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Smart-Grid Policies: An International Review

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ABSTRACT

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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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 serve individual consumers. Both electricity and information flow 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. With the advancement of technology, the increasing demands of a digital society, growing threats to infrastructure security, and concern over global climate disruption, the current electricity infrastructure has become a constraint to progress. The result is a growing awareness of the need for electricity infrastructure modernization and the virtues of a “smart grid”.

Smart grid architectures can integrate a diverse set of electricity resources, including large power plants as well as distributed renewable resources, electric energy storage, demand response, and electric vehicles. 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, the nature of the customers being served and other demand-side issues. By implementing a smart grid, electric systems can operate at higher levels of power quality and system security.[1] 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 non-technical losses that undermine grid economics in many developing countries. Without the development of the 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 will not be fully realized.

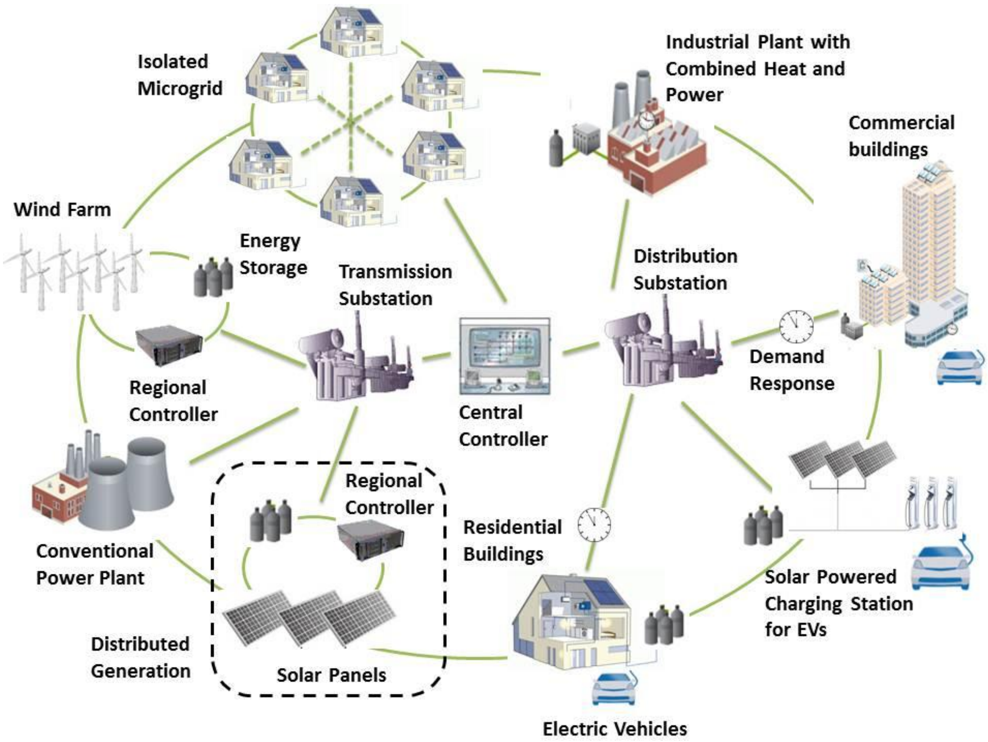

Figure 1 Smart Grid: A Vision for the Future

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 that hinder smart-grid deployment and the drivers that motivate it. We then review experiences with smart-grid policies in the U.S., 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 Great Britain and Italy. To illustrate the smart-grid policies used in other hemispheres, we also describe policy initiatives in China, South Korea 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

Although many smart-grid technologies are available today, their widespread deployment is limited. To be effective, policies must address the key barriers that hinder deployment. Policies should also be designed to leverage the drivers that promote investments in smart-grid technologies.

2.1 Smart-Grid Barriers

Access to Capital. Large upfront cost and lack of access to capital is one of the greatest challenges to the deployment of smart grids.[2] Like many other green technologies, deployment requires significant initial investment, yet the resulting benefits may not be fully realized for many years.[3] For example, the Electric Power Research Institute estimates that smart grid investments needed in the U.S. would cost the average residential customer $1,000 to $1,500; amortized over a 10-year period, this would cause the average residential electricity bill to increase by 8 to 12%.[4] On the one hand, the benefits could be 3 to 6 times larger than these costs, such as lower meter reading costs, improved billing processes, reduction of non-technical losses, enhanced reliability, improved power quality, increased national productivity and enhanced electricity service. On the other hand, without guaranteed cost-recovery timelines or sound business mechanisms to reduce risks for smart-grid investment, utilities and policy makers tend to be reluctant to move toward a smart grid.[2]

Technical Risks. 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 distributed generation (DG) on existing infrastructure can threaten system stability.[2] Developing complex integrated systems also places demanding requirements on a wide range of technologies, especially advanced metering infrastructure (AMI) and cost-effective energy storage systems.[2] At the same time, AMI and storage systems are evolving rapidly, which introduce performance risks.

Regulation and Monopoly Structure. Although electricity market reforms have been pursued in many countries, the utility business model based upon a negotiated rate-of-return that adequately recovers utilities' capital investments is still dominant in modern economies. 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.[5] 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 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 do not typically reflect the marginal cost of electricity production or the conditions of the wholesale electricity market.[6] Without dynamic pricing that reflects the time-dependent cost of electricity generation, customers who only receive an end-of-the-month bill tend not to be interested in smart-grid technologies or end-use efficiency.[7]

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 DG. Incumbent electricity providers and distribution (and transmission) companies have incentives to discourage the deployment of smart grids in light of its 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.[6]

Incomplete and Imperfect Information. Many consumers and investors do not see the benefits of a smart grid, nor do they understand the social and economic costs associated with today's outdated power system.[6] The fear of carcinogenic effects from radio frequency waves has created negative public opinion about the safety of AMI, demand-response end-use systems, electric vehicle charging stations, and other smart grid technologies.[8] Utilities and policy makers could play important roles in defining and communicating any health and safety effects and the benefits of smart-grid systems to various stakeholders.[3]

Privacy and Security Concerns. Many technologies that enable the deployment of smart grids, such as smart meters and sensors can increase the vulnerability of the grid to cyber-attacks.[3] As the number of participants and distributed generators in the electric system increases, so does the complexity of security issues.[6] The tension between protection of consumer privacy and development of smart grid also imposes challenges on 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 the meters and data on electricity consumption create barriers to market entry for new smart-grid players.[7]

2.2 Smart-Grid Drivers

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.

Increasing Electricity Demand. Global electricity demand is expected to increase by over 150% between 2007 and 2050 under the International Energy Agency (IEA)'s 2010 Baseline Scenario.[9] Due to the rapid development of home appliances and a lack of real-time pricing signals, peak demand is expected to increase steadily over time. Since 1982, growth in peak demand for electricity in the U.S. has exceeded the growth of transmission system infrastructure by almost 25% every year,[10] with an expected average annual growth rate of 1.7% between 2009 and 2019.[11] Rising peak demand stresses the electricity system and requires higher reserve margins for unforeseeable outages. 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 renewable DG.

Energy Price Escalation and Electricity Reliability Concerns. Under EIA's Reference and High Oil Price Scenarios, world oil prices are forecast to increase from $59 per barrel in 2009 to $135 and $210 per barrel respectively in 2035.[12] Rising petroleum prices have underscored the uncertainties associated with the long-term electricity market. Meanwhile, power systems that are largely based upon technologies developed in the early 20th century and that operate following a business-as-usual (BAU) approach will likely become increasingly vulnerable and fail to meet challenges associated with the new demands in the future. 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 prevent widespread electric service interruption by shedding loads and redispatching power.

Climate Change and Clean Air Concerns. Energy-related human activities are a major emission source of greenhouse gases and air pollutants. As in most industrialized countries, the electric power and transportation sectors in the U.S. are the largest carbon emission sources, accounting for 40% and 34% respectively of U.S. total emissions in 2010.[13] Many countries have set targets for low-carbon and renewable electricity generation to combat climate change, 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 and transport systems.

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. As of 2008, 19% of world electricity was generated by renewable energy, and forecasts suggest a rise to 23% by 2035, with an annual growth rate of 3%.[14] Most of the new renewables is expected to come from variable and difficult-to-predict wind generation.[15] The transport sector is also undergoing an electrification revolution, which is expected to consume 10% of total electricity by 2050.[9] As electric vehicles gain market share, it may become difficult for conventional grid infrastructures to provide reliable and stable electricity services.[9] 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.

Economic Development and Business Opportunities. 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. The savings businesses obtained through the adoption of smart-grid technologies could also be redirected to other business investments; hence improve their competitiveness in both domestic and international markets. It is clear that countries pioneering in smart-grid deployment are building competitive advantage for their future economy.

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 U.S. is second only to China in total energy-related CO_2 emissions

– at 5,610 million metric tons (Mt) of CO_2 in 2010.[16] On a per capita basis, the U.S. is also highly carbon intensive – averaging 18.1 metric tons per person in 2010. 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.[17] 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 11% of its electricity currently comes from renewable sources, compared with 27% in Italy and 19% in China. (See Table 7 for a list of data sources and a comparison with the other pioneering smart countries examined here.) Given the President's clean energy imperative, the government recognizes that a smarter, modernized and expanded electric system is essential to America's world leadership in a clean-energy future.[18] Development of policies has occurred at both federal and state levels to facilitate the evolution towards a 21st century grid.

3.1 Smart-Grid Legislation and Policy Context

The Energy Policy Act of 2005 is the first federal law that specifically promotes the development of smart meters. It directs utility regulators to consider time-based pricing and other forms of demand response for their states. Utilities are required to 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 is the key legislation for modernizing the nation's electricity transmission and distribution system. It authorizes the Department of Energy (DOE) to establish the Federal Smart Grid Task Force as the main platform 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 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 next important legislative effort is the American Recovery and Reinvestment Act of 2009. It accelerates the development of smart-grid technologies by appropriating $4.5 billion for electricity delivery and energy reliability modernization efforts. Utilities and other investors can apply stimulus grants to pay up to 50% of the qualifying smart-grid investments. To date, the Smart Grid Investment Grant authorized under this Act has 99 recipients, with a total public investment of $3.5 billion.[19]

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.[20] 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 and 10 metric tons of CO2 per capita in New York and California, respectively, to 17 and 24 metric tons in Georgia and New York. The percent of their electricity generation coming from renewable resources ranks similarly, with only 5 and 7% renewables in Georgia and Texas, but fully 22 and 29% in New York and California.[21] The results show that four types of policies are widely implemented in these pioneering states: net metering policies, interconnection standards and rules, smart metering targets, and dynamic pricing policies.

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 1). Eligibility criteria are commonly defined by sectors (e.g., residential, commercial and industrial), types of renewable resources (e.g., solar, wind, and combined heat and power (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.[22]

Table 1. Net Metering Policies in Four U.S. States

	Qualifying Facilities		Cumulative Generating Capacity (% of utility's aggregate peak demand)	Buy-back rate
	Eligible Technologies	**System Capacity Limit**		
CA	Solar, wind, biogas, fuel cell	1 MW	5%	Retail rate
TX	Renewable energy sources	50 kW	No limit	Avoided energy cost
GA	PV, wind, fuel cell	- 10 kW (residential) - 100 kW (non-residential)	0.2%	A predetermined rate
NY	Wind, solar, fuel cell, micro-CHP, micro-hydroelectric, farm waste	10 kW - 2MW	- 0.3% (wind); - 1% (solar, biogas, micro-CHP and fuel cell combined)	- Retail rate (wind, solar, farm waste) - Avoided energy cost (micro-CHP, fuel cell)

Interconnection Standards and Rules. Interconnection standards establish uniform processes and technical requirements for utilities when connecting DG systems to the electric grid. It allows DG 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 available to certain generation facilities, depending on their generating capacity, sector, and technology type (See Table 2).

Table 2. Interconnection Standards and Rules in Four U.S. States

	Main Provisions	Targeted Systems
CA	• Standard interconnection, operating, and metering requirements • Application and evaluation procedures, fees and costs	Facilities to be connected to utility distribution systems
TX	• Requirements for generators and network interconnection of DG • Requirements for control, protection and safety equipment	Facilities with capacity ≤10MW and connection voltage ≤ 60kV
GA	• Customers are required to meet applicable interconnection requirements, such as the National Electrical Code and the National Electrical Safety Code	Residential (≤ 10kW) and Commercial (≤ 100kW) facilities that use PV, wind and fuel cells
NY	• Interconnection procedures • Requirements for the design and operation of DG facilities • Application procedures, fees and maximum expenses	Facilities ≤ 25kW; 25kW ≤ Facilities ≤ 2MW

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 the consumers. Smart metering targets typically establish smart meter reader 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. Many states have set smart metering targets to be implemented by utilities (See Table 3). Georgia, in particular, aims to install smart meter readers for every consumer by 2012.

Table 3. Smart Metering Targets in Four U.S. States

	Utility/Agency	Deployment Timeline	Targets	
			Electric Meters (Million)	Gas Meters (Million)
CA	Pacific Gas and Electric	2007-2011	5.1	4.2
	San Diego Gas & Electric	2007-2011	1.4	0.9
	Southern California Edison	2008-2012	5.3	-
TX	Center Point	2009-2012	2.1	-
	Oncer	2008-2012	3.4	-
	AEP Texas	2009-2013	1.1	-
GA	Georgia Power	2008-2012	Every customer will be provided with a free smart meter reader	
NY	Public Service Commission	2006	Utilities must file proposals for integrating smart meter readers into their systems	

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 consumption at higher prices or to cut electricity usage during peak times. It is currently available in many sectors, and is most widely used in commercial and industrial sectors (See Table 4). 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 prices variability The most common dynamic pricing policies include time-of-use pricing, critical peak pricing and real-time pricing.

- **Time-of-Use Pricing (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.

- **Critical Peak Pricing (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.

- **Real-Time Pricing (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.[23] Technology innovations of the last decade have enhanced customers’ ability to respond to real time prices, and eliminated the conflicting issues between greater advanced price notification and more accurate price signals, enabling the greater use of RTP.[23]

Table 4. Dynamic Pricing Policies in Four U.S. States

	Types of Rates	**Targeting Systems**			
		Residential Sector	Commercial and Industrial Sectors	Agricultural Sector	Electric Vehicles
CA	CPP	√	√	√	√
	RTP		√	√	
	TOU	√	√	√	√
TX	TOU	√			
GA	TOU	√	√	√	√
	RTP		√		
NY	TOU	√			
	RTP		√		

Besides the four types of policies described above, access to real-time metered data is illustrative of the new issues requiring public regulation. U.S. states are beginning to set requirements regarding data security and privacy of smart meters. Texas, for example, has determined that all meter data, including data used to calculate charges for service, historical load data, and any other proprietary customer information, will belong to a customer; however, customers can allow retail electric providers to access the data under rules and charges established by the Public Utility Commission of Texas.

The ownership of renewable energy credits (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.

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. Numerous different types of dynamic pricing rates have emerged over the past decade, typically starting with large industrial customers, followed by commercial and large non-residential customers. Research has shown that dynamic pricing can not only remove subsidies embodied in flat rates, but also reduce peak demand.[24] [25] Variability among dynamic pricing rates also reflects the differences in policy goals of cost recovery and demand response programs.

Despite this wide-ranging policy variability, some policy principles are emerging. Cost allocation rules need to ensure the recovery of smart grid costs and to facilitate investment in 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 of the European Union

The EU is the second largest energy market in the world, with over 450 million customers.[26] The objective of EU energy policies in the 21st century is to achieve a sustainable, competitive and secure energy supply.[27] 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 5.

Table 5. Smart Grid Legislation and Regulations in the European Union

	Policy Emphases			
	Inter-Connection Standards	**Smart Meters**	**Demand Response & Dynamic Pricing**	**Electric Vehicles**
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)		√		

4.1 Smart-Grid Policies in Italy

Italy emitted 416 Mt CO_2 in 2010, a 2% increase above 2009 but lower than its peak of 467 in 2006. Its carbon intensity (at 7.0 metric tons of CO_2 per capita) exceeds that of China but is lower than the other four countries examined here.[28] Its modest carbon footprint is achieved in part by its significant investment in renewable power, which represents 27% of its total electricity generation. 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.[29] The Italian government plans to increase the country's renewable consumption from 5.2% of total energy consumption in 2005 to 17% in 2020.[30]

Efforts at various levels of governments have been made to accelerate energy infrastructure optimization. In 2007, the European Commission approved the Operational Program - "Renewable Energy Sources and Energy Saving" in southern Italian regions (Apulia, Campania, Calabria and Sicily) with a budget of €1.6 billion ($2.0 billion US dollars).[31] One priority of this program is to improve the infrastructure of transmission networks to promote renewable energy and small/micro scale cogeneration, which receives €100 million ($123 million US dollars) from European and Italian state funds.[32] 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 capacity between 100 kW and 1 MW.[32] 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.[33]

Italy has one of the largest and most extensive smart metering programs in the world. In Regulatory Order 18 December 2006 no.292/06 and Regulatory Order 26 September 2007 no.235/07, Italian legislators introduced mandatory installation of smart meters for all household and non-household low voltage customers starting from January 1, 2008, and minimum performance standards for the meters were also provided.[34] Italy's smart metering deployment has an emphasis on the distribution system operators, which 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 has installed smart meters for 32 million customers in its electrical distribution system and provided advanced services enabled by smart meters, such as the hourly-based tariff system.[35] It 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.[35] Besides smart meters, Enel also launched the E-mobility Italy program in three Italian cities: Rome, Milan and Pisa in 2008.[36] The program will deliver 100 electric vehicles to selected drivers in the three cities, and build 400 intelligent electric vehicle recharging stations.

In order 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 photovoltaics. 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.[37] However, no incentives will be awarded to PV plants entering into operations after 2016.

4.2 Smart-Grid Policies in the UK

The UK was responsible for 532 Mt CO_2 from energy use in 2010, down from before the 2008 economic downturn, but 2% above its 2009 figure.[38] On a per capita basis, the UK and Italy are similar, and both have less than half the carbon footprint of the U.S. The British government sets 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.[39] A critical part of this framework is to commit the country to generate 15% of its energy from renewables by 2020.[40] Only 7% of the UK's current electricity generation comes from renewable resources. The British power system is owned and operated by three transmission network operators and nine distribution network operators, 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.[41] Integration of diverse generation from low-carbon technologies inevitably requires transformation of the electric system.

To modernize and reduce the carbon footprint of electric grids, one major initiative of the UK 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.[42] Early government action can be traced to the 2008 Energy Act, which allows Secretary of State to take measures to install or facilitate the installation of smart meters.[43] Energy Bill 2010-11 provides financial incentives to encourage smart meter installation by householders, private landlords and businesses.[44] In July 2010, the Department of Energy and Climate Change (DECC) and Office of the Gas and Electricity Markets (Ofgem) published the "Smart Metering Implementation Program: Prospectus" which sets design requirements, central communications, data management and the rollout plan for the deployment of smart meters to all homes and small businesses in Great Britain.[45] The Government's *Response to Prospectus Consultation* in 2011 requires energy suppliers to provide smart meters that meet specific technical standards.[46] It also includes selection and regulatory procedures for a new, licensed Data and Communications Company to manage smart metering data. With respect to privacy protection, customers will be able to 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 introduces Feed-In-Tariffs (FITs) for low carbon electricity generation facilities with a generating capacity less than 5 MW.[43] Eligible technologies include anaerobic digestion, solar photovoltaics, hydro-electric power, wind, and micro CHP systems. Total capacity of solar PV registered in FITs has reached 1 GW by 2012, with the FIT payment rates ranging from 8.9 to 21.0 p/kWh ($0.14~$0.33/kWh).[47] Between 2010 and 2015, Ofgem was committed to provide a £500 million ($785 million US dollars) Low Carbon Networks (LCN) Fund to help distribution network operators (DNOs) develop trial projects of new technologies and commercial arrangements that enhance energy security and combat climate change.[48] British energy regulators believe that the up scaling 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.[42]

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.[49]

5. Smart-Grid Policies of East Asia

5.1 Japan

As a country that is only 16 percent energy self-sufficient, Japan is the world's largest importer of liquefied natural gas (LNG), second largest importer of coal and the third largest net importer of oil.[50] Its energy use was responsible for approximately 1,160 Mt CO_2 in 2010, and one-third of these emissions were produced by its industrial sector. On a per capita basis, Japan is half the carbon intensity of the U.S. (9.2 versus 18.1 metric tons of CO_2 per capita).[51] Japan aims to reduce its carbon emissions by 30% by 2030 compared to the 1990 level, and to have 70% of its electricity generated from zero-emission sources by 2030, while in 2010, only 1 percent of Japan's total energy consumption was from non-hydro renewables.[50] [52] 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.[52] The 2011 Fukushima nuclear incident which put the country in an unprecedented energy crisis, has greatly accelerated 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.[53]

Japan's power industry is dominated by ten regional monopolies, which accounts for 85 percent of the country's total installed generating capacity.[50] 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.[53] The FIT scheme - "New Purchase System for Photovoltaic Electricity" launched in 2009 is a key government incentive for renewables.[54] Surplus electricity generated from solar photovoltaics 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 Ministry of Economy, Trade and Industry (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, including the charging infrastructure, and create new services using smart meters and ICT networks.[55] 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 (U.S.), Hawaii (U.S.), Lyon (France) and Malaga (Spain).[56] [57]

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 New Energy and Industrial Technology Development Organization (NEDO) in 2010 provides a platform for the participation of a wide range of smart grid stakeholders.[58] 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.[59]

5.2 South Korea

South Korea imports 97% of the energy it consumes and is highly dependent on imported petroleum and liquefied natural gas. Its energy system emitted 579 Mt CO_2 in 2010, representing a steady increase from 484 in 2006, mirroring its economic growth. Its per capita CO_2 emissions have also been on the rise, reaching 11.9 metric tons in 2010, reflecting a growing carbon intensity. Renewable energy only accounts for 1% of its electricity generation, which is the lowest among the six countries examined here.[60]

Korea doubled its CO_2 emissions between 1990 and 2010, the fastest growth among OECD countries.[61] By 2035, its carbon emissions are expected to increase 35% from the 2002 base line, compared to less than 15% for all the OECD countries.[60] Although as a non-Annex I Party, South Korea is not obliged to reduce its carbon emissions under the Kyoto Protocol, the Korean government sets a voluntary goal of reducing its greenhouse gas emissions by 30% below the BAU case by 2020.[60] 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 is to be operating by

2015.[62]

The electric system of South Korea is more reliable and efficient than many other developed countries.[63] 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.[64]

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.[65] 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.[60] 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 another key step.[66] The roadmap will be implemented in five sectors: smart power grid, smart consumers, smart transportation, smart renewables and smart electricity services. 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 minutes in 2012 to 9 minutes 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.[67] A total of $50 million public funds and $150 million private funds will be 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 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.[64] 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 greenhouse gases by 2030.[66]

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 U.S. in 2007 at 6,184 Mt CO_2, and its economic growth has catapulted China's emissions to 8,321 Mt CO_2 in 2010.[16] Between 1990 and 2010, China's electricity generation increased from 621 to 4,206 Terawatt-hours (TWh),[68] with annual growth rates of electricity demand ranging from 10% to 15%.[69] In 2010, 19% of China's electricity generation came from renewable resources, second only to Italy among the six countries examined here.

China has experienced several major power outages since 2005, and the shortfall in electricity has started to hurt China's economy.[69] In order to meet the increasing demand and secure economic growth, the Chinese government will invest 286 billion yuan ($45 billion US dollars) in smart-grid deployment between 2011 and 2015.[70] 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.

Promoting the development of clean energy and smart grids is among the top priorities of the government. 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.[71] The 12th Five-year Plan, a series of major social and economic initiatives, sets separate targets for energy intensity (16% reduction by 2015), non-fossil fuel energy (11% of the total primary energy consumption by 2015) and carbon intensity (17% reduction below 2011 by 2015).[72] Smart grids and clean energy technologies are seen as effective approaches to achieve these targets. 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 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 1000 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 May, 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 information and communication technologies, flexible power transmission technology and equipment, and smart grid integrated comprehensive demonstrations.[73] 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.[73]

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.[74] In May 2009, SGCC announced a plan for developing a “strong and smart grid” in China by 2020.[75] UHV transmission and highly efficient distribution transformer that enables the expansion of transmission and distribution capacity and reduces 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 and hydropower are located in remote areas, and there are huge disparities among power generation in different regions. Other reasons for the focus on transmission might be the relatively primitive structure at the distribution ends, and the unique asset ownership and management structure of utilities and electric markets.[76] 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.[77]

6. International Collaboration

The SmartGrids European Technology Platform was established in 2004, with an aim to enhance the level of coherence between the European, national and regional efforts addressing smart grids. One important role of this platform is to cooperate with other countries, especially North America and Japan, to ensure international development paths for smart grids are complementary and consistent with the development of commercial products.[51]

The IEA Implementing Agreement on Electricity Networks Analysis, Research and Development (ENARD) was developed by fourteen IEA member countries in July 2006. Its mission is to provide comprehensive and unbiased information, data and advice to key stakeholders and policymakers of the issues relating to current and anticipated developments in electricity transmission and distribution networks.[78] Some of the work programs that are closely linked to smart grids include Annex II (DG system integration), Annex III (infrastructure asset management), and Annex IV (transmission system issues). ENARD is currently focusing its activities within the IEA member countries; however, it is open to participation by non-IEA member countries, private sectors and non-governmental organizations.

Established in April 2010, the Global Smart Grid Federation (GSGF) brings together the key smart grid stakeholders around the world, including the U.S. GridWise Alliance, Australia, Canada, Ireland, Korean Association, India, and Japan.[79] Its goals are to facilitate the collaboration of governments and nongovernmental organizations, to support the development of smart-grid technologies and foster knowledge sharing. The International Smart Grid Action Network (ISGAN) was launched at the first Clean Energy Ministerial in Washington, D.C. in July 2010 to accelerate the development of smart-grid technologies at the global level. ISGAN focuses on five principal areas including policy, standards and regulation; finance and business models; technology and systems development; user and consumer engagement; and workforce skills and knowledge.[80] It includes four projects: the global smart grid inventory, smart grid case studies, benefit-cost analyses and toolkits and synthesis of insights for decision makers.

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 (see Table 6).

Table 6. Smart-Grid Policies to Tackle Barriers and Leverage Drivers

	Barriers					**Drivers**				
Smart-Grid Policies	Access to Capital	Technical Risks	Regulation and Monopoly Structure	Incomplete & Imperfect Information	Privacy & Security	Increasing Electricity Demand	Rising Energy Prices & Reliability Concerns	Climate Change & Clean Air	Deployment of Renewable Power& Electric Vehicles	Economic Development and Business Opportunity
Net Metering	×	×	×			×	×	×	×	×
Interconnection Standards and Rules	×	×	×	×	×	×	×	×	×	×
Dynamic Pricing	×		×	×		×	×		×	
Smart Metering Targets			×	×		×	×	×	×	×
Renewable Energy Subsidies& Regulations	×	×	×			×	×	×	×	×

International Smart-Grid Collaboration	×	×		×		×	×	×	×	
Smart-Grid Demonstration Projects		×		×		×	×	×	×	×

Countries are in different stages of smart-grid deployment and have set various targets for future development. Table 7 summarizes the energy and climate change targets of five nations and regions, and describes the drivers and focuses of their smart-grid policies. Although smart-grid policies vary across U.S. states, most states have implemented net metering policies and interconnection standards. Many utilities are installing smart meters using funds from American Recovery and Reinvestment Act appropriations, and dynamic pricing programs are widely used in industrial and commercial sectors. Smart-grid programs are critical components of the EU’s low carbon agenda. The 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 of low-carbon technologies. Japan and Korea are both focusing on innovation and export of smart grid technologies to build competitive advantages of domestic industries. Power shortage which comes along with the 2011 nuclear incident in Japan also accelerates 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 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.

Table 7. Status, Targets, Policy Drivers and Emphases, by Country

	CO_2 Emissions		Renewable Electricity		Policy Drivers	Policy Emphases
	Metric tons of CO_2 per Capita*	**CO_2 Emissions Targets**	**Percent Renewable Generation****	**Renewable Electricity Targets**		
USA	U.S.: 18.1 CA – 10 GA –17 NY – 9 TX – 24	17% below 2005 level by 2020	U.S.: 11 CA – 29 GA – 5 NY – 22 TX – 7	U.S.: None. (80% clean energy by 2035) CA - 33% by 2020 TX - 5880 MW by 2020 NY - 29% by 2015 GA - none	- Power system reliability - Renewable energy and energy efficiency - Economic revitalization	-Technical and operational standards - Smart meters - Dynamic pricing and demand response programs
EU	Italy: 7.2 U.K.: 8.5	20% below 1990 level by 2020	Italy: 27 U.K.: 7	20% by 2020	- Renewable energy and energy efficiency - Carbon emissions reduction	-Technical and operational standards - Competitive retail market - Smart meters - Transmission and distribution networks modernization
Japan	9.2	30% below 1990 by 2030	10	70% zero-emission power by 2030	- Energy security - Carbon emissions reduction - Enhancing competitiveness of domestic industries	- Smart community - Smart meters - Solar photovoltaic generation
South Korea	11.9	30% below BAU by 2020	1	11% by 2030	- Energy Security - Carbon emissions reduction - Enhancing competitiveness of	- Smart power grid - Smart consumers - Smart transportation - Smart renewables - Smart electricity

					domestic industries	services
China	6.3	Carbon intensity: 17% below 2011 by 2015	19	11% of total energy consumption by 2015	- Reducing power generation disparities between regions - Reducing energy/carbon intensity - Strategic economic restructuring - Renewable Energy	- UHV regional transmission - Upgrading and modernizing urban and rural electric grid

***** Source of data for countries: U.S. Energy Information Administration, International Energy Statistics (2010): http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=90&pid=44&aid=8&cid=regions&syid=2006&eyid=2010&unit=MTCDPP

Sources of data for individual U.S. states: U.S. Energy Information Administration, State Energy Data System (2009): http://www.eia.gov/state/seds/

**Total renewables for country data include hydroelectric, geothermal, wind, solar, tide and wave, biomass and waste.

Source: U.S. Energy Information Administration, International Energy Statistics (2010): http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=alltypes&aid=12&cid=regions&syid=2006&eyid=2010&unit=BKWH

For data on individual U.S. states, renewable energy includes geothermal, hydroelectric, solar thermal, PV, wind, wood and wood derived fuels, and other biomass.

Source: U.S. Energy Information Administration, Electricity (2010): http://www.eia.gov/electricity/data.cfm

https://explore.data.gov/Energy-and-Utilities/Electricity-Generation-by-State-by-Type-of-Produce/rhyi-ndfk

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, and China suggests that considerable progress has been made to develop effective policy frameworks. 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.[20]

As the interoperability of technologies is essential for a 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 cyber security issue across all sectors.

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.

A competitive electricity market that encourages variable business models could enhance the flexibility of electricity systems and support an increasing penetration of renewable generation technologies. 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. 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 DG may significantly reduce peak demand and make some generation facilities redundant. 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.

Collaboration on smart-grid standards and sharing experiences from demonstration projects can reduce repetition and overlap in smart-grid deployment efforts. Disseminating best practices can be particularly beneficial to those developing countries, where electricity infrastructure is expanding rapidly.

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