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UPDATE

Smart grid governance: An international review of evolving policy issues and innovations

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The electric power systems of many industrialized nations are challenged by the need to accommodate distributed renewable generation, increasing demands of a digital society, growing threats to infrastructure security, and concerns over global climate disruption. The "smart grid"—with a two-way flow of electricity and information between utilities and consumers—can help address these challenges, but various financial, regulatory, and technical obstacles hinder its rapid deployment. An overview of experiences with smart grids policies in pioneering countries shows that many governments have designed interventions to overcome these barriers and to facilitate grid modernization. Smart grid policies include a new generation of regulations and finance models such as regulatory targets, requirements for data security and privacy, renewable energy credits, and various interconnection tariffs and utility subsidies.

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KEYWORDS

cyber security, grid resilience, policy innovations, policy review, smart grid

1 | INTRODUCTION

The electric grid in most industrialized countries was designed to deliver electricity from large power plants via a high voltage network to local electric distribution systems that served individual consumers. Both electricity and information flowed predominantly in one direction, from generation and transmission to distribution systems and consumers. One of the original rationales for this system design was the assumption that electricity production and supply is a natural monopoly, where a single firm can produce the total market output at a lower cost than a collection of competing firms. Massive power stations with industrial boilers, turbines generators, pumping stations, and cooling towers benefited from unbeatable scale economies. But with the advancement of distributed energy resources (DERs), the information and communication revolution of a digital society, growing threats to infrastructure security, and concerns over global climate disruption, the current electricity infrastructure needs to be transformed. By moving toward a "smart grid," numerous distributed assets can be integrated, aggregators and intermediaries can add value, and consumers can better manage their electricity consumption so that their "load" enhances grid reliability.

Smart grid architectures can integrate a diverse set of electricity resources, including central station power plants as well as distributed renewable resources, energy storage, demand response, energy efficiency, and electric vehicles (Litos Strategic Communication, 2014). Figure 1 portrays a complex smart grid system with both central and regional controllers managing the two-way flow of electricity and information between utilities and consumers. The actual mix of controls and technologies will depend upon a region's transmission and distribution system, its electricity governance and business model, and the nature of the customers being served. By implementing a smart grid, electric systems can operate at higher levels of power

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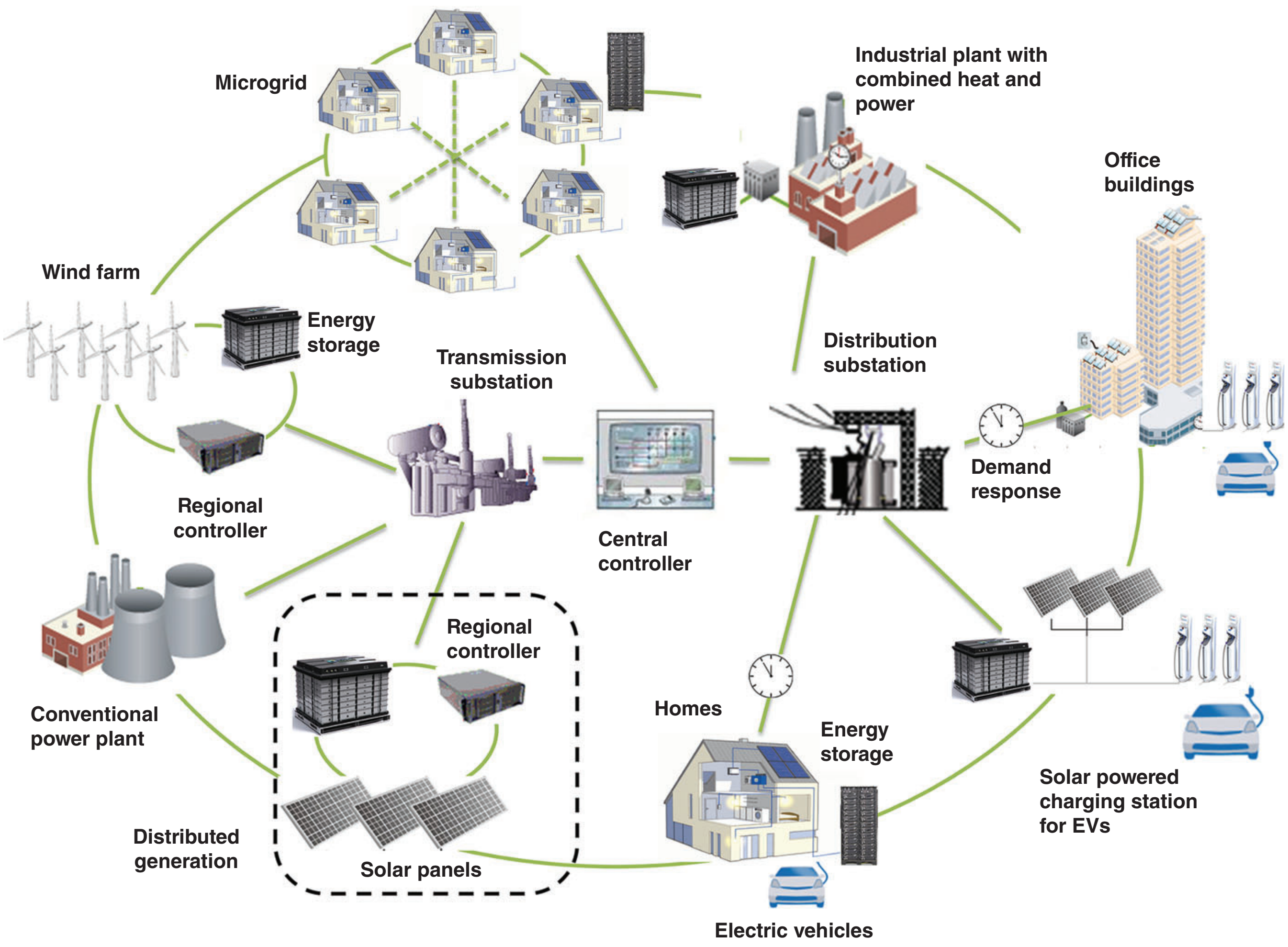

FIGURE 1 Smart grid: A vision for the future

quality and system security (The European Smart Grid Task Force, 2010). The efficiency of power delivery can be promoted by dynamic pricing and smart meters that enable consumers to play an active role in managing their demand for electricity. Payment systems can be made more efficient with digital communications and can reduce nontechnical losses that undermine grid economics in many developing countries. Without a smart grid, the full value of individual technologies such as distributed solar photovoltaics (PV), electric cars, demand-side management, and large central station renewables such as wind and solar farms cannot be fully realized.

The electric power industry is experiencing a significant transformation in the way electricity is generated and delivered throughout the grid. DERs are attracting a growing amount of capital investment and will become more important as consumers and states increasingly value choice, resilience, and clean energy resources (Electricity Advisory Committee, 2017). For example, in the United States, today:

- More than 14 million electric customers are supplying power back into the grid, out of the total 160 million electric customers in 2015 (Energy Information Administration, 2017).
- More than 80 GW of combined heat and power (CHP) generation facilities, accounting for more than 8% of total U.S. generating capacity, are operated by commercial and industrial customers in 2016 (U.S. Department of Energy, 2016).
- Distributed solar capacity nearly doubled from 7.3 GW in 2014 to 13.8 GW in February 2017 (Energy Information Administration, n.d.).
- Out of the total 147 million electric customers, more than 9 and 6 million customers participate in incentive-based and time-based demand response programs, respectively, in 2014 (EIA, 2017; Federal Energy Regulatory Commission [FERC], 2016a).
- More than 12 million generators have been installed in the United States, among these 9 million are designed for backup generation. The total generation capacity of these generators was estimated to be over 200 GW in 2007 (Pentland, 2013).

- The charging cycles of roughly 542,000 electric vehicles are being managed in 2016, providing yet another DER (Bhuiyan, 2016).

Additionally, a growing number of utilities are relying on distributed generation or storage to avoid more costly grid investments (Reilly, 2018). Some are also relying on distributed power electronics, operating on a subcycle basis, to optimize voltage and reduce generation requirements.

This is a period of significant power system innovation and technology transformation. Still, established T&D systems remain the backbone of the ability to deliver electricity in most countries. Households, businesses, and other organizations rely on this essential public service to live, study, produce goods/services and, ultimately, to thrive. Safety, reliability, affordability, and environmental stewardship are still the core principles that guide decisions on electricity generation, transmission, and delivery. In this era of transformation, these core principles remain guideposts for decision-making, even as the ability to satisfy them becomes more complex.

The growth of DERs presents opportunities to improve power systems; however, it also introduces key challenges. For example, ensuring the cybersecurity of the grid has grown more complex given the development of the "Internet of things (IoT)" and increasingly global supply chains (Cerf, 2017; Sanders, 2017). Further, the notion of reliable service has expanded to include the importance of a resilient grid, particularly in response to extreme weather conditions and widespread and sustained outages that are becoming more common with global climate change. Affordability is a constant concern, even in an era of declining or stable energy prices. For customers, the cost pressures of repairing and replacing aging infrastructure is coupled with the capital needed to incorporate "smart" technologies and DERs into an existing system while simultaneously ensuring the system remains safe, cyber-secure, and reliable.

In this vibrant era, there are countless new business ideas and technologies competing for attention and customer dollars. Not every new technology or potential resource can or should be adopted. Yet, it is recognized that many DERs can provide real value to the operation of the electric grid, as well as to customers and to providers themselves. Appropriate valuation of DERs and the smart grid is a key concern and essential building block for ensuring that they do in fact provide net value to the system.

Despite their numerous benefits, various obstacles hinder smart grids from gaining rapid and widespread market share. A wide array of policies have emerged worldwide to overcome these obstacles and protect the public's interest in affordable, dependable, and clean electric power by promoting the deployment of smart grids.

This paper begins by providing an overview of barriers and concerns that hinder smart grid deployment and the drivers and motivations that promote it. We then review experiences with smart grid policies in the United States, at both the federal and state levels. In particular, activities of four states (California, Georgia, New York, and Texas) are examined in detail. This paper also provides insights into European Union (EU) smart grid policies, with a special focus on the United Kingdom and Italy. To illustrate the smart grid policies used in other hemispheres, we also describe policy initiatives in China, South Korea, India, and Japan, and we discuss the unique value proposition for the smart grid in nations with substantial electricity poverty. Acknowledging that the transition to a smart grid is only beginning, this paper ends with a brief discussion of lessons learned and recommended future directions.

2 | BARRIERS AND DRIVERS IMPACTING THE DEPLOYMENT OF SMART GRIDS

Many smart grid technologies are available today, and their market penetration is accelerating. Nevertheless, the public benefits that could result from deep smart grid deployment are still largely theoretical because the market transformation is still in an early stage. To accelerate this transition, smart grid policies must address the key barriers that hinder deployment and leverage the drivers that motivate smart grid investments.

2.1 | Smart grid barriers and concerns

2.1.1 | Financial concerns

Large upfront cost and lack of access to capital is one of the greatest challenges to the deployment of smart grids (U.S. Department of Energy, 2009). Like many other green technologies, deployment requires significant initial investment, while the resulting benefits may not be fully realized for many years (Electricity Advisory Committee, 2017). For example, the Electric Power Research Institute estimates that smart grid investments needed in the United States would cost the average residential customer $1,000 to $1,500; amortized over a 10-year period, this would cause residential electricity bills to increase by 8 to 12% (The Electricity Advisory Committee, 2008). Although the benefits could be 3 to 6 times larger than these costs, such as lower meter reading costs, improved billing processes, reduction of nontechnical losses, enhanced reliability, improved power quality, increased national productivity and enhanced electricity service, the uncertainty in long-term benefits, and short-term costs in infrastructure and personnel training may create financial barriers to private sector investment in smart grid technologies. Without guaranteed cost-recovery timelines or sound business mechanisms to reduce risks for smart grid investment, utilities, policymakers, and other investors are reluctant to move toward a smart grid (U.S. Department of Energy, 2009).

2.1.2 | Regulation and market structure

Although electricity market reforms have been pursued in many countries, the utility business model in most modern economies is typically based upon a negotiated rate-of-return that adequately recovers utilities' capital investments. When their profits are linked with sales, utilities have a financial incentive to maximize the throughput of electricity across their wires; hence they are often reluctant to adopt technologies that improve the efficiency of power supply (Natural Resources Defense Council, 2012). Moreover, rate-of-return regulation requires that utility rates are set to provide a “reasonable” return on invested capital, and any added investments must be demonstrated to be cost-effective. As many societal benefits associated with smart grids are not fully rewarded by markets or regulators, utilities that bear all the cost of smart grid investments have little incentive to invest in these technologies.

From a consumer's perspective, electricity rates generally reflect the average and not the marginal cost of electricity production (National Energy Technology Laboratory, 2007a). Without dynamic pricing that reflects the time-dependent cost of electricity generation, customers are less likely to be interested in smart grid technologies or end-use efficiency (Brown & Salter, 2010).

Under current policy schemes, smart grid technologies face disadvantages when competing with conventionally regulated power systems. To ensure system reliability, utilities and regulators often impose strict and discriminating rules on interconnection and DERs. The FERC's November 17, 2016 Notice of Proposed Rulemaking (NOPR) has indicated that market rules have created undue discrimination against DERs aggregations, and regulatory actions are still needed to eliminate these regulatory barriers (Department of Energy and Federal Energy Regulatory Commission, 2016). Incumbent electricity providers, especially vertically integrated utilities have incentives to discourage the deployment of smart grids in light of their potential to increase competition in the electricity market. A lack of consistency among policies at different levels of governments, together with outdated codes and standards has also prevented effective collaboration and integration across regions (National Energy Technology Laboratory, 2007a).

2.1.3 | Cybersecurity, reliability, and data privacy

Network operators tend to be conservative and risk averse. Widespread and prolonged blackouts are costly and can threaten political stability in some nation–states. The high-level penetration of DERs on existing infrastructure can threaten system stability (National Academy of Sciences, 2017; U.S. Department of Energy, 2009, 2017). Developing complex-integrated systems also places demanding requirements on a wide range of technologies, especially advanced metering infrastructure (AMI) and energy storage systems (U.S. Department of Energy, 2009). Because the electric grid is an inherently open system, changes on the customer side of the meter—such as demand fluctuations and the output of distributed resources—can disrupt system operations. As a result, grid vulnerability is increasing as more devices connect to the Internet and with growth in DERs. In addition, many of the technologies that enable the deployment of smart grids, such as smart meters and sensors, can increase the vulnerability of the grid to cyberattacks (The Electricity Advisory Committee, 2008). As the number of participants and distributed generators in the electric system increases, so does the complexity of maintaining cybersecurity (National Academy of Sciences, 2017; National Energy Technology Laboratory, 2007b). Recent assaults to the grid combined simultaneous attacks on the power systems and communications infrastructure (e.g., Metcalf, CA; Metcalf Sniper Attack, n.d.) The virus that caused substations to be disconnected from the grid on December 23, 2015 in the Ivano-Frankivsk region of Ukraine caused loss of power to 225,000 customers (Lee, Assante, & Conway, 2016). Sources have reported a cyberattack on Irish power grid (EirGrid) on April 20, 2017, where attackers were able to access routers and ultimately unencrypted communications (McMahon, 2017). There are reports of similar attacks on the Wolf Creek Power plant near Burlington, Kansas (Walton, 2017).

The potential cost of such attacks is very large—as high as $243B to $1 T (Lloyds, 2015). The use of sensors and development of microgrids could reduce the grid's vulnerabilities (National Academy of Sciences, 2012). While it is doubtful that microgrids by themselves will provide sufficient “firewalls” against cyberattacks, work on the smart grid has helped develop grid technologies and cybersecurity architecture for the grid (Electricity Advisory Committee (EAC), 2015a).

The tension between protection of consumer privacy and development of the smart grid can challenge privacy protection rules. It is essential for both customers and smart grid service providers to have access to energy consumption data in order to optimize the use of smart grid technologies. This can be difficult when incumbent utilities that are currently controlling

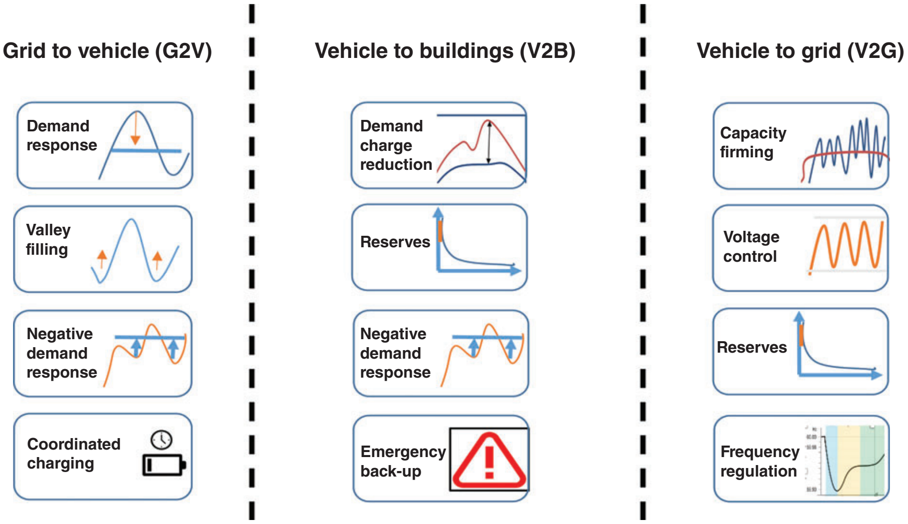

FIGURE 2 Potential services of electric vehicles in a smart grid

the meters and data on electricity consumption create barriers to market entry for new smart grid players (Brown & Salter, 2010).

2.2 | Smart grid drivers and motivations

Over the past few decades, electricity markets and technologies have experienced rapid growth and development, with increasing focus on reliability. The desire for cleaner air through renewable resources and for oil independence through electric vehicles also motivates interest in smart grids.

2.2.1 | Increasing electricity demand

Global electricity demand is expected to increase by over 150% by 2050 under the International Energy Agency (IEA)'s 2010 Baseline Scenario (International Energy Agency, 2010). Due to the proliferation of home and office appliances and a lack of real-time pricing signals, peak demand is expected to increase steadily over time. Between 1982 and 2008, growth in peak demand for electricity in the United States has exceeded the growth of transmission system infrastructure by almost 25% every year (U.S. Department of Energy, 2008). With the expectation of continued demand growth, rising peak demand (The Brattle Group, Freeman Sullivan, & Co., 2009), and stress on the transmission system, the Energy Policy Act of 2005 charged DOE to identify National Interest Electric Transmission Corridors (NIETCs). Designation as a NIETC enables developers to request federal siting authority if transmission projects are denied by state jurisdictions (Venora, 2008). As a result, transmission investments have increased over the past decade. Looking ahead, rising temperatures could cost U.S. utilities as much as $180 billion this century due to greater electricity demand (Auffhammer, Baylis, & Hausman, 2017). Smart grid technologies can help reduce demand by enabling demand-side management programs, and can improve the efficiency of electricity supply through better integration of distributed renewable and energy storage devices.

2.2.2 | Managing electricity reliability

The huge economic and social losses caused by supply failures have stimulated efforts to enhance the reliability of electricity supply. Smart grid technologies such as phasor measurement units allow utilities to monitor the grid system based on real-time information, and intelliRupter switches provide real-time telemetry that is sent to utility SCADA systems every 4 s (National Academy of Sciences, 2016). Such equipment can prevent widespread electric service interruption by shedding loads and redispatching power, while also exploiting opportunities to insert distributed resources into the grid.

For example, numerous types of ancillary services can be provided by electric vehicles with two-way charging in a smart grid (Figure 2). Most analysts focus on the potential for electric vechiles (EVs) to decrease dependency on petroleum fuels and to reduce greenhouse gas (GHG) emissions when charging with nonfossil sources of electricity. In addition, however, there may be benefits to the grid itself. First, EVs can increase the stability of the grid with coordinated charging (in a grid-to-vehicle or G2V mode). Second, EVs can strategically return stored electricity to the grid to increase capacity and provide ancillary services such as frequency regulation and reserve capacity (in a vehicle-to-grid or V2G mode; Kempton & Letendre, 1997). Finally, EVs plugged into homes, office or businesses (in a vehicle to buildings or V2B mode) can provide backup and emergency services to consumers and can activate charging in response to the grid's need for end-use consumption when prices are negative.

2.2.3 | Climate change and clean air concerns

Energy-related human activities are a major source of GHG emissions, air pollution, and climate change. As in most industrialized countries, the electric power and transportation sectors in the United States are the largest carbon emission sources, with electric power accounting for 35% of U.S. total emissions in 2016 (EIA, AEO, n.d.). Electricity generation from fossil fuels also contribute significantly to the emissions of criteria air pollutants and hazardous air pollutants, such as sulfur dioxide (SO_2), oxides of nitrogen (NOx), particulate matter (PM_{10} and $PM_{2.5}$), and mercury. In particular, electric utilities accounted for 64% of total SO_2 emissions, ranking the top among all sectors (Environmental Protection Agency, 2017). Many countries have set targets for low-carbon and renewable electricity generation to combat climate change and reduce air pollution, which require extensive changes to the current power systems. Smart grids could help to more fully exploit the potential of carbon emissions reduction and air quality improvement in energy sectors, as it enables low-carbon distributed power generation, demand management, and transport systems.

2.2.4 | Deployment of renewable power and electric vehicles

Efforts to combat climate change have encouraged the rapid development of environmentally friendly power generation and transportation technologies. In 2016, 23.5% of world electricity was generated by renewable energy, and forecasts suggest an annual growth rate of 3% (Renewables, 2016). This new tranche of renewables is expected to be dominated by wind generation (National Renewable Energy Laboratory, 2012). The transport sector is also undergoing an electrification revolution, which could consume 10% of total electricity by 2050 (Energy Technology Perspectives, 2010). As electric vehicles gain market share, it may become difficult for conventional grid infrastructures to provide reliable and stable electricity services (Energy Technology Perspectives, 2010). In particular, the intermittency of renewable energy and electric vehicle charging have to be managed intelligently to avoid supply failures, which provide an excellent opportunity for the deployment of smart grids.

2.2.5 | Economic development and access to energy

Along with the development and diffusion of smart grid technologies comes the growth of key industries, such as electric vehicle, smart appliance, and smart meter manufacturers. Their earnings could be redirected to other business investments, hence improving their competitiveness in both domestic and international markets. Countries pioneering in smart grid deployment are clearly building competitive advantage for their future economy. In the developing world, smart micrograms powered by distributed resources hold the promise of delivering electricity to the more than one billion people who do not currently have access to electricity (International Energy Agency, 2016).

Countries and their subregions and states are in different stages of smart grid deployment and face different barriers and drivers to change. Across the countries and states, we examine here are carbon footprints that range from 1.6 metric tons of CO_2 per capita in India to 23.1 metric tons of CO_2 per capita in Texas. Renewable electricity penetration ranges from 1.6% in Korea to 43% in Italy. Energy prices vary, as do levels of energy poverty, and the ability of government policies and market structures to facilitate technological innovation is equally wide ranging. Within this array of conditions, we compare and contrast the use of smart grid policies across the United States, EU, and Asia. Table 1 provides some of the key background statistics that help to explain the smart grid policy landscape.

3 | SMART GRID POLICIES OF THE UNITED STATES

The United States aspires to a low-carbon economy, but its current energy system is carbon intensive. The United States is second only to China in total energy-related CO_2 emissions—at 5,146 million metric tons (Mt) of CO_2 in 2015 (U.S. Energy Information Administration, 2017). On a per capita basis, the United States is also highly carbon intensive—averaging 15.8 metric tons per person in 2015. Its CO_2 emissions are down from a peak of 6,016 metric tons in 2007 and from 19.9 metric tons per capita in the same year, just preceding the 2008 economic downturn (U.S. Energy Information Administration, 2012a). In his 2011 State of the Union address, President Obama proposed a goal of generating 80% of the nation's electricity from clean energy sources by 2035; however, only 15% of its electricity currently comes from renewable sources, compared with 32% in Italy and 20% in Asia (see Table 7 for comparative energy use and carbon emissions data.). In 2017, President Trump expressed an intent to remove the United States from the Paris Accord on Climate Change, a policy reversal that will require at least 2 years to complete (Stavins, & J. Meyer Professor of Energy, & Economic Development John F. Kennedy School of Government, Harvard University, 2017). In the meanwhile, the U.S. Department of Energy recognizes that a smarter, modernized and expanded electric system is essential to America's world leadership in a clean-energy future (Executive Office of the President of the United States, 2011).

TABLE 1 Energy consumption, CO_2 emissions, and targets, by country and state

	Energy use (quad-rillion Btu)	CO_2 emissions (MMmt)	Population (millions)	Carbon footprint (mtCO_2/ Capita)	CO_2 emission reduction target (compared to 2005 level)	GDP (billion 2010 $)	Renewable electricity (%)
USA	97.0	5,146	325	15.83	26–28% by 2025 versus 2005 (U.S. Cover Note, INDC and Accompanying Information.pdf, 2015)	16,651	15.4
California (Litos Strategic Communication, 2014)	7.68	358	40	8.97	40% by 2030 versus 1990 (Subnational Global Climate Leadership Memorandum of Understanding, 2015)	2,603	39.8
Georgia	2.85	140	10	13.59	40% by 2030 versus 2009 (Atlanta; City of Atlanta Under 2 MOU Appendix Profile, 2015)	525	6.4%
New York (Litos Strategic Communication, 2014)	3.72	170	20	8.63	40% by 2030 (NY Under 2 MOU Appendix, 2015)	1,488	24.2
Texas	12.90	642	28	23.01	45% by 2030 versus 2010 (Austin; Under 2 MOU Appendix—City of Austin, Texas, 2015)	1,617	13.4
OECD-EU	80.7	3,930	573	6.86	40% by 2030 versus 1990 (Intended Nationally Determined Contribution of the EU and its Member States, 2015)	20,321	32.1
Italy	6.0	319	61	5.27	40% by 2030 versus 1990 (Italy Strategies, 2017)	1,850	43.4
UK	7.2	426	67	6.49	90% by 2050 (United Kingdom Strategies, 2017)	2,619	19.4
Asia	244.1	16,788	4,034	4.16		24,870	19.7
Japan	19.5	1,140	127	8.97	26% by 2030 versus 2013 (Submission of Japan's Intended Nationally Determined Contribution (INDC), 2015)	6,048	15.0
South Korea	12.2	688	50	13.76	37% by 2030 (Submission by the Republic of Korea Intended Nationally Determined Contribution, n.d.)	1,301	1.6
China	136.3	10,010	1,376	7.27	60–65% per unit of GDP by 2030 versus 2005 (Department of Climate Change, National Development, & Perform Commission of China, 2015)	9,510	23.5
India	29.8	2,108	1,311	1.61	33–35% by 2030 versus 2005 (India's Intended Nationally Determined Contribution: Working Towards Climate Justice, n.d.)	2,354	15.0
World	580.7	34,095	7,336	4.65		76,796	23.5

Notes. U.S. energy consumption and CO_2 emission data for specific U.S. states are for 2014, data are for 2015. All other data are for the year 2016 (USEIA, the State Energy Data System, n.d.; USEIA, 2017a, 2017b). GDP = gross domestic product.

3.1 | Smart grid legislation and policy context

The Energy Policy Act of 2005 was the first federal law to explicitly promote the development of smart meters. It directed utility regulators to consider time-based pricing and other forms of demand response for their states. Utilities must provide each customer a time-based rate schedule and a time-based meter upon customer request.

The Energy Independence and Security Act (EISA) of 2007 authorized the Department of Energy (DOE) to establish the Federal Smart Grid Task Force to implement and coordinate national smart grid policies. The DOE is also required to establish smart grid technology research, development, and demonstration projects to leverage existing smart grid deployments. The National Institute of Standards and Technology (NIST), a major standards developing federal agency, is directed by ELSA to develop a smart grid interoperability framework that provides protocols and standards for smart grid technologies. EISA also established a federal smart grid investment matching grant program to reimburse 20% of qualifying smart grid investments.

The American Recovery and Reinvestment Act of 2009 accelerated the development of smart grid technologies by appropriating $4.5 billion for electricity delivery and energy reliability modernization efforts. Utilities and other investors used stimulus grants to pay up to 50% of the qualifying smart grid investments (Recovery Act: Smart Grid Investment Grant (SGIG) Program, n.d.).

U.S. federal legislation has also attempted to foster electric vehicles. Currently, the United States has about 16,000 public EV charging stations (Schoettle & Sivak, 2017) and the number is growing due to recent legislative acts. For instance, the Fixing America's Surface Transportation (FAST) Act passed in 2015 (CONGRESS.GOV, 2015) facilitates usage of EVs by creating Alternative Fuel Corridors, which identify near- and long-term need for, and location of, EV charging infrastructure (Alternative Fuel Corridors, 2017). The Corporate Average Fuel Economy (CAFÉ) standards lead to higher market share for EVs, perhaps expanding to 29% by 2030 (Sen, Noori, & Tatari, 2017). Moreover, car buyers can take advantage of a federal tax credit of $7,500 for qualified EVs (Plug-In Electric Drive Vehicle Credit (IRC 30D), 2017). Electric storage participation in wholesale markets was addressed by the U.S. FERC in November 2016 (FERC, 2016b). This participation can be achieved by DER aggregation in order to satisfy size and performance requirements as proposed by the California Independent System Operator (CAISO). FERC has requested that electricity providers make changes to their existing models such as reforming their tariffs, to allow direct participation of DER aggregators.

3.1.1 | Data privacy and cyber security

Smart grid relies heavily on the two-way communication of data between utilities and consumers. Data can be stored in a variety of physical locations in the grid, which raises privacy and security concerns. Some existing federal legislation oversees the smart grid-related data privacy and cybersecurity issues, such as the Federal Privacy Act of 1974, the Federal Trade Commission Act, and the Electronic Communications Privacy Act, the Stored Communications Act, and the Computer Fraud and Abuse Act. FERC and NIST have the authority to develop smart grid cybersecurity and reliability guidelines and standards. FERC approved the Critical Infrastructure Protection cybersecurity reliability standards developed by the North American Electric Reliability Corporation (NERC) in 2008 (FERC, 2008). NIST released the Guidelines for Smart Grid Cybersecurity report in 2014, which can be used by organizations to develop effective cybersecurity strategies tailored to their smart grid features (Guidelines for Smart Grid Cybersecurity, 2014). In 2015, DOE and the Federal Smart Grid Task Force developed a Voluntary Code of Conduct that addresses privacy related to data enabled by smart grid technologies. Finally, an executive order was issued by President Trump in May 2017 that calls for actions to strengthen the nation's cybersecurity (The White House, 2017).

3.2 | State and local efforts

Building on the policy directions set by federal legislation, state and local activities also form an important part of the nation's overall grid modernization efforts. The scope and pace of smart grid deployments naturally vary according to the diverse needs, regulatory environments, energy resources, and legacy systems of different states. Decentralized policy efforts provide local flexibility and stimulate experimentation and innovation in policy design and implementation; thus, it is useful to examine smart grid policies developed at the state and local level (Brown & Sovacool, 2011). In this section, four U.S. states are selected for in-depth investigation: California (CA), Georgia (GA), New York (NY), and Texas (TX).

These states have a wide range of carbon footprints, from 9 metric tons of CO_2 per capita in New York and California to 14 and 23 metric tons in Georgia and Texas. The penetration of renewable electricity ranks similarly, with only 6 and 13% renewables in Georgia and Texas, but fully 24 and 40% in New York and California (U.S. Energy Information Administration, 2012b). Our review suggests that six types of policies are also widely implemented in these two pioneering states: net metering policies, interconnection standards and rules, smart metering targets, dynamic pricing policies, electric vehicle policies, and data privacy and cybersecurity policies.

3.2.1 | Net metering policies

Net metering allows customers to use a single meter to measure both the inflow and outflow of electricity, thus enabling them to install and interconnect their own generators with utility grids. With net metering, customers can use the electricity generated from their on-site facilities to offset their electricity consumption and sell excess generation to the utility typically at a retail price, thereby encouraging the deployment of customer-owned distributed energy systems. By allowing utilities to buy back surplus electricity, net metering helps overcome financial barriers faced by distributed renewable facility owners. The buy-back price, together with the cumulative generating capacity is determined by utility regulators; therefore, they often differ across regions (see Table 2). Eligibility criteria are commonly defined by sectors (e.g., residential, commercial, and industrial), types of renewable resources (e.g., solar, wind, and CHP), and generating capacity (e.g., less that 10 kW or up to 1 MW). Net metering rules are often updated by policy makers to meet the needs and priorities of the market. In general, the trend is to increase the system capacity cap, as in the cases in New York and Massachusetts and to broaden the eligible renewable resources (Doris, Busche, & Hockett, 2009). There have been concerns about net metering consumers not paying

TABLE 2 Net metering policies in four U.S. States (DSIRE, 2011)

	Qualifying facilities		
	Eligible technologies	**System capacity limit**	**Buy-back rate**
CA	Solar, wind, biogas, fuel cells	1 MW 5 MW for specified systems	Retail rate
GA	Solar, wind, fuel cells	- 10 kW for residential - 125% of demand for commercial	A predetermined rate
NY	Wind, solar, fuel cells, micro-CHP, microhydroelectric, farm waste	10 kW—2 MW depending on the source type and sector	- Retail rate (wind, solar, farm waste) - Avoided energy cost (micro-CHP, fuel cell)
TX	Renewable energy sources	Austin-20 kW–AC El Paso-50 kW Brenham-10 MW Others: No residential, 50 KW for commercial	Austin, El Paso, Brenham: Avoided energy cost Others: Retail rate for first 500 KWh, 50% beyond

CHP, combined heat and power.

their part for maintaining grid infrastructure and connection, and that net metering subsidies are unfair for those who do not own distributed generation resources (Johnson et al., 2017; Lydersen, 2017). Some states (e.g.,. *Indiana*), with strong advocacy from distribution utilities, have introduced bills to terminate their net metering policies (Indiana General Assembly, 2017). Others are working on new forms of policies and rate designs that encourage distributed renewables and allow distribution utilities to maintain a viable business model (CERES, 2015). For instance, increasing monthly fixed charges on all customers, monthly service charges for net metering customers, and revising net metering buy-back rates to be based on the wholesale value of electricity provided by distributed renewables.

3.2.2 | Interconnection standards and rules

Interconnection standards establish uniform processes and technical requirements for utilities when connecting distributed generation (DG) systems to the electric grid. It allows DER developers to predict costs and time, and ensure the safety and reliability of interconnection processes. Technical requirements often include protocols and standards that guide how generators interconnect with the grid, ranging from system capacity limits and qualifying generators, to the types of interconnection equipment required for reliability purposes. Interconnection policies can also specify connection and operation procedures, which can reduce uncertainties and prevent time delays for approving grid connections. Interconnection standards are often designed for certain generation facilities, depending on their generating capacity, sector, and technology type (see Table 3).

3.2.3 | Smart metering targets

A smart meter reader is a device that can measure real-time electricity consumption and communicate the information back to utilities. A smart meter, on the other hand, communicates back to both the utility and consumer. Smart metering targets typically establish smart meter deployment plans for utilities, covering the timeline, and the type and number of smart meters to be installed. Sometimes, utilities are required to conduct cost-benefit analysis (CBA) of the proposed smart metering programs. Over the last 5 years, many states set smart metering targets that have now been implemented by utilities (see Table 4). In Georgia, in particular, every customer has a smart meter today. In New York, utilities must file proposals for integrating smart meters into their systems.

3.2.4 | Dynamic pricing policies

Dynamic pricing is a market-driven approach to boost demand response in electricity markets. The fundamental idea is to provide accurate price signals to customers and let them decide whether to continue consuming at higher prices or to cut

TABLE 3 Interconnection standards and rules in four U.S. States (DSIRE, 2011)

	Main provisions	**Targeted systems**
CA	• Standard interconnection, operating, and metering requirements • Application and evaluation procedures, fees, and costs	Facilities to be connected to utility's distribution systems and transmission grid, plus all net metered facilities in utility's service territory
GA	• Customers are required to meet applicable interconnection requirements, such as the IEEE, Underwriters Laboratories, and the National Electrical Safety Code	Residential ($\leq$ 10 kW) and commercial ($\leq$ 100 kW) facilities that use photovoltaics (PV), wind and fuel cells
NY	• Interconnection procedures • Requirements for the design and operation of DG facilities • Application procedures, fees, and maximum expenses	Simplified six-step process for systems up to 50 kW; 11-step process for systems between 50 kW to 5 MW
TX	• Requirements for generators and network interconnection of DG • Requirements for control, protection, and safety equipment	Facilities with capacity $\leq$10 MW and connection voltage $\leq$60 kV

TABLE 4 Smart meters in four U.S. States (IEI Report, 2016)

	Utility/agency	
CA	Pacific Gas and Electric	5,209,000
	San Diego Gas & Electric	1,428,000
	Southern California Edison	5,034,000
GA	Georgia Power	4,388,000
NY	Public Service Commission	4,100
TX	Center Point	2,322,000
	Oncer	3,365,000
	AEP Texas	1,577,000

electricity usage when prices are high. Some form of dynamic pricing is currently available to most customers, and it is widely used in commercial and industrial sectors (see Table 4). Research has shown that dynamic pricing can not only remove subsidies embodied in flat rates, but also reduce peak demand (Faruqui & Hledik, 2009; Faruqui & Sergici, 2009; Zethmayr & Kilata, 2017). Under dynamic pricing schemes, utilities charge different rates for electricity based on time, generating cost and conditions of the grid; hence, customers are exposed to some level of electricity price variability. Numerous different types of dynamic pricing rates have emerged over the past decade, typically starting with large industrial customers, followed by commercial and large nonresidential customers. The most common dynamic pricing policies include time-of-use pricing (TOU), critical peak pricing (CPP), and real-time pricing (RTP) (Table 5).

TOU sets and publishes electricity prices for different time periods in advance. Electricity prices in peak periods are higher than off-peak, which encourages customers to shift electricity consumption to a lower cost period and reduce the peak demand. The rates for each time block are usually adjusted two or three times each year to reflect changes in the wholesale market; however, TOU pricing does not address unforeseen weather conditions or equipment failures. It is also unable to reflect shifting peak hours, which can occur with high levels of variable renewable energy.

CPP is similar in rate structure to TOU pricing, but it adds one more rate that can vary with the wholesale market. Electricity prices during a limited number of hours of the year, which refer to the "critical peak hours," rise to levels designed to recover the full generation cost, while electricity prices during other times are lower than the critical periods. There can be a number of CPP event days in a year, and utilities usually will notify customers of the events and rates ahead of time.

RTP reflects the hourly or an even smaller time-interval marginal cost of electricity, which can be announced at the beginning of the time period or in advance. RTP can capture most of the true variation in the wholesale market, but it gives customers little time to react to price changes (Borenstein, Jaske, & Rosenfeld, 2002). The IoT has enhanced customers' ability to respond to real-time prices, and has eliminated the conflict between greater advanced price notification and more accurate price signals, expanding the use of RTP (Kempton & Letendre, 1997).

3.2.5 | Electric vehicles policies

Parallel to policy trends at the national scale, many individual states have created a variety of EV incentives including tax credits and registration fee reductions as well as emissions test deferrals and high-occupancy vehicle (HOV) lane exemptions (State Efforts to Promote Hybrid and Electronic Vehicles, 2017). These rebates start from $1,000 in Maryland and go up $6,000 in Colorado (Table 6; State & Federal Incentives, 2017). Some states such as Georgia also impose fees on EVs to compensate for the loss of gasoline taxes that pay for transportation infrastructure (Kramer, 2017).

TABLE 5 Dynamic pricing policies in four U.S. states

		Targeting systems			
	Types of rates	Residential sector	Commercial and industrial sectors	Agricultural sector	Electric vehicles
CA	CPP	√	√	√	√
	RTP		√	√	
	TOU	√	√	√	√
GA	TOU	√	√	√	√
	RTP		√		
NY	TOU	√			√
	RTP		√		
TX	TOU	√			[a]

CPP = critical peak pricing; RTP = real-time pricing; TOU = time-of-use pricing.

[a] Discounted rates for EVs from 7 to 2 p.m. the next day on weekdays and anytime on weekends provided by Austin Energy.

TABLE 6 Electric vehicle policies in four U.S. States (State & Federal Incentives, 2017)

State	Rebate amount	Grant/credit	Incentives
CA	- Up to $2,500 and $1,500 rebate for the purchase or lease of battery electric vehicles and plug-in hybrid electric vehicles, respectively. Additional $2,000 for vehicles purchased or leased by qualifying low-income households.[a]	"Disadvantaged community" can receive up to $5,000 per EV and $2,000 per charging station	- Eligibility to use HOV lanes for BEVs and PHEVs - Discounted rates for residential vehicle charging during off-peak hours - Financing programs available to support installation of charging station
GA	A tax credit for commercial medium/heavy duty plug-in electric vehicle (PEV) trucks purchased equal to the lesser of the income tax liability of the owner or $250,000		- Eligibility to use HOV lanes for BEVs - Subsidies for Level 3 charging stations - Exemption for emissions testing for BEVs
NY	Up to $2000 rebate for BEV or PHEV A $5,000 rebate for EVs expired in 2016	Up to $5,000 credit for the installation of charging station to certain qualified property	- Eligibility to use HOV lanes on the Long Island expressway as well as 10% discount on toll roads - Exemption for emissions testing for BEVs
TX	Up to $3,500 rebate for purchase of PEVs for qualified buyers	- Up to $1,500 rebate to qualified businesses for the purchase and installation of charging stations - A rebate of up to 50% of the cost to install a Level 2 charging stations for multifamily properties	- Exemption for emissions testing for BEVs

[a] PG&E is offering a $500 clean fuel rebate for PG&E customers who own or lease a PEV, and SCE is offering a $450 clean fuel rebate for SCE customers who own or lease a PEV. HOV = high-occupancy vehicle.

3.2.6 | Data privacy and cybersecurity policies

Many states have adopted policies to regulate smart meter data security and privacy concerns (Zhou & Matisoff, 2016). Such policies closely regulate who owns smart meter data, who has access to the data, and cybersecurity management rules. For example, California passed the Senate Bill 674 "Telecommunications: master-metering: data security" in 2011. It requires that an electrical corporation shall not share, disclose, or otherwise make accessible to any third party a customer's electrical consumption meter data without the consent of the customer. Texas requires independent security audits of investor owned utilities (IOUs) that deploy AMI (Table 7).

3.2.7 | Other policies

Besides the six types of policies described above, the ownership of renewable energy certificates (RECs) from customer-owned renewable facilities is another issue that is only now being clarified. The issue is important because RECs have significant economic value, and clear rules and regulations regarding their ownership could help reduce confusion and uncertainties associated with smart grid investment. This policy issue is also contentious as it involves the design and consideration of several policy regimes, including renewable electricity standards, net metering, interconnection policies, and utility subsidies for renewable projects.

In the United States, when renewable energy is generated and fed into the electrical grid, the accompanying RECs can then be sold on the open market (Reusable Energy Progression,). There are two types of RECs markets. In compliance markets, states with Renewable Portfolio Standards require utilities to either generate renewable energy or purchase RECs from elsewhere to fulfill the renewable portfolio standard (RPS) requirements. In voluntary markets, consumers and corporations purchase renewable energy out of their own desire.

The four case studies show that the goals and design of smart grid policies are highly variable across states. While most U.S. states have net metering and interconnection standards, the specifics of these policies vary widely (e.g., eligible technologies and customers, application, and evaluation procedures). States also are in different stages of smart-meter deployment; however, there is a growing consensus that smart meters are an essential enabler of grid modernization. Additional policy principles are emerging. Cost allocation rules need to ensure the recovery of smart grid costs and to facilitate investment in

TABLE 7 Data privacy and cybersecurity policies in four U.S. states as of 2017

State	Legislation/regulation/plan	Requirements and recommendations
CA	- Senate Bill 674 - Senate Bill 1476	- Prohibit utilities sharing, disclosing, or selling customers' data absent customer authorization - Require utilities to adopt security procedures and practices
GA	- None	- None
NY	- New York PSC Case 10-E-0285	- Defers adoption of interoperability/security standards until the NIST standards are completed - Not necessary to develop and adopt prescriptive smart grid privacy rules
TX	- Texas Energy Assurance Plan 2012	- Recommends identification of threats and vulnerabilities in the energy sector, especially with regard to grid modernization efforts - Describes prevention and mitigation strategies applicable to energy emergencies
	- PUC Rule §25.130	- Requires independent security audits of IOUs that deploy AMI

Source: State public service commission websites. NIST = National Institute of Standards and Technology.

TABLE 8 Smart grid legislation and regulations in the European Union

	Policy emphases				
	Interconnection standards	**Smart meters**	**Demand Response and dynamic pricing**	**Electric vehicles**	**Data protection and cybersecurity**
Directive 2001/77/EC	√				
Directive 2003/54/EC	√		√		
Green Paper (2005)		√	√		
Green Paper (2006)	√				
Directive 2006/32/EC		√	√		
COM (2007) 723 final	√				
Directive 2009/72/EC		√			
Conclusions of the European Council of February 4, 2011		√		√	
Commission recommendation on preparations for the roll-out of smart metering systems (C/2012/1342)		√			
EC standardization mandate for smart meters (M/441)		√			
EC standardization mandate for electric vehicles (M/468)				√	
EC standardization mandate for smart grids (M/490)		√			
Commission recommendation of October 10, 2014 on the data protection impact assessment template for smart grid and smart metering					√
Directive 2014/94/EU on the deployment of alternative fuels infrastructure				√	
Commission recommendation (2014/724/EU) on the data protection impact assessment template for smart grid and smart metering system					√
Directive (EU) 2016/1148 concerning measures for a high common level of security of network and information systems across the union					√
General Data Protection Regulation (EU) 2016/679					√

Notes. We exclude two general policies: Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure and the 2008 Directive on European Critical Infrastructures (2008/114/EC).

new smart grid infrastructures. CBA and evaluation metrics are also becoming essential, and some government agencies are beginning to require the collection of such information.

4 | SMART GRID POLICIES IN EUROPE

The EU is the second largest energy market in the world, with a population of 573 million (76% more than the United States) in 2016.[1] The objective of EU energy policies in the 21st century is to achieve a sustainable, competitive, and secure energy supply (Commission of the European Communities, 2006). The EU consumes approximately 20% less energy than the United States, and emits about 31% fewer tons of CO_2 than the United States.

The deployment of smart grids is an essential part of the EU's climate change and clean energy initiatives, as it can transform traditional electricity markets and networks. The breadth of EU smart grid policies is illustrated in Table 8. Early Directives (in 2006 and 2012) recommended large-scale smart meter deployment to enhance energy efficiency. Economic assessments were emphasized in a 2009 Directive, and more recently targets were set: at least 80% of consumers equipped with smart meters by 2020 (Zhou & Brown, 2017).

Despite these motivating EU policies, the penetration of smart meters across Europe is quite variable. As of 2014, smart meter penetration rates of most EU member states were below 10%, including the United Kingdom, France, Germany, and the Netherlands. Sweden, Italy, and Finland have achieved more than 90% smart meter market share, ranking the highest in the EU (Zhou & Brown, 2017). Here, we look more closely at the United Kingdom and Italy as examples of European countries with low versus high penetrations of smart meters.

4.1 | Data privacy and cybersecurity policies

Data privacy and cybersecurity policies issues have been particularly critical in European countries. For instance, the Dutch smart meter mandatory roll out target was adopted only after it improved privacy protection and data security, while Germany has made limited progress in smart meter deployment as the government seeks to adopt stringent technical standards and certification rules to ensure smart meter data privacy, security, and interoperability (Zhou & Brown, 2017). Because data privacy and cybersecurity have played a role in the social acceptance of smart grid technologies, we begin with a description of this policy context.

In 2012, the European Commission recommended all states to be aware of data protection and security considerations. These recommendations address a wide range of risks associated with protection of personal data and data security (General Data Protection Regulation [GDPR], 2012). In 2013, the Smart Grid Task Force (SGTF) published the list of security measures for smart grid threats for all electricity domains from generation to consumer premises (Smart Grid Task Force EG2, 2013). The list became more comprehensive when it was published in 2014, including regulatory recommendations and a Data Protection Impact Assessment (DPIA) template addressing a wide range of challenges with clarifying examples (Data Protection Impact Assessment Template for Smart Grid and Smart Metering systems, 2014). The European Parliament emphasized legislative implementation guidelines such as the appointment of a central authority, incident reporting, information sharing, alignment of activities, and development of security standards in their study on Cybersecurity Strategy for the Energy Sector (2016). However, challenges still exist such as the need for new European standards, clarification of data protection in terms of authorization of data usage, and the risks associated with losing dispatch schedules and control over EVs and appliances (European Commission, 2017).

4.2 | Smart grid policies in Italy

Italy emitted 467 Mt CO_2 in 2006, but only 319 Mt CO_2 in 2016. Its carbon intensity (at 5.3 metric tons of CO_2 per capita) is now lower than the EU average of 6.9, and much lower than the U.S. average of 15.8. Its modest carbon footprint is achieved in part by its significant investment in renewable power, which represents 43% of its total electricity generation, higher than the EU average of 32%. Modernization and expansion of the electricity transmission and distribution networks has been a critical step in the successful integration of renewables in Italy's energy system (Italian National Renewable Energy Action Plan (In line with the provisions of Directive 2009/28/EC), 2010).

Efforts at various levels of governments have been made to accelerate energy infrastructure optimization. In 2007, the European Commission approved the "Renewable Energy Sources and Energy Saving" Program in southern Italian regions with a budget of €1.6 billion ($2.0 billion US dollars; European Commission, 2007). One priority of this program was to improve the infrastructure of transmission networks to promote renewable energy and small/microscale cogeneration, which receives €100 million ($123 million US dollars) from European and Italian state funds (Italian National Renewable Energy Action Plan, 2010). Within this context, the Italian Ministry of Economic Development and Italy's largest power company—Enel Distribuzione—together launched a €77 million ($95 million US dollars) "Smart Medium Voltage Networks" project in southern Italy to make medium voltage distribution networks more favorable to photovoltaic systems with installed capacities of 100 kW to 1 MW (International Energy Agency, 2011). In addition, the Italian Regulator Authority for Electricity and Gas has awarded eight tariff-based financial projects on active medium voltage networks, to demonstrate at-scale advanced network management and automation solutions necessary to integrate DG (Renner, Albu, Elburg, et al., 2011).

Italy has one of the largest and most extensive smart metering programs in the world. In Regulatory Orders in 2006 and 2007, Italian legislators introduced mandatory installation of smart meters for all household and nonhousehold low voltage customers starting from January 1, 2008, and minimum performance standards for the meters were also provided (Renner et al., 2011). Italy's smart metering deployment emphasizes distribution system operators and is designed to support the liberalization of the energy market and prevent electricity theft. Enel Distribuzione is the major player in Italy's smart meter deployment. By 2011, Enel had installed smart meters for 32 million customers in its electrical distribution system and provided advanced services enabled by smart meters, including hourly based tariff system (Enel Distribuzione, 2011a.) Enel will also install smart meters in its gas distribution grid, and will extend the smart metering system to its distribution grids in Spain, where 13 million smart meters will be installed between 2010 and 2015 (Enel Distribuzione, 2011b). Besides smart meters, Enel also launched the E-mobility Italy program in three Italian cities: Rome, Milan, and Pisa in 2008 (Emery, n.d.), where 400 intelligent electric vehicle recharging stations were built.

To encourage renewable DG, the Italian government guarantees priority access of electricity generated from renewable to the grid, and provides feed-in tariffs to solar PV. The Fourth *Conto Energia* (feed-in tariff) approved by the Ministry for Economic Development in 2011, provides a differentiated incentive system for solar PV, including a specific expense budget designed for large PV plants between 2011 and 2012, and pre-established half-yearly expense budgets provided to all PV plants between 2013 and 2016 (Metering & Smart Energy International, 2015). However, no incentives have been awarded to PV plants entering into operations after 2016.

4.2.1 | Data privacy and cybersecurity policies

Cybersecurity plays a critical role in Italy, which is the fourth largest market for Information and Communication Technology (ICT) services in the EU. Enel operaties in 30 countries has faced many attacks (Metering & Smart Energy International, 2015). As a result, Enel has implemented new technical standards and participates in the European Energy Information Sharing & Analysis Center that is a joint initiative of four major European utilities to tackle cybersecurity and resiliency of the smart grid (EE-ISAC, 2017) In 2013, the Italian government published the "National Strategic Framework for Cyberspacesecurity" to frame their cyber strategy to protect the ICT infrastructure (Italian Presidency of the Council of Ministers, 2013). Moreover, the Italian privacy regulator or Data Protection Authority (Garante) has issued six-step guidelines to implement EU GDPR to protect data privacy (Corragio, 2017).

4.3 | Smart grid policies in the United Kingdom

The United Kingdom was responsible for 426 Mt CO_2 from energy use in 2016, down from 532 in 2010 (DECC, 2010). On a per capita basis, the United Kingdom is slightly less carbon intensive than the EU, and it is less than half as carbon intensive as the United States. The British government has set a firm, long-term and legally binding framework to cut carbon emissions by at least 34% by 2020 and 80% by 2050—below the 1990 baseline (HM Government, 2011). A critical part of this framework is to commit the country to generate 15% of its energy from renewables by 2020 (Redpoint Energy, & Trilemma UK, 2010). About 19% of UK electricity is from renewable resources, which is less than the EU average (32%) and much lower than Italy (at 43%).

The British power system is owned and operated by three transmission network operators and nine distribution network operators (DNOs), which makes it difficult to achieve a country-wide smart grid vision. Stakeholders in the system, including generators, suppliers, traders and customers, act according to the British Electricity Trading and Transmission Arrangements (BETTA) to ensure supply and demand are balanced at all times (Energy and Climate Change Committee, 2010).

To modernize and reduce the carbon footprint of electric grids, one major initiative of the United Kingdom is to encourage energy efficiency through smart meter deployment. The British government expects full penetration of smart meters by 2020, with a total financial investment of £8.6 billion ($13.5 billion US dollars) and total benefits of £14.6 billion ($22.9 billion US dollars) over the next 20 years (DECC, 2009). Early government action can be traced to the 2008 Energy Act, which allows the Secretary of State to take measures to install or facilitate the installation of smart meters (The UK Parliament, 2008). Energy Bill 2010-2011 provides financial incentives to encourage smart meter installation by householders, private landlords, and businesses (The UK Parliament, 2011). The July 2010 publication of the "Smart Metering Implementation Program: Prospectus" set design requirements, central communications, data management, and a rollout plan for the deployment of smart meters to all homes and small businesses in Great Britain (Department of Energy and Climate Change,, & Office of the Gas and Electricity Markets, 2010). The Government's *Response to Prospectus Consultation* in 2011 requires energy suppliers to provide smart meters that meet specific technical standards (Department of Energy and Climate Change,, & Office of the Gas and Electricity Markets, 2011). It also includes selection and regulatory procedures for a new, licensed Data and Communications Company to manage smart metering data. Customers can choose how their consumption data is used and by whom, except when data is required for regulatory purposes.

Multiple incentives are designed to encourage innovative decarbonizing initiatives in the UK's power system. The 2008 Energy Act introduced Feed-In-Tariffs (FITs) for low-carbon electricity generation facilities smaller than 5 MW (The UK Parliament, 2008). Eligible technologies include anaerobic digestion, solar PV, hydroelectric power, wind, and micro-CHP systems. Total capacity of solar PV registered in FITs reached 1 GW by 2012, with the FIT payment rates ranging from 8.9 to 21.0 p/kWh ($0.14~$0.33/kWh; Feed-In Tariffs Ltd, 2012). Between 2010 and 2015, The Office of Gas and Electricity Markets (OFGEM) was committed to provide a £500 million ($785 million US dollars) Low Carbon Networks (LCN) Fund to help DNOs develop trial projects of new technologies and commercial arrangements that enhance energy security and combat climate change (Office of the Gas and Electricity Markets, 2012). British energy regulators believe that the upscaling of many critical components of smart grids, such as demand side management, DG, and electric vehicles can only be achieved through significant changes of the distribution networks. A £6 million ($9.4 million US dollars) Smart Grid Demonstration Fund is also in place to facilitate the development of smart grid technologies, focusing primarily on the supply chain and the regional integration of alternative energy sources (DECC, 2009).

The British government has designed multiple institutions and platforms to increase fundraising for smart grid development. A typical example is the Energy Technologies Institute, a partnership between the British government and industrial sectors. It allows for a variable mix of public and private funding to accelerate the development of low-carbon technologies, including energy storage, building energy management, and DG (Energy Technologies Institute, 2012).

More recently, England has established a number of incentives to encourage electric vehicles. For example, EVs are exempt from excise taxes and national insurance contributions Bakker, Lima, & Trip, 2012). There are also grants for plug-in cars and vans. Between 2011 and 2015, a £43 million subsidy program offered consumers incentive for EVs and PHEVs, reducing the cost of eligible cars by 25% up to a maximum of £5,000 for both private and business buyers; for light trucks and vans, purchasers were eligible to receive a 20% subsidy up to a maximum of £8,000. In addition, some local authorities in England provide EVs with parking subsidies and other reduced charges, and EVs receive a discount on the London congestion charge, saving drivers up to £2,000 per year (Berkeley, 2012; Kotter & Shaw, 2013).

4.3.1 | Data privacy and cybersecurity policies

The office of Cybersecurity was established in 2009. In 2015, OFGEM established a £500 M fund to support security of supply in a low-carbon economy including smart grid cybersecurity (Low Carbon Networks Fund, 2015). A new regulatory framework was also initiated by OFGEM with incentives for innovation and outputs and new price control to overcome smart grid challenges. The Energy Network Associations (ENA) helped the government to develop standards to tackle cybersecurity issues (Tritscheler & Mackay, 2011).

5 | SMART GRID POLICIES OF ASIA

As a whole, the electricity systems of Asian countries (home to 4 billion people) are quite diverse. Altogether, 20% of Asia's electricity is generated from renewable resources. The average carbon footprint is only 4.2 Mt/capita, the smallest of the countries and states examined here. With one third of global gross domestic product (GDP) and only 244 Quads of energy consumption, Asia is responsible for just 16.8 billion tons of CO_2.

5.1 | Japan

As a country that is only 16% energy self-sufficient, Japan is the world's largest importer of liquefied natural gas (LNG), second largest importer of coal and the third largest importer of oil (U.S. Energy Information Administration, 2012c). Its energy use is responsible for approximately 1,140 Mt CO_2 in 2016, and one third of these emissions were produced by its industrial sector. On a per capita basis, Japan is nearly half as carbon intensive as the United States (9.0 vs. 15.8 metric tons of CO_2 per capita; Greenhouse Gas Inventory Office of Japan, 2012). This compares to 1.16 for India and 13.8 for South Korea.

Japan aims to reduce its carbon emissions by 30% by 2030 compared to 1990, and to have 70% of its electricity generated from zero-emission sources by 2030, while today, about 15% of Japan's total energy consumption is from renewables (U.S. Department of Energy, 2010; U.S. Energy Information Administration, 2012d). To achieve these goals, major changes are expected to take place in the energy system. The official goal is to build “the world's most advanced next-generation interactive grid network,” to realize “smart grids and smart communities” and to promote “the development, installation of smart meters and relevant energy management systems” as early as possible in the 2020s (Ministry of Economy Trade and Industry [METI], 2010a). The 2011 Fukushima nuclear incident, which put the country in an unprecedented energy crisis, has greatly accelerated the government's investment in electric grid infrastructure. It is estimated that smart grid market value in Japan would increase from $1 billion in 2012 to $7.4 billion in 2016 (Zpryme, 2012).

Japan's power industry is dominated by 10 regional monopolies, which account for 85% of the country's total installed generating capacity (U.S. Energy Information Administration, 2012e). Tokyo Electric Power Company (TEPCO), the largest utility company in Japan serving over 28 million customers, plans to install 17 million smart meters by 2019 (Zpryme, 2012). The FIT scheme—“New Purchase System for Photovoltaic Electricity” launched in 2009 is a key government incentive for renewables (METI, 2009). Surplus electricity generated from solar PV is purchased at ¥48/kWh ($0.59/kWh) for residential sector, and ¥24/kWh ($0.30/kWh) for industries, businesses and schools. The buyback prices will decrease each year based on the innovation and price trends of solar photovoltaic technologies.

Japan's METI is the major government agency responsible for smart grid development. Its objectives are to enable further integration of renewable energy, facilitate the development of electric vehicles, and charging infrastructure, and create new services using smart meters and ICT networks (Ito, 2009). METI has implemented demonstration projects at both regional and international levels to facilitate the penetration of smart grid technologies, including a $73 million investment on community grid system (Remote Island Smart Grid Project, Smart Charge Project, and Smart House Project), $1.1 billion on four smart grid technology pilot projects (Kansai Science City, Yokohama City, Kitakyushu City, and Toyota City), and four smart community demonstration projects located in the State of New Mexico (USA), Hawaii (USA), Lyon (France), and Malaga (Spain) (METI, 2010b; New Energy and Industrial Technology Development Organization [NEDO], 2011).

There have been increasing cooperation and collaboration between Japan's public and private sectors in smart grid deployment. For instance, the Japan Smart Community Alliance established by the NEDO in 2010 provides a platform for the participation of a wide range of smart grid stakeholders (Japan Smart Community Alliance, 2010). The concept of “smart community," which refers to a new, intelligent and sustainable way of living, not only stimulates changes in the electricity market, but also motivates innovations in automobiles, telecommunications, and home appliances industries. Toshiba Corporation, Tokyo Electric Corporation and TEPCO are also working together to launch a venture into the commercialization of smart meters (Yogasingam, 2009).

The approval of the fourth Basic Energy Plan in April 2014 marked a major reform of Japan's energy sector in recent years. This plan presents the basic energy policy principles of Japan, including energy security, reliability, efficiency, affordability, reduced emissions, and increased consumer choice (International Trade Administration, 2016). The plan aims to establish a national grid and fully liberalize the electricity markets. Although a new renewable energy target was not established, the plan commits that renewable energy will exceed 20% by 2030. The plan set a carbon emission reduction target of 3.8% by 2020.

Two regulatory government bodies were established by METI in 2015: the Organization for Cross-Regional Coordination of Transmission Operators (OCCTO) and the Electricity Market Surveillance Committee (EMSC). OCCTO oversees utility power generation and exchange, as well as the development of regional transmission grids. EMSC monitors the electricity market and is responsible for Japan's smart meter rollout. Bloomberg New Energy Finance predicts 6 to 10 million smart meter installations per year through 2022 (Bloomberg New Energy Finance, 2016).

5.1.1 | Data privacy and cybersecurity policies

Japan is one of the leading countries in implementing a smart grid and initiating supportive smart grid policies, focused on protecting its smart grid against cyberattacks. Specifically, new standards were developed by the Japan Electrotechnical Standards and Codes Committee (JESC) in 2016, including security guidelines to protect Japan's smart meter and power control systems (Sasakawa Peace Foundation, 2017). As a result, the Electricity Business Law, which is a set of technology standards and security regulations, requires utility companies to include cybersecurity in their systems (Sasakawa Peace Foundation, 2017). Recently, the Information Sharing and Analysis Centers in Japan (JE-ISAC) and Europe (EE-ISAC) signed an agreement to collaboratively protect their cybersecurity (Metering & Smart Energy International, 2017).

5.2 | South Korea

South Korea imports 97% of the energy it consumes and is highly dependent on imported petroleum and LNG. Its energy system emitted 688 Mt CO_2 in 2016, up from 579 in 2010 and 484 in 2006, mirroring its rapid economic growth, which is the fastest among OECD countries (United Nations Environment Programme, 2010). Its per capita CO_2 emissions have also been on the rise, reaching 13.8 metric tons in 2016 compared to 11.9 in 2010, reflecting a growing carbon intensity. Renewable energy accounts for less than 2% of its electricity generation, which is the lowest among the countries and U.S. states examined here (Greenhouse Gas Inventory Office of Japan, 2012).

Although South Korea is not an Annex I country, it nevertheless announced its intention to reduce its carbon emissions under the UN Framework Convention on Climate Change by 37% below the business-as-usual (BAU) case by 2030 (Submission by the Republic of Korea Intended Nationally Determined Contribution, n.d.). Reducing the nation's energy dependence and carbon intensity is one of the top priorities of the Korean government and a mandatory cap-and-trade system has been operating since 2015 (Han, 2012).

The electric system of South Korea is more reliable and efficient than many other developed countries (Bae & Wheelock, 2010). Korea Electric Power Corporation (KEPCO) was created in 1961 to supply electricity to the entire economy. KEPCO is responsible for the generation, transmission, and distribution of electricity which comprises six power generation companies, four subsidiaries, and four affiliated companies (KEPCO, 2011).

The deployment of smart grid technologies started in 2005 when Korea launched the Power IT National Program in order to develop digital, environmental friendly and intelligent electric power devices and systems, and advance Korean electric power and electrical industries (Ministry of Knowledge Economy, Korea Smart Grid Institute, 2005), In August 2008, President Lee Myung-bak announced "Korea's National Strategy for Green Growth," which proposes a total investment of 107 trillion won ($101 billion US dollars) between 2009 and 2013 (Yale Center for Environmental Law & Policy, 2012). The deployment of smart grid technologies is a key part of this five-year plan. Among the 27 core green technologies listed in its national plan, more than one third are related to the development of smart grid and smart cities.

Korea's "Smart Grid Road Map 2030" is to be implemented in five sectors: smart power grid, smart consumers, smart transportation, smart renewables, and smart electricity services (Ministry of Knowledge Economy, Korea Smart Grid Institute, 2005). By 2030, a nationwide smart grid and 27,140 power charge stations for electric vehicles will be built; and the penetration rate of smart meters and AMI will reach 100% by 2020. In addition, Korea will have 11% of its energy from renewables, and achieve a maximum of 10% power reduction by 2030. The annual blackout time per household will be reduced from 15 min in 2012 to 9 min in 2030, and the power transmission and distribution loss rate will decrease from

3.9% in 2012 to 3.0% in 2030. A total of 27.5 trillion won ($25.85 billion US dollars) will be allocated for the technology development and infrastructure construction in this plan.

As a first step to implement the Road Map, the Korean government started a pilot program on Jeju Island in June 2009, which consists of a fully integrated smart grid system for 6,000 households, wind farms and four distribution lines (Smart Grid Revolution, 2011). A total of $50 million public funds and $150 million private funds were invested between 2009 and 2013. More than 100 companies from automobile, renewable, power, telecommunication, and home appliance industries participate in the program. KEPCO is participating in all five sectors of Jeju Island's pilot program. KEPCO is also committed to develop green technologies such as export-ready nuclear power plants, electric vehicle charging infrastructure, integrated gasification combined cycle (IGCC) and carbon capture and storage (CCS) technologies (KEPCO, 2011). The second stage includes the expansion into metropolitan areas. The last stage expands to the nationwide intelligent grid networks. The anticipated effect is to generate 50,000 new jobs every year and reduce a total of 230 million tons of GHGs by 2030 (Ministry of Knowledge Economy, Korea Smart Grid Institute, 2005). In 2016, KEPCO announced that it will begin its national deployment of smart grid technologies following a successful trial conducted between 2009 and 2013.

The Special Act on Establishment of Nationwide Smart Grid came into effect in 2011. This Act provides a regulatory basis for smart grid technology implementation in the country. It also regulates the utilization and protection of smart grid information, allocates financial resources, and designates supporting organizations for smart grids. Following this legislation, a five-year master plan was established to guide the smart grid technology development from 2012 to 2016 (Cheon, 2013). Policy goals and implementation strategies were set to guide the construction of smart grid pilot cities in six additional districts.

5.2.1 | Data privacy and cybersecurity policies

Cybersecurity has gained much attention in the Republic of Korea. In this regard, one of the main laws passed in 2003 was to protect information technology and communications (ITC) users, which is a necessary precursor to smart grid implementation (South Korea: Act on Information Protection—unpan1.un.org, n.d.). Subsequently, the Korea Internet & Security Agency (KISA) was founded and a Presidential Directive (No. 141) was promulgated: the National Cybersecurity Management Regulation (Kim, 2013). The government launched a “Cyber Command Center” in 2010 to oversee required tasks for cyberspace operations (Cluley, 2010). Subsequently, the National Cybersecurity Master Plan was announced in 2011 to carry a national collaborative effort to prevent cyberattacks. The plan addresses five main areas: prevention, detection, response, systems, and security (Defense of Japan, 2014). Parallel to these efforts, the Korean Communications Commission and KISA have initiated several programs to increase public attention toward resiliency (MSIP & KISA [1], 2014), and the Personal Information Protection Act passed in 2011 (Korea, 2011).

5.3 | The People's Republic of China

Since the 1980s, China's energy consumption has been growing at an unprecedented rate due to rapid economic development. Its CO_2 emissions first eclipsed the United States in 2007 at 6,184 Mt CO_2, and its annual emissions are now approximately 10,010 Mt CO_2 in 2016. Rapid economic growth has catapulted China's emissions (U.S. Energy Information Administration, 2012f). Between 1990 and 2010, China's electricity generation increased from 621 to 4,206 Terawatt-hours (TWh) (BP Statistical Review of World Energy, 2011), with annual growth rates of electricity demand ranging from 10 to 15% (Austin, 2005). In 2010, 24% of China's electricity generation came from renewable resources.

China has experienced several major power outages since 2005, and the shortfall in electricity has started to hurt China's economy (Austin, 2005). In order to meet the increasing demand and secure economic growth, the Chinese government invested 286 billion yuan ($45 billion US dollars) in smart grid deployment between 2011 and 2015 (Smart Grid China Summit, 2011). The country's transition to a high-tech and high value added manufacturing and service economy also directs enormous government support to the new energy industry and transport system.

Based on the 2014 China–U.S. Joint Announcement on Climate Change and Clean Energy Cooperation, China will increase total energy consumption generating from zero-emission sources to around 20% by 2030. In order to meet the target, China needs to create an extra 800–1,000 GW of clean energy, such as solar, wind, nuclear, and other zero emission sources by 2030, and to robustly upgrade its grid system to accommodate the large amount of renewable energy (The White House, 2014). In addition, China's target for the Paris Agreement is to peak its carbon dioxide emissions around 2030. This would reduce China's emissions by at least 1.7 Gt or 14% from the most optimistic BAU scenario. China also pledged to lower its carbon dioxide emissions per unit of GDP by 60 to 65% from the 2005 level, and to increase the share of nonfossil fuel energy sources to around 20% (Center for Climate and Energy Solutions [C2ES], 2015). Smart grids and clean energy technologies are seen as effective approaches to achieve these targets.

A diverse set of legislation and regulations have been adopted to promote the development of clean energy and smart grids. The Amendment of the Renewable Energy Law (2009) urges utilities to develop and apply smart grid and energy storage technologies to improve grid operation and management, and facilitate interconnection of distributed renewable energy (The National People's Congress Standing Committee, 2009). The 12th Five-Year Plan sets separate targets for energy intensity (16% reduction by 2015), nonfossil fuel energy (11% of the total primary energy consumption by 2015), and carbon intensity (17% reduction below 2011 by 2015; Xinhua News Agency, 2011). New sources of electric power and vehicle propulsion are two of the seven strategic emerging industries to receive financial and regulatory support from the government. By 2015, several long-distance ultra-high voltage (UHV) transmission lines and 200 thousand kilometers of transmission lines (333 kV and above) will be constructed. The 12th Five-Year Plan also proposes the “Rural Electricity Supply Project” to upgrade rural electric grids and meet the increasing demand of rural areas. Some of the targets include: developing 1,000 PV demonstration villages, 200 green energy counties, 300 hydropower and rural electrification counties, and 10,000 MW of small hydropower.

The Ministry of Science and Technology released the “Special Planning of 12th Five-Year Plan on Smart Grid Major Science and Technology Industrialization Projects” in 2012. It identified nine key tasks, including large-scale grid-connected intermittent renewable energy technology, grid technology for supporting electric vehicles, large-scale energy storage systems, intelligent distribution technology, intelligent grid operation and control, intelligent transmission technology and equipment, grid ICT, flexible power transmission technology and equipment, and smart grid integrated comprehensive demonstrations (Ministry of Science and Technology of the People's Republic of China, 2012). Resource allocation optimization, clean energy development, power system reliability, diverse customer needs, energy efficiency improvement, and technology innovation are the major drivers for smart grid deployment in China (Ministry of Science and Technology of the People's Republic of China, 2012).

State Grid Corporation of China (SGCC), the largest power company and the major smart grid policy implementer in China, provides services to over one billion customers and covers 88% of the national territory (SGCC, 2012). In May 2009, SGCC announced a plan for developing a “strong and smart grid” in China by 2020 (SGCC, 2011). UHV transmission and highly efficient distribution transformers to enable the expansion of transmission and distribution capacity and reduce line losses are key technologies to be developed and deployed. SGCC's smart grid development plan is distinct in its focus on the transmission, rather than the distribution side, due to the fact that major power generation sources in China, such as coal, wind, and hydropower are located in remote areas, and there are huge disparities among power generation in different regions (Li, 2009). With an emphasis on power generation and transmission, the Chinese electricity market still has a long way to develop an effective interaction mechanism between customer and utility companies, such as dynamic electricity prices and demand response programs (SGCC, 2009).

In 2015, the National Development and Reform Commission (NDRC) and the Department of Energy adopted “Guidelines for Smart Grid Development” (NDRC, 2015). It sets a target of building a reliable, efficient, and sustainable smart grid national wide by 2020. The 13th Five-year Plan (2016–2020) and the NDRC's “Five-year Plan for Energy Sector (2016–2020)” set national priorities for the energy sector, including the development of hydropower, renewable energy, nuclear power, natural gas, energy storage, demand response, energy security, electric vehicles, and the smart grid (National Development and Reform Commission, 2016).

5.3.1 | Data privacy and cybersecurity policies

Cybersecurity regulations are new in China. In 2017, the Cyberspace Administration of China (CAC) announced draft regulations on the security protection of critical information infrastructure after releasing the “Cybersecurity Law” in 2016 (Overview of China's Cybersecurity Law, 2017).

5.4 | India

India's electric grid infrastructure faces many challenges. India today is home to one sixth of the world's population (1.3 billion people) and it is the third largest economy. Yet it accounts for only 6% of global energy use and emitted only 2,106 million metric tons of CO_2 in 2016 (40% of the United States and 20% of China). One in five of the Indian population—more than 240 million people—still lack access to electricity.

With policies in place via the “Make in India” program, population and incomes are on the rise. As a result, demand for coal in power generation and industry is surging, increasing the share of coal to almost half of the energy mix and making India the largest source of growth in global coal use (International Energy Agency, 2015). Major drivers of the smart grid in India include reducing power losses across its electricity system, providing varying electricity price signals to consumers, and integrating renewable energy sources (Sinha et al., 2011).

India is aggressively pursuing renewable energy development, which serves as the foundation for its climate mitigation strategies. Its 12th Five-Year Plan set a renewable generation target of 41 GW by the end of 2017 (Government of India, 2011). Currently, India's electricity is only 15% renewable, less than the 20% average for Asia. Policy goals for smart grids in the 12th Five-Year Plan include the deployment of smart meters and AMI, substation renovation and modernization, deployment of microgrids and distributed renewables, creating EV charging infrastructure, provision of harmonic filters and other power quality improvement measures, and real-time monitoring and control of distribution transformers. India's target under the Paris Agreement was 40% of total electricity capacity from nonfossil fuel sources by 2030. A draft 10-year energy blueprint published in 2016 predicted that 57% of India's total electricity capacity will come from nonfossil fuel sources by 2027 (Ministry of Power, 2016).

Both the Electricity Act of 2003 and the National Electricity Policy of 2005 emphasized the need to implement a dynamic tariff structure. The National Tariff Policy of 2006 requires utilities to introduce two-part tariffs and time-differentiated tariffs for large consumers with demand exceeding 1 MW. It also provides for the deployment of smart meters. In 2015, the Bureau of Indian Standards adopted the “Indian Standards for Smart Meters” (Bureau of Indian Standard, 2015).

In 2013, the Ministry of Power developed the “Smart Grid Vision and Roadmap for India.” The National Smart Grid Mission (NSGM), housed under the Ministry of Power, is the major government body that oversees smart grid implementation. The Ministry of Power has awarded 17 smart grid pilot projects to utility companies across the country, with a total project cost exceeding $212 billion (Sodha, Kumar, & Wadhwa, 2013).

Many cities in India suffer from air pollution. India's National Electric Mobility Mission Plan envisions a deployment of 5 to 7 million EVs in the country by 2020 Ministry of Power, 2017). This will reduce carbon emissions from vehicles by 1.3% by 2020, with a total investment of $3 billion (Ministry of Power, 2017).

5.4.1 | Data privacy and cybersecurity policies

In 2011, the National Cybersecurity Policy was announced to monitor and protect information against cyberattacks (National Cybersecurity Policy, 2011) Three years later, the ministry of communications and information technology established the National Critical Information Infrastructure Protection Center (NCIIPC) to protect critical sectors including the power and energy sectors (NCIIPC, 2016). NCIIPC has submitted the guidelines of the power sector that set standards for all sector entities to the ministry of power in May 2016 (Datta, 2016). Subsequently, the Central Electrical Authority (CEA) published functional requirements for AMI (Functional Requirements of Advanced Metering Infrastructure (AMI) In India, 2016). In order to share and analyze all cybersecurity incidents in the power sector, the Information Sharing and Analysis Center (ISAC-Power) was formed under the ministry of Power (Central Electricity Authority, 2017).

6 | SMART GRID POLICIES IN THE DEVELOPING WORLD

Electricity grids developing countries are getting smarter, to varying degrees. The motivations for smart grid upgrades range from the desire to integrate more distributed renewable resources into the grid, the need to prevention of electricity theft, and the challenge of universal access to energy (Pica, Vieira, & Dettogni, 2011).

In South America, for example, Brazil has been a harbinger of smart grid activity. Led largely by the Brazilian Electricity Regulatory Agency and designed to respond to exponential growth in the demand for energy, the government created the Brazilian National Energy Plan for 2008–2017. This Plan set a goal to build 54 GW of installed capacity by 2017, a goal which caused almost all Brazilian electric utilities to begin studying smart grid technologies (Fadaeenejad, Saberian, Mohd Fadaee, Radzi, & AbKadir, 2014). In east Asia, the mega smart grid project in Malaysia and the Provincial Electricity Authority (PEA) smart grid in Thailand are two major smart grid initiatives, but they both face technological challenges. Countries in the Middle East such as Iran and Egypt have also studied the possibility of upgrading to smart grids (Fadaeenejad et al., 2014).

Sub-Saharan African countries have been motivated by the desire for universal access to energy by leapfrogging from traditional power systems to more widespread electrification (Welsch et al., 2013) The dynamic pricing scheme enabled by smart grids may benefit the poor by providing access to low-cost electricity during off-peak hours. Policymakers in these countries need to focus on building stakeholder capacity, promoting affordable and reliable electricity, and balancing the development of micro-, regional, and national grids. In addition, the leapfrogging enabled by the smart grid is beginning to take advantage of the ICT infrastructure and the rapid development of cell phone markets in African countries.

7 | CONCLUSIONS AND RECOMMENDED FUTURE POLICY DIRECTIONS

Along with the recent introduction of smart grid technologies has emerged a new generation of regulations and fiscal policies to ensure that the public's interests are protected. Current smart grid policies address many of the barriers that hinder deployment and are aligned with many key drivers. Countries are in different stages of smart grid deployment and face unique barriers and drivers for change.

Although smart grid policies vary across U.S. states, most states have implemented net metering policies and interconnection standards. Many utilities have installed smart meters using funds from American Recovery and Reinvestment Act appropriations, and dynamic pricing programs are widely used in industrial and commercial sectors (Electricity Advisory Committee (EAC), 2015b.) Smart grid programs are also critical components of the EU's low-carbon agenda. British regulators have been very active in not only the roll out of smart meters and modernized distribution networks, but they have also supported innovative low-carbon technologies. Japan and Korea are both focusing on innovation and export of smart grid technologies to build competitive domestic industries. Power shortages which followed the 2011 nuclear incident in Japan also accelerated the country's investment in smart grid infrastructure, with the aim to integrate variable energy sources. China, the largest developing country in the world, sees the smart grid as essential for renewable deployment and strategic energy industries. It also plans to close the power generation gap between regions by constructing high-voltage direct current transmission lines. India and other developing countries are planning to adopt smart grid to leapfrog the traditional power grid system and to enhance universal access to affordable and reliable electricity.

Evidence from the past decade suggests that the rapid and widespread deployment of smart grid technologies will not occur without supporting policies. This review of emerging smart grid policies in the United States, EU, Japan, Korea, China, and India suggests that considerable progress has been made, covering a diverse set of technologies in the smart grid system, such as electric vehicles, renewable energy, energy efficiency, and smart meters. With the completion of the first stage of smart grids (e.g., the implementation of smart meters), industrialized countries are gradually moving forward, integrating diverse energy generation sources as well as customer participation. Nevertheless, further advances are needed to harmonize policies across nations, states, and localities, and to learn from recent experiences with this new generation of electric grid technologies (Brown & Sovacool, 2014).

Embracing a diverse set of electricity generation technologies may present new risks and reliability challenges for utility companies. When introducing alternative energy sources, regulators may reduce their expectation for reliability, which is often set at a high level in the traditional energy system dominated by fossil fuel. Additional policy incentives may be provided to encourage the R&D and commercialization of energy storage technologies, to support the large-scale penetration of alternative energy sources.

As the interoperability of technologies is essential for large-scale and integrated deployment of smart grids, development of standards at the national and global level will be particularly important in the future. Establishment of lead agencies to coordinate efforts at various levels of governments would facilitate the standardization process, as well as address the cybersecurity issue across all sectors. At this moment, privacy policies, technical standards, and implementing procedures at the local, regional/state, national, and international levels are often inconsistent. This opens the door to significant cybersecurity and privacy risks in the electric grid that need to be managed. In addition, energy regulators and companies are often inexperienced in addressing customer privacy concerns compared to those in some other industries (e.g., the financial sector). The extensive amount of data stored in smart grids, and the data flow between customers and utilities, counsel for the adoption of privacy rules and regulations in the use of energy customer information. Well-established privacy protection methods in banking and other industries may be adapted to facilitate the privacy policy development in the smart grid regime.

The electric power industry is facing tremendous opportunities and becoming increasingly important in the emerging low-carbon economy. The costs required for the full deployment of smart grids are large. Currently, government is still the key player in smart grid investments. This suggests the need for a policy framework that attracts private capital investment, especially from renewable project developers and communication and information technology companies. For utility companies, especially those owned by private investors, their investment in modern grid infrastructure is closely regulated by government. How the cost recovery rules are set and interpreted by regulators greatly affect utility decisions in smart grid investments. Reforming the rate design mechanisms that are currently discouraging utilities' investment in advanced technologies, and ensuring that costs and benefits are shared among all stakeholders are also important future directions. Another issue with smart grid financing is related to the transboundary nature of the electric infrastructure. Transmission lines that connect states and cities are often under the jurisdiction of national level government (e.g., in the United States, the FERC oversees the transmission and wholesale markets). Electricity distribution and supply, however, are regulated by regional or local governments. Financing policies at the different levels may be designed and coordinated to support smart grid infrastructure development in areas of transmission, distribution, generation, and consumption.

TABLE 9 Policy drivers and policy emphases, by country

	Policy drivers	Policy emphases
USA	• Power system reliability • Clean electricity • Economic development and jobs	• Technical and operational standards • Smart meters • Dynamic pricing and demand response programs
EU	• Renewable energy and energy efficiency • Carbon emissions reduction	• Technical and operational standards • Competitive retail market • Smart meters • Transmission and distribution networks modernization
Japan	• Energy security • Carbon emissions reduction • Enhancing competitiveness of domestic industries	• Smart communities • Smart meters • Solar photovoltaic generation
South Korea	• Energy security • Enhancing competitiveness of domestic industries • Carbon emissions reduction	• Smart power grid • Smart consumers • Smart transportation • Smart renewables • Smart electricity services
China	• Reducing power generation disparities between regions • Reducing energy/carbon intensity • Strategic economic restructuring • Renewable energy	• Electric vehicles • Solar photovoltaic generation • Upgrading and modernizing urban and rural electric grid
India	• Economic growth and access to energy • Providing price signals to consumers • Renewable energy and electric vehicle integration • Reducing electricity theft	• Smart power grid • Electric vehicles • Quality power for all • Dynamic tariffs

A competitive electricity market that encourages variable business models could enhance the flexibility of electricity systems and support an increasing renewables penetration. Regulatory changes that remove barriers to a competitive energy market could also optimize overall operations and costs, hence increasing the net social benefits from smart grids.

As the deployment of smart grids progresses, demand response and DERs may significantly reduce peak demand and make some generation facilities redundant, leading to "stranded assets." This requires sophisticated resource planning and CBA at the early stages of smart grid deployment. Smart grid customer policies, such as dynamic pricing and customer protection, require an understanding of customer behavior. New policies should be developed based on social science studies of consumer feedback and response to smart grid technologies and regulations. These will be important next steps to deliver consumer benefits from smart grids.

Collaboration on smart grid standards and sharing experiences from demonstration projects can reduce repetition and overlap in smart grid deployment efforts. Disseminating best practices from the North to the South can be particularly beneficial to those developing countries, where electricity infrastructure is expanding rapidly. For developing countries that are still (Table 9) struggling to provide their people with electricity and combat air pollution, smart grids provide an opportunity for them to leapfrog the traditional power system, and to benefit from the low-carbon, more reliable and diverse energy services. In this sense, South–South collaboration and learning can be helpful for countries to effectively develop their smart grid roadmap, and to identify technology solutions that suit the best to their rural electric infrastructure. Assistance and support from the global communities shall also be directed to capacity building of government officials, utilities, and entrepreneurs in developing countries. This will ensure the less developed countries have their pool of human resources to design and implement a supportive policy scheme and to operate the energy market efficiently.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

NOTE

[1] The United Kingdom is on course to leave the European Union in 2019. All the data for technology and policy developments referred to in this paper were for the year of 2016 and before, when the United Kingdom was still a member state of the EU.

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