DERs into markets and monetize their services**
  - Clearly define role, asset type, and ownership of DERs
  - Enable adequate market design, allowing independent aggregation and location-based valuing of DERs
- **Modernize system planning**
  - Shift from distribution network operators to distribution service platform providers
  - Break regulatory siloes (geographies, industries, sectors) through integrated plans
  - Reassure investors by clarifying the transition path and regulatory timeline
- **Use price signals by redesigning rate structures**
  - Introduce dynamic prices and assess efficacy of flexible demand charges

Deploy enabling infrastructure

Ensure the infrastructure enabling new business models can be timely deployed

- **Define model to deploy enabling infrastructure that is flexible, open and interoperable**
  - Define what is considered enabling infrastructure (e.g. recharging stations, broad-band telecom, smart meters)
  - Remove uncertainty by deciding rules on ownership and cost-recovery of enabling infrastructure - targeting a market-based approach whenever sensible
  - Convene open standards for DERs and communication infrastructure to ensure multiple services can be combined
- **Ensure customers and third parties benefit from data generated by DERs and digital grid**
  - Define rules and legal structures for data ownership, access and sharing for grid and customer data

Grid Edge Technology Solutions

The recommendations from the actionable framework can be distilled into a number of specific example solutions for each major grid edge technology, depending on the technology's largest opportunities and challenges. The solutions below are considered among the highest priority solutions for each technology. Numerous recommendations from the actionable framework apply to many or all of the technologies, including those that advocate a level playing field, cost reflectiveness, and long-term reliable and innovation-oriented regulation.

Grid edge technology	Sample solutions from the actionable framework
Electric vehicles	– Invest in deploying public charging stations rather than vehicles, since vehicles will be economical without subsidies in the near future – Encourage flexible charging of electric vehicles through differential pricing of electricity – Develop innovative business models to incent electrification of private sector fleets (such as Uber, Lyft and Google) – Update regulations on insurance and liability to enable autonomous vehicles
Distributed generation	– Invest in distributed generation where it makes economic sense – for example, where there are constraints on land use due to congestion, infrastructure or other factors – Consider planned distributed generation as electricity system plans are developed – and not just for building or replacing the grid, but for capacity planning as well – Incentivize innovation through outcome-based schemes, as opposed to subsidizing specific technologies
Storage	– Modernize system planning to include planned distributed storage and other options for a smart grid – Connect storage to wholesale markets through focused and transparent price signals that reflect true cost/benefit of resource
Energy efficiency	– Set efficiency standards and invest in other upstream initiatives (e.g. Energy Star) – Encourage opt-out schemes to make energy efficient products the default option – Segment customers and tailor offers to target energy conscious customers
Demand response (DR)	– Create a seamless customer experience that is automated and self-learning (e.g. more flexible, automated and convenient "shallow" demand-response products) – Ensure interoperability between devices for integrated demand response (e.g. single technology standards) – Allow independent aggregation – Set price signals (e.g. time of use)
Digitalization	– Develop data laws to ensure data sharing across market actors – Develop innovative business models for the use of data – Encourage time-of-use or dynamic pricing – Set codes and standards for smart devices – Set interoperability standards

These recommendations are based on lessons learned across mature markets. Priorities for action will differ from one country to another, depending on the local energy market, regulatory and policy objectives. All the recommendations are expected to remain priorities in mature markets, with advanced electricity systems, while priorities may vary more in emerging markets. The transition outlined in the recommendations depends on well-established regulatory bodies, organized corporations that can act on these changes, and clear definitions of roles and responsibilities.

- **Regulatory entities**, independent, with the ability to clearly define and track outputs and performance metrics, including technical, commercial and operational KPIs for reliability, power quality, workforce, system losses and other aspects of the electricity system
- **Well-organized energy corporations** with strong transparency and accountability in financial and performance reporting, as well as the capacity to take appropriate actions to adapt to changing rules and scenarios
- **Clear roles and responsibilities between organizations** in the market, which can include independent power producers (IPPs), utilities, transmission system operators (TSOs) or distribution system operators (DSOs)

These essentials are the basics for acting on the recommendations in this report, and every market should consider their establishment as the first step toward successfully implementing grid edge technologies. Markets also vary in terms of specific infrastructure or structural characteristics:

- **Affordability**, specifically, how residential and commercial prices ($ per MWh) compare to global averages; it is important to consider the amount of non-energy costs, taxes and obligations included in tariffs as they shape the public perception of energy costs and prices
- **Installed capacity**, including both overall installed capacity and clean energy-specific installed capacity per capita, which can also show the value of flexibility in that market and the overall penetration of grid edge technologies
- **Structure of the power system**, including the availability of a competitive wholesale generation market, independent transmission system and unbundled power sector
- **Security of supply**, which takes into account access to electricity and frequency of power outages

Although this report focuses primarily on opportunities for grid edge technologies in markets with well-advanced electricity systems, the World Economic Forum also looked at their adoption in several emerging markets. Some of these markets have electricity systems that are ready, in terms of the institutions and infrastructure described above, to take advantage of grid edge technologies and accelerate the transition to advanced electricity systems.

Countries such as Argentina, Brazil, Colombia, China, Malaysia, Mexico, Peru, Saudi Arabia and Vietnam could all take advantage of the deployment of grid edge solutions to solve current electricity system issues and to be ready to face the future electricity system challenges and needs.

The trends and the actionable framework of recommendations were discussed at the Forum's Annual Meeting 2017 in Davos-Klosters, Switzerland, in a high-level roundtable that included policy-makers, technology innovators and pioneers, automakers and utilities leaders. The discussion revolved around two main themes: the potential and the impact of grid edge technologies on the electricity system, and how to design innovative new policy and initiatives to unlock the value of these technologies.

Some elements clearly emerged out of the discussion, which were in line with the actionable framework of recommendations:
Introduce dynamic price signals and tariff designs that send the right signals to customers and further justifies the investment of digital technologies such as smart meters
Support digitalization of the grid, both on the hardware and software side, which is vital to increase flexibility and enable the transformation
Ensure the ability to protect customer data
Promote clear rules for storage and its remuneration
Develop harmonized regulatory frameworks that align across borders and energy markets

Priority actions include developing public-private partnerships in EV infrastructure and smart cities, together with the creation of industrial ecosystems to accelerate the effectiveness and overall value of the transformation. The implementation of the actionable framework in specific markets will require a preliminary analysis of the problems each market aims to solve – such as reliability, energy access and decarbonization.

The Forum intends to continue on this work and collaborate with various countries to examine the adoption of grid edge technologies in emerging markets and implementation of the recommendations in greater depth, the output of which will be released in an upcoming report. A first step forward is leveraging the actionable framework to accelerate the path towards smart grids in Colombia under a grid edge transformation initiative led by the Colombia Ministry of Energy and Mines and supported by the relevant private and public sector stakeholders.

Conclusions

Grid edge technologies are paving the way towards a new energy system that will unlock significant economic and societal benefits. However, there is a great risk for value destruction if the system fails to efficiently capture the value of distributed energy resources, which could leave generation or network assets stranded and see customers defect from the grid. This risk represents one more reason to identify and take the right actions that will accelerate and make the transition cost effective.

The speed of adoption and the success in shaping the transformation in the most beneficial way for the society and the system overall will depend on a broad range of factors, which fall under four main dimensions: regulation, infrastructure, business models and customer engagement. The public and private sectors will need to contribute to successfully accelerate adoption of grid edge technologies, as neither can do it alone.

Policy-makers will have to redesign the regulatory paradigm, adapting the network revenue model and tariffs, planning the electricity system (taking into account both utility scale and distributed energy resources), and using price signals.

Regulators will have to foster agile governance by adopting stable long-term regulation that includes faster reaction cycles, involving more stakeholders and including an urban regulatory dimension.

The private sector will have to acknowledge the new reality of a digital, customer-empowered, transactive electricity system by embracing new business models and simplifying and redesigning the experience of residential, commercial and industrial customers.

All stakeholders will have to deploy enabling infrastructure that is flexible, open and interoperable. Public-private partnerships will help build enabling infrastructure, even if it is not yet commercially viable and thus requires initial public intervention.

Emerging markets that may be less encumbered by existing infrastructure, investments, or system structure may have the opportunity to leapfrog some of these challenges and head straight to mass adoption of these new technologies.

The World Economic Forum examined the opportunities and challenges inherent in the advent of grid edge technologies and believes these are exciting technologies that offer more choice for customers, greater efficiency and better economics for stakeholders in the electricity ecosystem. The findings and recommendations in this report will be useful for policy-makers, regulators and private enterprise as they work to accelerate the adoption of these technologies and the positive changes they offer to electricity markets worldwide.

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