INFORMING U.S. ELECTRICITY POLICY:

INDEPENDENT DATA-DRIVEN POLICY TOOLS TO SUPPORT

REGULATORS, POLICY MAKERS AND UTILITIES

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INFORMING U.S. ELECTRICITY POLICY:

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LIST OF SYMBOLS AND ABBREVIATIONS

ARRA	American Reinvestment and Recovery Act of 2009
ASCE	American Society of Civil Engineers
ATSP	Appliance, Technology and Service Providers
BRICS	Brazil, Russia, India, China, and South Africa
BMC	Business Model Canvas
CBA	Cost Benefit Analysis
CO_2	Carbon Dioxide
DG	Distributed Generation
DOE	Department of Energy
EEI	Edison Electric Institute
EISA	Energy Independence and Security Act of 2007
EPA5	Energy Policy Act of 2005
EPRI	Electric Power Research Institute
EUBMF	Electric Utility Business Model Framework
EUBMT	Electric Utility Business Model Finance Tool
EV	Electric Vehicle's
FERC	Federal Energy Regulatory Commission
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emissions
GT-DSM	Georgia Tech – Demand Side Management tool
HHI	Herfindahl-Hirschman Index
IEA	International Energy Agency
IRP	Integrated Resource Plan
ISO	Independent System Operator
kWh	Kilo watt hour
LEED	Leadership in Energy & Environmental Design

MW	Megawatt
MWh	Megawatt hour
NARUC	National Association of Regulatory Utility Commissioners
NERC	North American Electric Reliability Corporation
NIST	National Institute of Standards and Technology
NR	Non-Recurring Program
NRECA	National Rural Electric Cooperative Association
OE	Office of Electricity Delivery and Energy Reliability
OECD	Organization for Economic Cooperation and Development
PPP	Purchasing Power Parity
PSC	Public Service Commission
PUC	Public Utility Commission
R&D	Research and Development
RFI	Request for Information
RR	Recurring Program
RTO	Regional Transmission Organization
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SEC	Securities Exchange Commission
SG	Smart Grid
SGCC	Smart Grid Consumer Collaborative
SGDP	Smart Grid Demonstration Projects
SGIC	Smart Grid Information Clearinghouse
SGIG	Smart Grid Investment Grants
SGIP	Smart Grid Interoperability Panel
SWOT	Strengths, Weakness, Opportunities, and Threats Analysis
T&D	Transmission and Distribution
TSM	Technical Support and Maintenance
U.S.	United States
UBMF	Utility Business Model Framework

SUMMARY

Electric grids are undergoing unprecedented changes to accommodate increased social demand for sustainability, better economics, improved reliability and greater efficiency. These transformed grids, or grids in transformation, are often referred to as “Smart Grids”. Achieving the objectives of the Smart Grid will allow the grid to be more flexible and autonomous; enabling it to better use current resources and respond to the needs of consumers. The objective of this dissertation is to study and understand U.S. Smart Grid progress, identify problems in Smart Grid development, and propose data-driven tools to help utilities and regulators address those problems. Three tools are proposed in this research (1) a Smart Grid development metric and (2) an electric utility business model framework and (3) an electric utility business model financial tool.

The dissertation is split into three segments. The first segment of the dissertation assesses U.S. Smart Grid progress based on information gathered directly from industry stakeholders. In that assessment eight areas were studied in depth and seven key recommendations were made. The second segment of the dissertation addresses the first recommendation identified in the Smart Grid assessment; a lack of specific Smart Grid goals and success metrics. This dissertation presents the Smart Grid development metric as a potential solution to this problem. The development metric solution is composed of twelve indicators that comprehensively measure Smart Grid progress either over time or in comparison to other nations/states. The third segment of the dissertation addresses the second problem identified; determining the appropriate way to calculate the costs and benefits of renewable generation and Smart Grid technology. The changes prompted

by the Smart Grid challenge many of the traditional electric utility methods for conducting business. This dissertation work creates an electric utility business model framework as a potential solution to this problem. The electric utility business model framework is intended to help utilities determine new ways to create value around Smart Grid technology and opportunities. The electric utility business financial tool is intended to assist utilities in understanding the possible financial implications of the new value streams generated from the electric utility business model framework.

CHAPTER 1

INTRODUCTION

1.1 Motivation

You come home from work, and the garage door won't open, so you park in the driveway. When you get inside your house, the lights won't turn on and it's hot. The power is out. Your kids are bored because there's no TV, video games, or Wi-Fi to get homework done. You can't cook dinner because all of your appliances run on electricity. You begin to worry that the food in the refrigerator will spoil. You also realize you won't be able to put on that load of laundry you had planned on doing or finish up the last bit of work you had planned to do.

That is life in America without power. Nothing gets done. Modern economies and society are dependent on electricity. Everyday inconvenience set aside, large scale power outages can cost billions of dollars and have deadly effects on human health and safety. During the 2003 Northeast U.S. blackout, 50 million people lost power, costing an estimated $6 billion dollars and contributing to eleven deaths, in just two days. [1]. One would assume that if a resource was this critical to everyday life, it would be well maintained. That is not the case with U.S. electricity infrastructure.

The final report on the 2003 blackout outlined a plethora of issues related to aging infrastructure and reliability standards that posed a danger to future U.S. electricity reliability. The report delineated 46 recommendations on how to mitigate future large scale blackouts in the U.S. The recommendations identified the need for increased reliability, better management and upkeep of electricity infrastructure, and increased security (both physical and cyber) [2]. Ten years later, in a different assessment of U.S. infrastructure, the American Society of Civil Engineers (ASCE) rated U.S. energy infrastructure as a D+. Their report detailed that the number of power outages in the U.S. had increased over 300% from 2007 to 2011. The ASCE also concluded that the U.S. is under investing in distribution infrastructure by $57 billion and $37 billion for transmission infrastructure. The ASCE again cited aging infrastructure and reliability issues related to lack of capacity/congestion as the principle challenges to the current and future reliability of the U.S. electric grid [3].

Both reports make it very clear that the U.S. is not doing enough to maintain its electricity infrastructure and ensure reliability. The Smart Grid has potential to serve as the solution to all of the above issues. The Smart Grid embodies a systematic overhaul of electricity infrastructure. It represents a holistic evolutionary way to bring electricity systems into the digital age.

The Smart Grid also has the potential to address other inadequacies in the current electric grid. Some of the most pertinent issues include incorporating renewables, addressing public value and market failures. American consumers have increasing interest in pursuing renewable energy [4]. When customers install renewable generation, they can use it to reduce the amount of electricity they purchase from the utility or sell that electricity back to the utility. In some parts of the U.S. it is difficult for customers to sell their excess electricity back to the utility because the grid does not support two-way power flows. Much of the current electric grid operates on a centralized control architecture established during the 1960's. This control architecture only meets the needs for a one way power flow system where utilities deliver power directly to consumers, supporting a generation-transmission-delivery paradigm. A centralized one-way architecture does not accommodate two-way power flow that would be needed for customers to sell energy back to the utility. With the rise in distributed generation and consumers wanting to "go-green" by adding generation sources to their personal residences a centralized architecture is inefficient. An updated, two-way, distributed architecture is needed and that need can be met by the Smart Grid [5]. Figure 1 depicts the changes from a one-way delivery system to a two-way power flow.

A.

B.

The traditional one-way grid architecture established in 1960 is shown in Figure A. The needed modern two-way architecture is show in Figure B. The modern architecture incorporates two way energy and information flow as well as the use of distributed generation.

Figure 1: Legacy Grid Architecture and Modern Grid Architecture [6]

The current electric also exhibits elements of public value failure. “Public [value] failure occurs when core public values are not reflected in social relations, either in the market or in public policy [7].” Bozeman separates public value failure into seven unique categories; (1) mechanisms for articulating and aggregating values, (2) imperfect monopolies, (3)benefit hoarding, (4) scarcity of providers, (5) short time horizon, (6) substitutability vs. conservation of resources and (7) threats to subsistence and human dignity. The current electric grid exhibits two characteristics of the categories; mechanisms for articulating and aggregating values and benefit hoarding. Recently, there has been increasing public concern over the environment and climate change [8]. The importance of environmental stewardship is not widely accounted for in the current electric grid, and this represents a public value failure [7].The future electric grid needs a way to incorporate environmental stewardship into its market evaluations so that the value of environmentalism is an active electricity cost factor.

The second public value failure present in the current electric grid is benefit hoarding. When the current electric grid was set up, it was established as a natural monopoly. Electricity providers were regulated by public utility commissions who allowed them to charge certain rates and receive a guaranteed margin of return. Initially, this guaranteed a certain quality of service and gave entrepreneurs incentive to participate in the industry. However, this arrangement can encourage utilities to generate additional electricity over pursuing energy efficiency, formally known as the throughput incentive [9]. In the traditional natural monopoly setup, utilities are incentivized to produce electricity to avoid losing a guaranteed margin of return. This is a form of benefit hoarding, because the utility is incentivized to hoard the benefit of guaranteed returns from selling additional electricity instead of pursuing other options to meet electricity needs like energy efficiency. The Smart

Grid can address some of these problems. An updated architecture and infrastructure can make integrating renewable energy easier, addressing some environmental concerns as discussed above. In addition, new market mechanisms can create alternative ways for utilities to receive compensation, reducing the incentive to hoard benefits.

The current electric grid also exhibits characteristics of market failure. Market failure occurs when the free market fails to efficiently allocate goods and services. Generally it is broken down into seven unique categories; (1) externalities, (2) imperfect information, (3) bounded rationality, (4) public goods, (5) monopolies, (6) excludability and (7) transaction costs [10] [11]. Four of these categories; monopolies, externalities, imperfect information and bounded rationality; are demonstrated in the current electric grid.

Monopolies represent one of the most poignant market failures in the current electric grid. There are states in the U.S. who have deregulated but many still operate under the traditional monopoly structure. The status of U.S. electricity restructuring as of 2010 is shown in Figure 2. As discussed in the bounded rationality section above monopolies lead to imperfect competition. Deregulating the electricity market or introducing new revenue mechanisms will help alleviate this market efficiency.

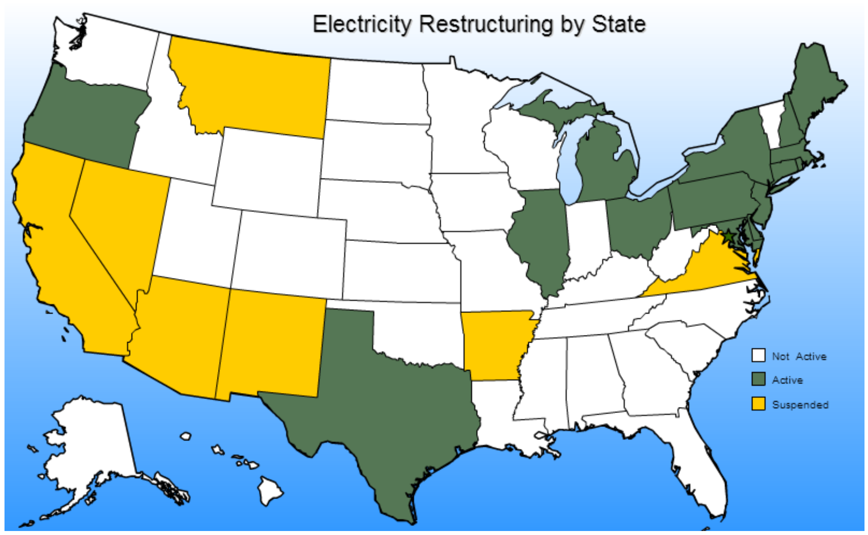

Figure 2: US Electricity Restructuring by State as of 2010 [12]

As far as externalities are concerned, a lack of environmental stewardship also represents an inefficiency of the current electric grid as discussed in the public value section [13]. In a perfect market, all costs and benefits are considered. In the current electric market, the cost of greenhouse gas emissions and pollution are not accounted for. In order to, know the true cost of electricity that would produce optimal consumption, these elements have to be factored in.

The last two factors of market failure work hand in hand. Electricity consumers are not educated about energy use. Industrial and large commercial scale consumers are knowledgeable but the average commercial or residential electricity consumer is not educated about energy use. A 2014 survey of American consumer's knowledge about Smart Grid indicated that only 25% of consumers had a basic to complete understanding of what the Smart Grid was and how it would work [14]. This lack of consumer education leads to imperfect information because the electricity provider is very educated on energy use and how much energy each customer class uses. This lack of education for the consumer leads to bounded rationality. Consumers make decisions based on imperfect information which leads to sub-optimal energy consumption. Also, a lack of knowledge about energy conservation results in repeated inefficient energy decisions. The Smart Grid can alleviate these market inefficiencies by providing the consumer with more information and applications to act upon on that information. For example, daily reports of their energy use or a home energy management system that works to optimize daily energy use based on data from previous days.

1.2 What is Smart Grid?

Smart Grid has become a buzz word to mean many things to many people. Technically, a Smart Grid is an electric grid that has been updated and digitized to enable two-way communication between producers and consumers. A Smart Grid can include advanced sensors, new communication devices and software, automatic devices like re-closers, upgraded infrastructure and improved information systems. Smart Grids also encompass new consistent standards for digital devices to encourage interoperability. An illustrative depiction of a Smart Grid is shown in Figure 3.

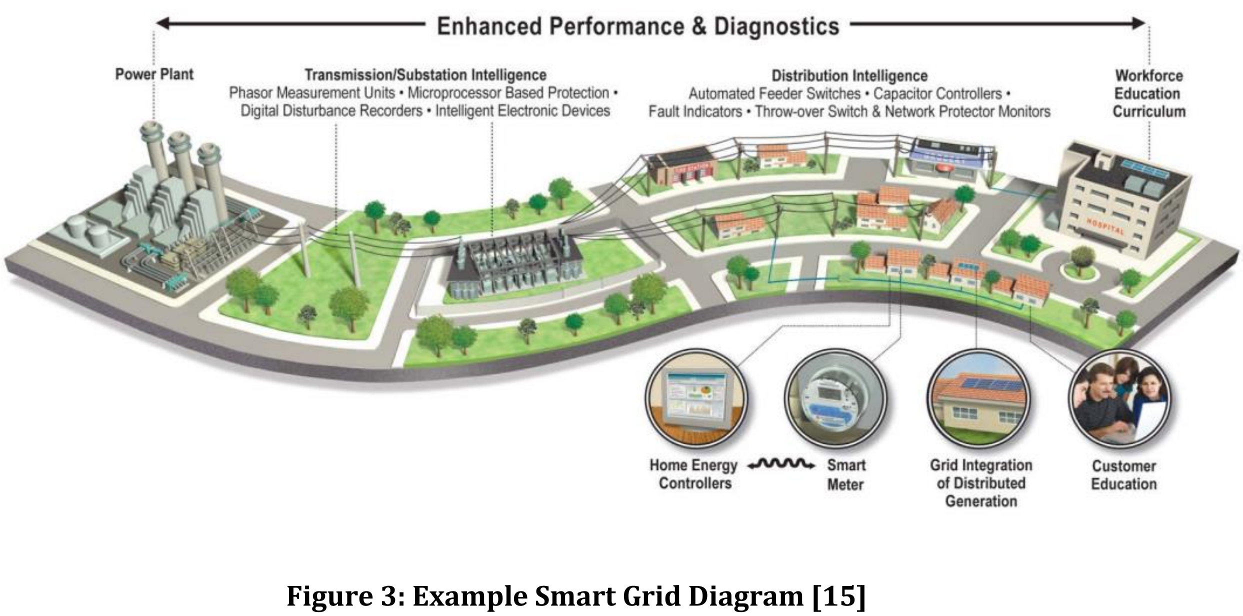

Figure 3: Example Smart Grid Diagram [15]

In broader terms, Smart Grid is viewed as a means to achieve social goals. Those goals can include increased sustainability, expanded use of renewable technology, more efficient use of energy, increased reliability, and increased physical and cyber security. The goals to be achieved vary according to the entity studied. The U.S. has defined seven goals that they would like their Smart Grid to achieve. The goals are: (1) Enable active participation by consumers; (2) Accommodate all generation and storage options; (3) Enable new products, services, and markets; (4) Provide power quality for the range of needs in a digital economy; (5) Optimize asset utilization and operating efficiency; (6) Anticipate and respond to system disturbances in a self-healing measure; and (7) Operate resiliently against physical and cyber-attacks and natural disasters [16].

1.3 Objective

Electricity is essential to the U.S. way of life and economy. Currently, the U.S. electric system is not maintained enough to ensure reliability in the future. The U.S. has begun to pursue a Smart Grid to remedy this problem, but there is still much work to be done. The objective of this dissertation is to study and understand U.S. Smart Grid development, identify problems in that development, and create data-driven tools to address those problems. Three tools are presented in this dissertation, (1) a Smart Grid development metric, (2) a utility business model framework and (3) a business model financial calculator. The tools are intended to assist policy makers, regulators and utilities in making decisions with the goal of improving U.S. Smart Grid development.

This dissertation is divided into three segments. In the first segment, an assessment U.S. Smart Grid development is presented. In that assessment, seven key problems are identified [17]. The second segment addresses the first identified problem in the Smart Grid assessment, "a lack of specific Smart Grid goals and success metrics". The Smart Grid development metric is presented as a potential solution to this problem. The development metric solution is composed of twelve indicators that utilize publically available data to comprehensively measure Smart Grid development for nations or states. The third segment addresses the sixth problem identified, "determining appropriate ways to calculate the costs and benefits of renewable generation and Smart Grid technology". An electric utility business model framework (EUBMF) and an electric utility business model finance tool (EUBMT) are presented as potential solutions to this problem. Technological and regulatory changes prompted by the Smart Grid challenge the traditional electric utility business model. The EUBMF is intended to help utilities determine new ways to create value around Smart Grid technology and opportunities. The EUBMT is intended to assist utilities in understanding the possible financial implications of the new value streams generated from the electric utility business model framework.

CHAPTER 2

U.S. SMART GRID PROGRESS

2.1 Motivation

The Energy Independence and Security Act of 2007 (EISA) established that the current electric grid was inadequate to serve U.S. needs. Congress mandated that the U.S. electricity industry transition to a more intelligent grid for the future. The Department of Energy (DOE) was tasked with making this goal a reality [18]. Six years later in 2013, only marginal progress had been made. Outside of smart meter rollouts and pilots programs funded through the American Recovery and Reinvestment Act of 2009 (ARRA), many issues still need to be addressed in order to realize the U.S. Smart Grid vision [19]. The barriers can be technological or arise from policy issues. This research will focus on the policy barriers. Issues ranging from vague Smart Grids goals issued by the DOE to a general lack of consumer knowledge about the Smart Grid [20] will be addressed.

This research seeks to identify the gaps in achieving the Smart Grid goals set forth by Congress in the EISA and make seven recommendations to address policy issues deterring the growth of the Smart Grid. The recommendations are based on outside literature and an analysis of the DOE's Request for Information (RFI) entitled "Addressing Policy and Logistical Challenges to Smart Grid Implementation" – herein referred to as the "policy RFI". Issues related to data access, data privacy, or communications requirements of the Smart Grid are not discussed because those issues were addresses by previous RFI's of the DOE.

2.2 Overview of U.S. Smart Grid Policy Progress

Each state in the U.S. is pursuing Smart Grid development in a different way. Some states are far ahead, and others are really just beginning. This review will only focus on Smart Grid progress being mandated at the federal level.

The U.S. federal government has enacted three key pieces of legislation that have initiated their progress towards a modernized grid. The first piece of legislation was the Energy Policy Act of 2005 (EPA5). It was a wide sweeping law that covered a variety of energy issues in the U.S., and there were three provisions that related to U.S. electricity infrastructure. First, the bill set new standards for reliability in the U.S. It designated that the Federal Energy Regulatory Commission would oversee an “Electricity Reliability Organization” that would be tasked with enforcing reliability standards [21]. The North American Electric Reliability Corporation was selected to be that Electricity Reliability Organization and now creates, monitors, and enforces reliability standards across the U.S. EPA5 also identified National Interest Electric Transmission Corridors where “geographic areas experiencing electric energy transmission capacity constraints or congestion that adversely affects consumers” could receive assistance in building needed new transmission lines [21]. Lastly, EPA5 attempted to streamline the federal transmission approval process by detailing how federal entities involved in the approval process should interact and how quickly they should respond to new citing requests [21].

The second key piece of legislation was the Energy Independence and Security Act of 2007 [18]. It was the first U.S. law to officially support the “Smart Grid” effort. EISA explicitly declared “it is the policy of the United States to support modernization of the nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve specified characteristics of a Smart Grid." EISA created the Smart Grid Advisory Committee, Smart Grid Task Force, and the Smart Grid Investment Matching Grant Program. These programs gave the DOE the responsibility to officially pursue U.S. Smart Grid efforts and required them to report to Congress annually on the U.S.'s progress. EISA also tasked the National Institute of Standards and Technology (NIST) to coordinate interoperability standards for the Smart Grid [18].

The third and final key piece of legislation was the American Reinvestment and Recovery Act of 2009 (ARRA), more commonly known as the stimulus package. It was an economic stimulus package meant to create and save existing jobs, provide temporary relief programs and invest in U.S. infrastructure. In total, $4.5 billion dollars were allocated towards Smart Grid modernization efforts [22]. The bill was enacted through four programs: Smart Grid Investment Grants (SGIG); Smart Grid Demonstration Projects (SGDP); workforce training programs and standards; and interoperability and cyber security activities. SGIG programs focused on implementing currently available Smart Grid technology to improve existing grid performance. SGDP focused on more advanced and upcoming technology that would provide valuable research for future Smart Grid projects [22]. The workforce training program provided funding to help develop curricula and training for future workers in the Smart Grid industry. The last program ensured that each SGIG and SGDP project considered interoperability and cyber security standards when implementing their project. The bill requires that all funded projects report on their interoperability and cyber security efforts to ensure they are in compliance and provide a body of research for future projects to learn from. ARRA was essential to Smart Grid development because it provided funding for a plethora of pilots and technology deployments as well as created a plethora of reports that future investors/projects can use as a source of background research.

2.3 Smart Grid Policy RFI

2.3.1 Overview

In May of 2010, the DOE began issuing RFI's related to the Smart Grid. The first RFI, released on May 11, 2010, sought comment on data access, third party usage of data, and privacy concerns. There were a total of 38 unique submissions [23]. The second RFI, also released on May 11th, sought comment on the communication requirements of electric utilities and the Smart Grid. There were a total of 49 unique submissions [23]. The policy RFI, released in September of 2010, sought comment on policy and logistical challenges to Smart Grid implementation. There were a total of 63 unique submissions [20]. The DOE identified eight problem areas that they wanted to seek commentary from stakeholders on. Table 1 provides an overview of the topics covered and Section 2.3.3 summarizes the breakdown of the submissions.

Table 1: Summary of topics covered in the policy RFI [20]

Category	Focus
Definition and Scope	• Best way to define the Smart Grid
Interactions with Implications for Residential and Small Business Consumers	• Best way to educate consumers and motivate consumers to be active participants in the Smart Grid • Consumer response to pricing programs or direct load control
Interaction with Large Commercial and Industrial Customers	• Benefits from and challenges to implementing the Smart Grid
Assessing and Allocations Costs and Benefits	• How should the benefits of the Smart Grid be quantified and when will they be realized • Future pricing programs available to consumers

Table 1 continued

Utilities, Device Manufacturers, and Energy Management Firms	• How should the federal gov. and states work together to handle issues related to the Smart Grid • Necessary policy changes
Long Term Issues: Managing a Grid with a High Penetration of New Technologies	• Best way to integrate renewable sources, electric vehicles, and legacy equipment
Reliability and Cyber Security	• What role federal, state, and local governments should have in ensuring that cyber security is maintained • New technology that will become available to increase reliability and cyber security
Managing Transitions and Overall Questions	• How should legacy equipment be handled and how soon utilities should upgrade

2.3.2 Stakeholders

The submissions to the policy RFI were divided into six stakeholder groups, (1) Appliance, Technology, and Service Providers (ATSP); (2) Consumer Protection Groups; (3) Energy Advocates; (4) Regulator's and Independent System Operators' (ISO); (5) Utility Providers; and (6) Researchers and Industry Experts. The response rate of each submission group is shown in Figure 4 .

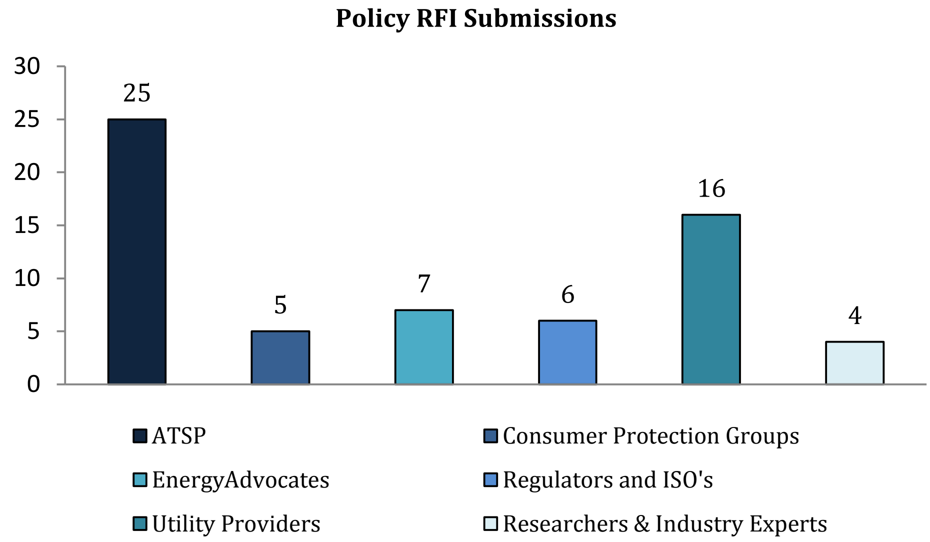

Figure 4: Breakdown of Policy RFI Submissions [20]

Appliance, Technology, and Service Providers (ATSP)

This stakeholder group is comprised of grid hardware providers, telecommunication service providers, home appliance producers, and companies that provide technological services to utilities and customers. In some instances, an entire industry was represented by their trade group instead of individual companies. The ATSP stakeholder group is very optimistic about the Smart Grid because its success could generate an entirely new industry from which their businesses can profit. Their main concerns were access to data, interoperability standards, pricing signals and appropriate cost allocation. The ATSP stakeholder group had a lot to say about allowing access to valuable meter data from consumers so that they can offer new goods and services. They were also concerned with open communication standards so that new goods and services can easily be interchanged and used anywhere in the US. They expressed that independent standards for each individual state could make doing business across state lines difficult and discourage investment. Pricing signals were another major discussion point for the ATSP group. They expressed that proper signals would do a lot to motivate consumers to make wise energy choices. The last major issue for the ATSP group was proper cost allocation. They expressed that Smart Grid technology should be evaluated like all other investments, and that whoever takes risk should receive benefits with regards to Smart Grid investments.

Consumer Protection Groups

This stakeholder group consists of organizations that exist to fight and protect consumer rights. They are predominantly concerned with Smart Grid security issues and costs. The Smart Grid has the potential to allow every watt of power used in a consumer's household to be monitored or recorded, which presents security and privacy issues. This group wants to ensure all measures are being taken to guarantee the safekeeping of all private data. They were also concerned with consumer bill rights. They wanted to ensure that remote disconnection and prepay energy service do not cause harm to consumers.

Consumer protection groups were also concerned with the costs of the Smart Grid. If the deployment of Smart Grid technology and pricing schemes create an influx in prices, consumer protection groups want to ensure that low income and fixed income consumers are not adversely affected. In addition, the average consumer is not eager to pay additional fees for energy. This group has a vested interest in ensuring that the Smart Grid is prudent about costs.

Energy Advocates

This stakeholder group incorporates energy advocates such as green energy advocates, smart grid coalitions, efficiency advocates and energy think tanks. In general, this stakeholder group viewed the Smart Grid as a positive endeavor and advocated for policy to encourage its realization. They expressed the importance of federal dollars to support the growth of the Smart Grid through research and development (R&D), tax incentives, and continued support for NIST and the Smart Grid Information Clearinghouse (SGIC). The energy advocates stakeholder group also felt that price signals were very important to the growth of the Smart Grid. They expressed that price was the best incentive to motivate and inform customers. Their last major concern was appropriate cost allocation and recovery. They stressed that it was important for utilities to be able to recover costs, and that costs should be allocated to the appropriate parties.

Regulators and ISO's

This stakeholder group is comprised of regulatory utility commissions and independent system operators. Regulatory utility commissions usually have a close relationship with utility providers, but at their core, they are focused on ensuring fairness to consumers and reliable operation of the grid. Not all utility commissions share the same views on the Smart Grid, but there is a common set of agreed upon views that are expressed through their association, the National Association of Regulatory Utility Commissioners (NARUC). ISO's coordinate, monitor, and control the operation of the electrical grid in a single state or across multiple states. They also have a close relationship with utilities as well, but they are primarily concerned with fairness and competition in electricity markets. The primary issues advocated by this group include consumer education, proper cost benefit analysis practices, and the importance of federal funding. This stakeholder group felt that long term consumer education about energy and the Smart Grid was essential. They also had strong beliefs about how cost benefit analyses should be conducted for the Smart Grid. They stressed the importance of state jurisdiction, verifying costs, and ensuring deployments happen at a measured pace consistent with benefits fulfilled. The regulators and ISO's also encouraged the importance of federal funds to support R&D for the Smart Grid, the SGIC, and NIST.

Utility Providers

This stakeholder group is composed of utilities and utility associations like the Edison Electric Institute (EEI) and the National Rural Electric Cooperative Association (NRECA). The majority of the individual utility responses came from utilities in the South, with the other responses coming from the Midwest and the Northeast. However, most of the utility submissions deferred to the EEI as the official response of the utility collective. Similar to consumer protection groups, utility providers want to ensure the Smart Grid is cost beneficial but for different reasons. In most Smart Grid implementation scenarios, utility providers take most of the risk and are heavily influenced by policy changes. They felt that if they have to take the majority of the risk, then they should benefit most and be compensated monetarily. This stakeholder group was opposed to any Smart Grid plan that would put them at risk for financial loss. Outside of proper cost and benefit allocation, this stakeholder group was also concerned with consumer education. Similar to the regulator and ISO stakeholder group, they believe consumer education is essential to secure consumer participation in the Smart Grid. The utility group also echoed the comments of the regulator group on two other issues; (1)The necessity of respecting state and regional control and (2) the importance of directing federal funds to R&D, NIST, SGIC and tax credits.

Researchers

This stakeholder group consists of research professors, the Electric Power Research Institute (EPRI) and people from the industry with intimate knowledge of its interworking's. Their viewpoints were varied based on their background. Each entities' submission incorporated some aspect of their own research/expertise area, ranging from grid architecture to the incorporation of flex fuel vehicles.

2.4 Recommendations

The recommendations below are split into two categories. Recommendations 1-5 are based primarily off of the responses of the submissions. Recommendations 6 and 7 were not widely discussed by the stakeholders but are discussed frequently in the literature. The recommendations are summarized in Table 2.

Table 2: Recommendations Summary [17]

Recommendations Summary
1. The Department of Energy needs to outline specific measurable Smart Grid goals and success metrics.
2. A coordinated nationwide Smart Grid education campaign should to be conducted. *Create a Smart Grid Education Panel*
3. The Department of Energy should continue to fund research and pilot programs and make the results available to all stakeholders. *Encourages and supports information sharing in a conservative industry*
4. Consumer participation programs should be voluntary and system wide upgrades should not be voluntary. *For consumer participation programs benefits can be reaped without mass participation; the reciprocal is true for system wide benefits*
5. The Department of Energy should continue to support the work of the NIST Interoperability Panel. *Open standards are needed to encourage interoperability*
6. Utilities need to revise their business models and cost benefit analyses to deal with new Smart Grid benefits and externalities.
7. FERC should coordinate a new streamlined transmission planning and approval process that engages all relevant stakeholders; additional siting authority should accompany that process.

2.4.1 Recommendation One: The Department of Energy needs to outline specific and measurable Smart Grid success metrics.

The first potential problem identified in the RFI was the DOE's Smart Grid definition and prescribed scope. Most of the submissions thought the DOE's definition of Smart Grid was sufficient. However, they did identify two issues that should be considered when defining and measuring Smart Grid success.

First, the submissions expressed that the DOE's Smart Grid metrics were too obscure. While the Smart Grid definition provided was adequate, the metrics used to measure successful completion of that definition were not. Metrics define the process by which objectives are to be achieved or reached. When metrics are unclear, it creates uncertainty or ambiguity for the entity trying to obtain the objective. In the 2009 Smart Grid System Report to Congress, the DOE defined 20 Smart Grid success metrics [24]. The DOE used eight levels to describe the current success and future trend of each metric. The levels were declining, nascent, low, moderate, flat, improving, mature, and high [24]. However, that rating system was too subjective and not explicit enough to clarify what successful completion was. To illustrate, I will use the "Grid-Connected Distributed Generation (DG)" metric as an example. In 2009, the DG metric was rated as having "low penetration" and a "high trend" [24]. In 2010, it received the exact same rating [25]. What is the significance of this? Was any progress made in 2009? What is high penetration? 50% of U.S. electricity production or 50,000 megawatts (MW)? The rating levels left many questions unanswered. It was easy to assign one of those levels to a metric and not fully understand the significance of it. More solid quantifiable metrics are needed to provide better context as to what has been accomplished.

Creating specific Smart Grid metrics will help to create clarity in the industry. Clarity from the DOE is important because the nation looks to the DOE for a vision of our current and future energy strategy. Explicit Smart Grid metrics will help to alleviate policy uncertainty surrounding the Smart Grid. Several of the RFI submissions stressed that the uncertainty surrounding the future of the Smart Grid can stymie investment. The electricity industry is already known to be capital intensive and requires long lead times for major investments [26]. Every three to five years, a utility will publish an Integrated Resource Plan (IRP). Inside, those IRP's utilities discuss their plan to meet electricity needs over 20-30 year time horizons. Utilities need to know electricity policy early in order to incorporate it into their 20-30 year time horizon. Given such long lead times, investors may shy away from the utility industry. Additional uncertainty sparked by the Smart Grid only acts as a new deterrent to investment. Defining explicit metrics contributes to clear goals. When there are clear goals, it is easier to advocate for policy that aligns with those goals consequently reducing uncertainty and thus encouraging investment.

Second, the submissions thought the scope of the Smart Grid should remain flexible so that each implementing entity could do what was most appropriate for them to fulfill the objectives of the Smart Grid. The Smart Grid scope should be defined holistically by a set of defined objectives, without a focus on specific technologies. This concept pairs well with having defined Smart Grid objectives that have correlating explicit metrics. The clear objectives signal to everyone what should be achieved, the metrics define how success will be measured, and an open scope allows each entity to select the appropriate technology and systems to achieve and fulfill the stated objectives and metrics.

2.4.2 Recommendation Two: A nationwide Smart Grid education campaign needs to be conducted by a new Smart Grid Education Panel.

The most frequent and clear message heard from submissions was the need for a substantial consumer education campaign. It is commonly stated that the success of the Smart Grid hinges on consumer engagement and participation [27] [28] [29]. A wide reaching education campaign is needed. The campaign should address consumers from all across the US at different income and education levels. The campaign needs to convey information about the Smart Grid itself as well as general electricity knowledge. The logic being, consumers should have enough basic electricity knowledge/understanding to be able to make educated decisions for themselves about the Smart Grid.

In order to effectively carry out an education campaign of that magnitude, every stakeholder will have to be engaged. There is too much information to disseminate and too many people to educate for it to be the responsibility of one stakeholder group. On the other hand, having every stakeholder participate increases the probability of the information becoming disjointed. To combat both of these issues, a stakeholder wide education campaign panel needs to be formed similar to the Smart Grid Interoperability Panel (SGIP) of the National Institute of Standards and Technology (NIST). The purpose of the panel would be to come to agreement about what information needs to be dispersed, then create a unified education campaign and decide how best to implement that education plan. One unified source of information assures that the information will be consistent. Once a unified education campaign was created, then it could be compartmentalized and carried out by the appropriate stakeholder group. The panel would be the central entity for consumer information relating to the Smart Grid and general electricity knowledge. The panel website could be the central authority and go to place for consumers to obtain knowledge in one easy convenient location. Consumers would only have to deviate from the panel website to receive information specific to their electric utility provider.

Each stakeholder group already provides educational materials to consumers. The Smart Grid Education panel can use that information as a guide to determine what each group should disseminate to consumers. The Department of Energy, federal agencies, and state PUC's are well suited to provide broad-spectrum Smart Grid information and general electricity information. They are well suited to deliver this information because many of them already provide electricity overview information to consumers. Energy advocates can provide advanced Smart Grid information to consumers that are interested in obtaining in-depth information and being aggressively involved in the Smart Grid. Consumer protection groups are well suited to inform customers of their rights and pertinent security/safety information. They are well suited for that purpose because that is what their current efforts consist of; Consumer protection groups advocate for and inform everyday consumer about their rights. Utilities are best suited to provide consumers with information regarding Smart Grid upgrades or improvements in their specific territory; i.e. when upgrades are coming and what will be available in specific areas. The ATSP group will promote the features and specifications of their appliances and services to customers; providing customers with options. This doesn't represent a significant change in the information any of the stakeholders currently disperses. However, funneling the information through the Smart rid Education Panel ensures that the information will be accurate, uniform, consistent and easily accessed from one central hub.

Another important task of the education panel will be dispersing information across as many mediums as possible. The Smart Grid Consumer Collaborative (SGCC) has been measuring consumer knowledge of the Smart Grid and smart meters. Currently, only 33% of the U.S. population has basic or complete understanding of the Smart Grid despite the efforts of many of the stakeholder groups to educate consumers [30]. This demonstrates that future advertising needs to reach across new platforms to try and reach more consumers. The Smart Grid Education panel should research new ways to disseminate knowledge to ensure more consumers are reached.

2.4.3 Recommendation Three: The Department of Energy needs to continue to fund research and pilot programs and make that information/data widely available to all stakeholders.

This RFI exposed a fairly common dichotomy found in the electric utility industry. Utilities require all technology or strategy they implement to be thoroughly researched and vetted. However, they do not appropriately invest in research and development. Table 3 shows the net sales and R&D expenditures for major U.S. industries performing industrial R&D in the United States in 2005. Excluding the utility industry, the average industry spent 8% of their sales on R&D. Contrastingly, the utility industry spent 0.1% of their sales on R&D. The pharmaceutical industry, which has comparative domestic sales as the utility industry, spent 174 times more money on R&D than the utility industry did in 2005 [31]. If an industry was stringent about testing and validating now technology, one would expect corresponding/correlating expenditure in R&D, but that does not hold true with the utility industry.

Table 3: Funds and Sales for industries performing industrial R&D in the United States, by industry: 2005 [31]

Industry	Domestic Net Sales	R&D Expenditures	Percentage of R&D
	(Millions of Dollars)		%
Pharmaceuticals & Medicines	$273,000	$34,800	12.7
Semiconductor & Other Electronic Components	$176,000	$18,700	10.6
Aerospace Products & Parts	$227,000	$15,000	6.6
Machinery	$231,000	$8,500	3.7
Utilities[1]	$223,000	$200	0.1

[1]The utilities industry includes all U.S. utilities: water, gas, and electricity

Many of the RFI submissions called for more pilots and increased testing. These calls most often came from the utility providers and ATSP stakeholder groups. Cumulatively, the utility and ATSP stakeholder groups have the most capital to invest in research but called on the DOE and other federal agencies to conduct the research and perform tests. This is a great example of the high risk-aversion in the electricity industry. Many of the stakeholders see the need for increased studies and pilots, but they are not willing to pay the costs to perform the research. Therefore, if essential research is going to be conducted, then it will have to be carried out by a different party. The best suited stakeholder group for conducting that research is the federal entities. The Department of Energy, FERC, and NERC already sponsor research projects and have an effective research staff. They are in a good position to spearhead future research and ensure that the proper research gets conducted in an orderly fashion. The federal stakeholder group represents the best option for two primary reasons.

First, by having the federal government conduct research, resources can be more efficiently allocated. Having one primary entity handle research efforts will prevent unnecessary duplication of tests and pilots. Instead of multiple utilities reproducing the same research or similar pilots, the federal government can have overseeing knowledge and make sure duplicate studies are not carried out, thus, promoting efficient use of limited funds and resources. Also, if a federal entity conducts the research, then the results are more likely to be broadly applicable instead of specific to one utility, again, being efficient with limited resources.

Second, if a federal entity conducts the research, then the results will be publically available to any interested party. Most utilities and companies are private about the advancements they make and do not go public with their findings until they have a patent, therefore, stifling industry wide innovation. By having major research conducted by a federal entity, more critical research findings will be available to everyone in the industry, thus, promoting industry wide innovation. The research gathered would be best shared through an information clearinghouse. The Smart Grid Clearinghouse (smartgridclearinghouse.com) is a great beginning effort that should continue and be used to hold future research. Many of the RFI submissions viewed the Smart Grid Clearinghouse in a positive light and felt that it should be continued [20].

2.4.4 Recommendation Four: Consumer participation programs should be voluntary. System wide upgrades should *not* be voluntary.

There was much consensus among the RFI submissions that consumer participation programs, like dynamic pricing and direct load control, **should** be voluntary, but system wide Smart Grid upgrades, like smart meter deployments, **should not** be voluntary. The main driver behind consumer participation programs being voluntary is that not everyone has to participate to reap the desired benefits. Most consumer participation programs are built to reduce demand in peak hours when generating electricity is most expensive. The goal is to keep demand below a threshold point so expensive peak generators do not have to de dispatched. **Figure 5** demonstrates that as demand exceeds the daily peak, prices rise sharply. If demand can be constrained to remain below the daily peak, then peak costs can be avoided.

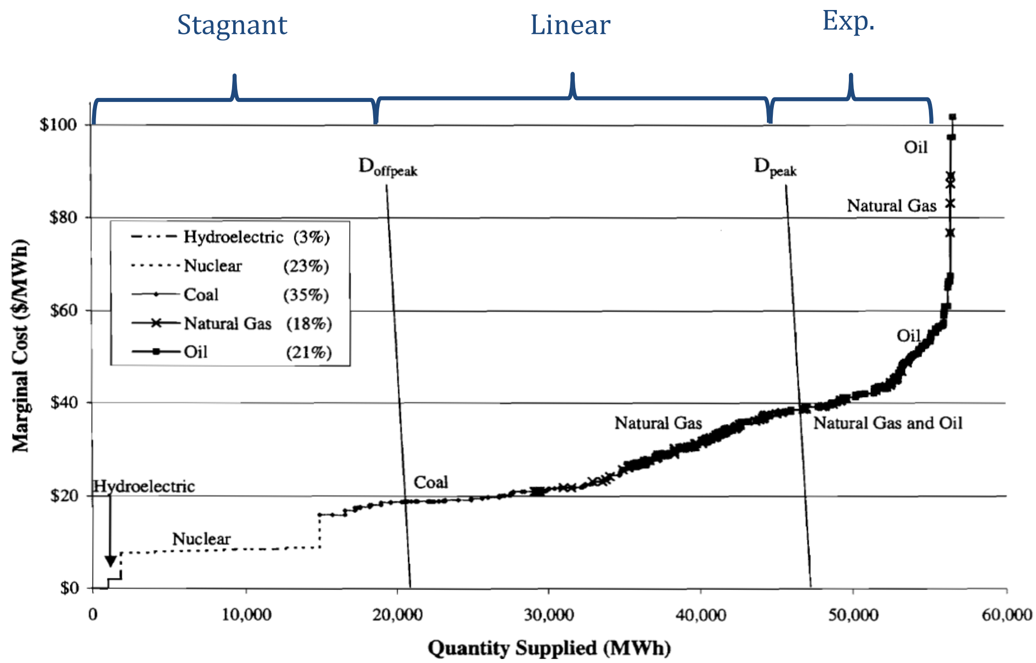

Figure 5: Competitive Supply and Demand in PJM [32]

Consumer participation programs can help avoid these peak costs. The reduced costs from eliminating the top 10% represented by peak demand can be used to create an incentive program. Participants in the program will be rewarded for their participation. This system has threefold benefit: (1) It eliminates the free rider problem. Yes, everyone in the system benefits, but the people that benefit most are the people reducing their consumption, i.e. “doing the work” and “paying the cost”. (2) It addresses the consumer advocates group concern about how these programs will affect vulnerable populations. If vulnerable populations are not able to participate, then there are no extra costs for them to bear, and they still reap the benefits of reduced demand overall. When overall demand is less, everyone pays lower costs for energy. (3) It also addresses stakeholder concerns about consumer apathy. Many of the RFI submissions were skeptical that all consumers would actively participate in the Smart Grid. Since consumer participation programs only require a minimal fraction of consumer participation, consumer apathy will be a smaller issue to overcome. It is more reasonable to create a program that addresses 10% of consumers versus all consumers. Voluntary participation by interested customers will reduce people’s fears about mass consumer adoption.

The driving justification for system wide upgrades not being voluntary is also connected to the free rider problem. When system wide upgrades are implemented, everyone benefits regardless of if everyone participates. The cost savings from a reduction in operations and maintenance, such as the rollout of meter reading trucks, won’t be fully realized without full consumer adoption. In addition, there are capital costs that that must be expended with large scale system upgrades regardless of initial consumer buy-in, such as data centers and software to handle “big data”. These high price items are built to last long-term and therefore are built to accommodate participation of all customers. If some customers opt-out, then they will be reaping the benefits without paying the costs. This is unfair to customers who pay to receive the benefits. This will mirror one of the categories of market failure. For this reason, it is important that system wide upgrades that benefit everyone be paid for by everyone, which means no voluntary participation for system wide upgrades. For certain system wide upgrades that face consumer opposition or hesitation, such as smart meter rollouts, utilities have allowed consumers to opt-out for a fee and monthly charge to offset the cost to other consumers [33].

2.4.5 Recommendation Five: Open standards are needed to encourage interoperability. The Department of Energy should continue to support the work of the NIST Interoperability Panel.

Many of the RFI submissions stressed the importance of having open standards. Open standards are needed to encourage interoperability. As stated by NIST, "Interoperability—the ability of diverse systems and their components to work together—is vitally important to the performance of the Smart Grid at every level. It enables integration, effective cooperation, and two-way communication among the many interconnected elements of the electric power grid [34]." Interoperability is important because the Smart Grid will be composed of many intricate pieces that will have to work together. If all of the pieces are built and modeled on the same open standards, then they should be interoperable. Currently, interoperability standards are being developed by the NIST Smart Grid Interoperability Panel which is composed of stakeholders from all sectors of the electricity industry. Most of the RFI submissions felt that the work of NIST was exception and should continue. The DOE should continue to support the NIST Interoperability Panel.

2.4.6 Recommendation Six: Utilities need to revise their business models and cost benefit analyses to deal with new Smart Grid benefits and costs.

This recommendation was discussed by only a few of the submissions but illuminated a possible solution to one of the most debated issues in Smart Grid discussions, financing. There are two unique ways in which financing presents a challenge in the electric utility industry. First, finding a way to counteract the effects of the "utility death spiral" famed by the EPRI report "Disruptive Challenges" [35]. In sum, the report talks about the cycle of customers seeking out distributed generation to reduce their utility bill. The consumer demand seen by utilities declines, causing revenue to decrease thus prompting the utility to seek a rate increase to recoup sunken costs. That rise in rates encourages more consumers to seek out distributed generation furthering the cycle until utility solvency might be compromised. This challenge has prompted much discussion about the way utilities should receive compensation in the future [36], [35], [37], [38]. How should regulators change the way utilities receive compensation? Also, how can utilities adjust the way they conduct business to improve their position? Utilities should work in coordination with their PUC to develop new utility business models that properly compensate them for the services they provide.

Smart Grid projects should be handled like all other large investment utility projects and subject to a cost benefit analysis (CBA). However, the cost benefit analyses used to evaluate projects need to be revised to incorporate societal desires for increased sustainability and ensure all sources of generation are treated equitably. Traditional utility cost benefit analyses were made for the legacy electric grid and do not account for new benefit streams that the Smart Grid will possess. Researchers have frequently commented that not all benefits of the Smart Grid are captured in the traditional utility CBA [39], [40], [41], [42], [43], and this needs to be addressed. Albert Einstein is attributed with the following quote, "Everybody is a genius. But if you judge a fish by its ability to climb a tree, it will live its whole life believing that it is stupid." This quote exemplifies the importance of selecting the appropriate judgment criteria in a CBA. New CBAs need to be created or the old CBAs need to be revised to properly account for all of the benefits and costs of the Smart Grid. There are two areas that should be considered when revising the traditional utility CBA. First, changing the way environmental and health costs/benefits are valued in CBAs when determining what kind of generation will be built as well as how that generation should be dispatched. There is discussion in the literature about monetizing air pollutants and incorporating them as a constraint in dispatch algorithms and implementing a carbon tax or budget [44]. Incorporating environmental/health costs directly into a cost benefit analysis, instead of trying to manage the effects once generation has been built or dispatched, will have a major effect on costs and perceived benefits for al projects being considered. Second, determining how to deal with the unique aspects of renewable generation that differ from traditional fossil fuel generation is also something to consider in a revised CBA, issues like intermittency and renewable source being more distributed. These issues present unique challenges and benefits and should be accounted for in the revised CBA.

2.4.7 Recommendation Seven: FERC should coordinate a new streamlined transmission planning and approval process that engages all relevant stakeholders; additional siting authority should accompany that process.

A survey of literature reveals that transmission planning is a fundamental barrier in the current electricity industry [45], [46], [47] [48], [49]. Contrastingly, a survey of the chief stakeholder groups doesn't reflect the same conclusion. Few of the submissions spoke on the need to streamline the transmission planning process [20]. However, transmission planning is vital to the success of the U.S. Smart Grid. One of the key objectives identified by the DOE was the need for the Smart Grid to accommodate all generation sources, especially renewable energy sources [16]. The strongest solar and wind resources in the U.S. are in the South West and Great Plains, but the largest energy demand centers are along the coast lines and in the

Great Lake states [50] [51] . If the U.S. is going to accommodate and utilize their strongest renewable sources, then they will need to plan and build transmission lines that connect those sources to the largest demand centers. The fact that stakeholders did not identify transmission planning as a barrier to the advancement of the Smart Grid only highlights the longstanding problem in interstate transmission planning.

Few traditional territorial utility stakeholders have a vested interest in transmission outside of their service area; so, wide area interstate transmission issues go unaddressed. Many traditional for-profit utilities are incentivized to build new generation over transmission lines[1]. Public Utility Commission interests fall in line with the traditional utility stakeholders. PUCs are most concerned about reliability and cost. If a utility proposes to build generation over transmission, a PUC will not oppose it as long as reliability is maintained and costs are prudent. Citing a new transmission line may be a more optimal solution than building new generation but choosing the less optimal choice is not considered to be "unfair and unjust"; it's just sub-optimal.

ATSP stakeholders are silent on the issue because they can benefit either way. They can build technology to advance transmission or encourage generation. Additionally, ATSP's primarily operate at the commercial and residential scale rather than at the bulk transmission scale where interstate transmission planning

[1] When a traditional utility builds new generation, if it is prudent, they will recoup costs and a guaranteed return on their investment from their PUC or equivalent. However, when they cite a transmission line, they only recover costs and not a return on investment. This incentivizes building generation over transmission.

matters. Their services and profits are not harmed if interstate transmission is inadequate.

The Energy Advocates were the only stakeholder group to address the need for increased transmission. The submissions that spoke on the need for increased transmission planning also indicate that this was important for the successful integration of renewable energy resources.

The afore mentioned stakeholder rationales illuminate that few stakeholders are concerned with large scale interstate transmission being built and instead concentrate on their personal objectives. This behavior demonstrates that most stakeholders are focused on the trees and few are seeing the forest. It is the responsibility of the DOE and the Federal Energy Regulatory Commission (FERC) to consider the best interest of the U.S. as a whole. They are tasked with seeing the forest and ensuring that large scale transmission needs are addressed. That includes streamlining the transmission citing process so essential transmission can be built.

Current concerns in electric grid system reliability are a perfect parallel to the issues in transmission planning. In 2003, there was a major blackout across the northeast part of the United States and portions of Canada. Prior to the blackout, each utility and territory felt that their system was reliable and secure. They were not concerned with their neighbors, only looking at the trees. Research after the blackout showed that while individual utilities may have been secure, the system wide state was not secure. There was a lack of "situational awareness" [52]. No one was paying attention to the forest. There was no wide area control or mandatory reliability standards. After the blackout, where billions of dollars were lost [53], it was evident that an entity should be tasked with paying attention to the whole picture. Someone needed to be responsible for the best interest of the entire United States and not just each specific utility. NERC was tasked with this effort for system wide reliability. Transmission planning requires a similar wide area perspective authority. A single authority (whether a single federal agency or a stakeholder commission) needs to monitor planning efforts and be responsible for ensuring that essential transmission lines are built.

FERC Orders 888, 889 and 2000 sought to address the issue of a lack of wide area transmission planning by creating ISO's and Regional Transmission Organizations (RTO's). The purpose of these organizations was to promote non-discriminatory access to transmission and encourage interstate transmission planning. These organizations have had success in increasing planning between states, but more work needs to be done. The map in Figure 6 shows how the various ISO's and RTO's are distributed across multiple states in the US. The chief problem ISOs and RTOs face are state by state regulations. When an ISO or RTO deems a transmission line should be built, they are not always able to act upon that judgment because of state restrictions [54]. FERC, the central entity over interstate energy transactions, lacks the authority it needs to cite essential transmission lines. FERC, or the afore mentioned siting authority, needs additional siting authority to help overcome state approval issues. To balance the need for states' rights, states, environmental groups, and other stakeholders should be involved in the planning and citing process. Aggregating FERC and all other relevant stakeholders into one siting process would streamline the transmission approval process. A smoother shorter transmission siting process will encourage investment in transmission lines.

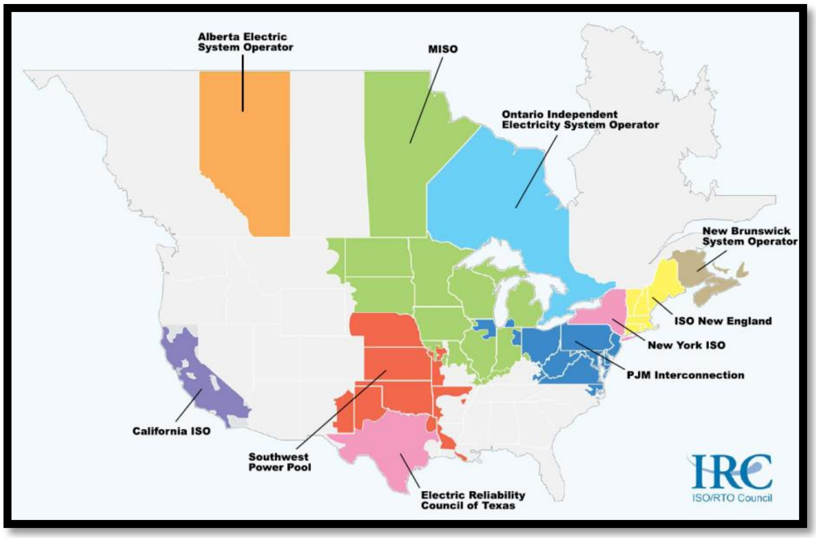

Figure 6: Map of North American ISO's and RTO's [55]

2.5 Conclusion

After studying the comments of stakeholders from all across the electricity industry, it is clear there is much consensus on what needs to be done to improve the future U.S. electric grid. There are seven essential findings that were distilled from the comments. The findings outlined can address many of the issues with the current electric grid as well as barriers deterring the growth of the Smart Grid. Detailed solutions for recommendations one and six will be presented in Chapter 3 and Chapter 4.

CHAPTER 3

SMART GRID ASSESMENT METRIC

3.1 Motivation

Electricity infrastructures face a wide range of demands, challenges and opportunities that engage policymakers at the national level. The goal of this chapter is to construct an in depth solution to the recommendation in section 2.4.1, outlining specific and measurable Smart Grid metrics to support national scale assessment of the status and development of electricity infrastructures.

Many entities are making efforts to create a smarter electric grid. The intent of this work is to create a system of metrics to measure the progress towards achieving a “Smart Grid” on the scale of nations or states. The approach draws on publically available data from organizations such as the International Energy Agency (IEA), the Organization for Economic Co-operation and Development (OECD), as well as industry trade journals. For this work, a Smart Grid will be characterized as having six key characteristics:

(1) Engages consumers

(2) Has a robust and renewable generation mix

(3) Has a modern infrastructure and is technically sound

(4) Highly efficient

(5) Socially acceptable

(6) Economically sound

The intent of this definition is to incorporate technical, social and policy ideals into one comprehensive characterization.

This chapter will present a metric system to measure a nation's progress toward a Smart Grid, conduct a Smart Grid progress assessment of 37 countries, discuss the results of the Smart Grid assessment and limitations of the metric system, and conclude with policy implications of the metric system created. Section two of this chapter will cover the methodology employed to create the Smart Grid metric system. Section three will present the Smart Grid metric conceptualization process. Section four of this chapter presents the 37 country Smart Grid assessment. Section five discusses the results of the Smart Grid assessment and limitations of the metric system. Section six concludes with the policy implications of this work.

3.2 Literature Review

Two approaches were used to develop the metric system. First, metrics from smart grid assessment literature were considered. Second, the methodological assessment approach used in energy security and energy resilience metrics was employed in the development of the Smart Grid metric system.

3.2.1 Smart Grid Assessments

The literature on Smart Grid assessments falls into two main categories, assessments focused on evaluating specific projects or proposals and assessments focused on measuring progress for entities. Nibler and Masiello [56], Herter et al. [57], and Personal et al. [58] established metrics and frameworks for evaluating individual Smart Grid projects or proposals. Nibler and Masiello [56] focus on defining a set of metrics to evaluate Smart Grid project proposals submitted to the U.S. Department of Energy (DOE) or other regulatory bodies. They defined four broad categories: economic stimulus effect, energy independence and security, integration and interoperability, and business plan robustness; they also created appropriate metrics for each category. A total of 44 metrics were presented, 9 of them qualitative. Metrics included direct jobs and wages retained and/or created, % and $ decrease in consumer energy costs, % of renewables than can be sensed and controlled, MW reduction at coincident peak, SAIDI improvement, and the use of open protocols. Nibler and Masiello [56] are unique in their approach by incorporating business aspects into their assessment. Few others incorporated business considerations when measuring a Smart Grid proposal. Nibler and Masiello [56] also stress that not all of the metric they present need to be utilized, only the metrics relevant to the submitted Smart Grid proposal.

Herter et al. [57] focus on creating an evaluation framework for Smart Grid Deployment plans in California. Their focus is to judge Smart Grid proposals based on their ability to provide benefits to customers and reduce environmental impacts. The authors define four essential goals: empower consumers, creates a platform for technologies and services, enable sales of demand-side resources in wholesale markets, and reduce the environment footprint; these goals will be addressed throughout five outlined sections of each Smart Grid Deployment plan. Each goal has a coordinating set of metrics associated with it. Each goal is also assessed on a scale of 0-4 for each section of the report, based on how well the relevant metrics are fulfilled. Herter et al. [57] presents 46 metrics total. Metrics included the amount of customer-controlled load, ease of connection, electric vehicle (EV) demand, system average interruption frequency index (SAIFI) , DG Energy, data access, green house gas (GHG) emissions, and Smart meter waste. The scoring card that Herter et al. [57] presents makes their paper unique by creating a simple quick reference card to assess projects side by side.

Personal et al. [58] developed a model to evaluate the success of Smart Grid projects and forecast future impacts for certain hypothetical scenarios. They present a total of 21 indicators that are directly measured from a database that collects information from smart meters, sensors, and other relevant technology in their Smart Grid network. Their model is structured by outlining three macro objectives which lead to seven corollary objectives and then breaks down into the 21 unique indicators. Some of the indicators presented include reduction in overall demand, percentage of renewable micro-generation, reduction in CO_2 emissions, extension in service life cabling, and reduction in maintenance costs. The greatest strength of the Personal et al. [58] paper is their use of real data pulled from smart meters and other sensors in their Smart Grid network. Personal et al. [58] is also unique in that their paper presents results from the implementation of the Smart Grid assessment.

Outside of assessments focused on specific projects or proposals, the other metric systems in the literature focus on measuring the progress of entities. The Office of Electricity Delivery and Energy Reliability (OE) [59], the U.S. Department of Energy [24] [25] and Arnold et al. [60] all present Smart Grid assessments to measure large-scale Smart Grid progress for entities. OE [59] presents the U.S.'s first attempt at creating a metric system to measure U.S. progress towards achieving a Smart Grid. The report aggregates the input of 140 industry participants and proposes a plethora of metrics based around the seven Smart Grid characteristics defined by the U.S. DOE. The laundry list of metrics was distilled down to 4-6 key metrics for each characteristic based on votes from participants. The "optimizes asset utilization and operation efficiency" characteristic was an exception to that rule. That characteristic was divided into 5 categories: transmission, distributions, consumer, crosscutting metrics, and overall; 3-5 metrics were listed for each of those categories. In total, the OE [59] presented 50 metrics to be used in future assessments of US Smart Grid progress. OE [59] is unique in that it collected valuable opinions from a variety of stakeholders.

The U.S. Department of Energy [24] and [25] built on the work of OE [59]. As a part of their update, the DOE distilled the number of metrics from 50 to 20 in [24] and 21 in [25]. In the DOE [25] report, an additional metric was added to measure the amount of grid-connected renewable resources and the coordinating amount of displaced CO_2 emissions. The DOE metrics in both reports were separated into four broad categories: area, regional and national coordination regime, distributed energy resource technology, transmission and distribution (T&D) delivery infrastructure, and information networks and finance. The DOE reports [24] [25] served as the official assessment of U.S. Smart Grid progress to congress for 2009 and 2010.

Arnold et al. [60] presents an approach to measuring electric distribution grid smartness by measuring how well the electric grid meets specified performance targets. The metric system is separated into four tiered levels: top, medium, low level targets, then measurements. The top level targets are economic performance, technical performance, product quality, environmental friendliness, and safety. Those targets are then broken down into 14 medium targets which lead to 37 measurements. Measurements include the total number of fatalities compared to population, number of outages per grid element, probability of compliance with harmonic compatibility levels, and the probability of violating voltage tolerances. Arnold et. al [60] is unique in the literature because they present the result of their Smart Grid assessment in a spider diagram to show a graphical representation of the medium and low level target achievements.

The goal of this chapter is to add to the literature by creating a metric system to measure Smart Grid progress on a large scale using publically available data. The results of that Smart Grid assessment will be presented in two ways, one visual and one numeric. This chapter will differ from the literature by focusing on Smart Grid goals that are technical, policy, and socially oriented; utilize publically available data; present Smart Grid assessment results in two unique ways and implement the Smart Grid assessment on 37 countries. This approach was taken because it is important to not focus solely only on technical achievements but also ensure that societal goals are considered. Additionally, using publically available data will make the Smart Grid assessment tool accessible to more entities. The metric systems presented by Nibler and Masiello [56], Herter et al. [57], and Personal et al. [58] rely heavily on technical data. While technical data are great for technical evaluations, that data can be very difficult to obtain on large scales for multiple projects, thus, making a multi-entity analysis very challenging. This chapter will also be unique in its dual presentation of the Smart Grid assessment results; it is inspired by the scorecard of Herter et al. [57] and the spider plot from Arnold et al. [60]. This dual presentation of the Smart Grid assessment results should ease comprehension of a multi-entity analysis and make it easier to draw conclusions from the data. Lastly, this chapter will add to the literature by implementing the proposed metric system with real data. Only two of the metric systems explored in the literature, Personal [58] and U.S. Department of Energy [25], implement their Smart Grid assessment with real data. This chapter will go beyond the work of the other two papers by implementing the metric system on multiple countries.

3.2.2 Energy Security

Energy security is most commonly defined as "the uninterrupted availability of energy sources at an affordable price [61]." While Smart Grid discussions are focused specifically on electricity, the concept has considerable overlap with broader energy security concerns. The relevant energy security literature includes literature related to the methodology of energy security ratings, energy security ratings related to renewable energy, and energy security ratings related to specific countries.

The dominant approach in the energy security literature centers on defining 4 – 5 crucial characteristics of energy security, justifying those characteristics, then selecting appropriate metrics to complement the characteristics. Hughes [62], Bert et al. [63], Sovacool [64], Sovacool and Mukherjee [65], Sovacool et al. [66], and Sovacool and Brown [67] use the "4A's" (availability, affordability, acceptability, and accessibility), or a version of them to define and assess energy security. The 4A's represent the most frequently defined characteristics of energy security. Outside of the 4A's methodology, the following authors, Cherp and Jewell [68], Chester [69], Hughes [70], Jewell et al. [71] and Mansson [72], all follow a similar structure to the 4A's but define their own unique characteristics. Energy resilience literature follows a similar methodology. Moluneaux et al. [73] and Roege et al. [74] define specific energy resilience goals similar to the 4A's, and then align metrics to complement those goals.

In both the energy security and energy resilience literature, metrics are evaluated in two principal ways: (1) over a multiyear time span or (2) making the data ordinal or unit-less, then comparing the various metrics directly. The Smart Grid metric system presented in this chapter employs the second technique. In future work, the metrics could be used to evaluate multiple countries over a multiyear timespan.

3.3 Conceptualizing Smart Grid Progress

Six Smart Grid goals are defined based primarily on the Smart Grid definition outlined in Table 4 below. This definition builds off of the U.S. Department of Energy's definition [16] and incorporates aspects of social acceptability and economics. The first four tenets of the proposed research Smart Grid definition are a condensed version of the U.S. DOE's seven defining Smart Grid characteristics from [16]. Table 4 shows the matchup between the six Smart Grid goals and the original DOE Smart Grid characteristic. These characteristics were a good starting place to define the Smart Grid definition and goals because the U.S. DOE definition was created from consensus in the U.S. electricity industry and is widely used throughout the U.S. electricity industry when discussing the vision of the Smart Grid. The 'Consumer Engagement' goal addresses the need for consumers to be active participants in the electric grid. Technology and communication upgrades allow consumers to be active in the grid like never before, whether they are making better electricity decisions because they are better informed from their smart meter, or participating in time of use pricing and/or demand response, or even selling energy on the electric grid. The potential shift in customer habits and actions is a major component of the Smart Grid and should be addressed by the Smart Grid goals. The 'Robust and Renewable Generation Mix' goal addresses the need for a diverse and reliable generation mix in the future. This mix should be composed of a variety of generation sources, including renewables, ensuring no one source is overly relied on. A diverse generation portfolio should also include storage to support weather variant renewables and additional backup to traditional sources in times of outage or stress on the grid. The 'Modern Infrastructure and Technically Sound' goal addresses the need for updated infrastructure in the electric grid which can include new hardware, communication software, security updates, and controls. The 'Efficient' goal addresses increased societal demand for energy and electricity efficiency; it includes new hardware and software that allows consumers to use energy more efficiently or new control algorithms to more efficiently dispatch generation.

Table 4: Smart Grid Goal to Characteristic Matchup

Smart Grid Goals	DOE Smart Grid Characteristics
Consumer Engagement	1. Enables active participation by consumers
Robust and Renewable Generation Mix	2. Accommodates all generation and storage options
Modern Infrastructure and Technically Sound	3. Enables new products, services, and markets 4. Provides power quality for the range of needs in a digital economy 5. Anticipate & respond to system disturbances in a self-healing measure 6. Operate resiliently against attacks and natural disasters
Efficient	7. Optimize asset utilization and operating efficiency
Socially Acceptable	
Economically Sound	

The intent of the Smart Grid assessment proposed in this chapter is to be applicable to any country. Basing the majority of our Smart Grid characteristics on a U.S. based definition has the potential to introduce bias. To address the potential bias, Smart Grid definitions from many countries and entities were reviewed to ensure that the Smart Grid goals identified were universally employed. The review of Smart Grid definitions from other countries revealed that the first four goals identified were commonly employed [75] [76] [77]. However, two other characteristics emerged that were frequently seen in other Smart Grid definitions. Those characteristics were 'Socially Acceptability' and 'Economically Sound' [78] [79] [80]. The 'Social Acceptability' goal is meant to address increasing societal demands for sustainability, especially with regard to greenhouse gas emissions. The 'Economically Sound' goal is meant to address continuing demand for electricity prices and costs to be prudent.

To identify metrics to complement each goal, 50 candidate metrics were developed, including those from Smart Grid assessment papers [[56], [57], [58], [59], [60], [25]], and energy security literature [[62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74]], and metrics devised from the researchers. Metrics with insufficient data in the public arena were eliminated. The eleven remaining metrics were paired with the Smart Grid goals. Table 5 lists the metrics and their corresponding Smart Grid goal. An explanation of each metric and how it fits into the respective category is explained below.

Table 5: Matchup of Smart Grid Goals and Metrics

Smart Grid Goals	Metric
Consumer engagement	Google Search LEED Professionals [2]
Robust and renewable generation mix	% Renewable [2, 3, 4, 5, 6] Diversity Index [2,7]
Modern infrastructure and technically sound	Loss Percentage [2, 3, 4, 8, 9] Presence of EV's [8] Research Patents [2] SAIDI [2, 4, 8, 10]
Efficient	Electricity Efficiency (Consumption/Production)[10]
Socially acceptable	g CO_2/kWh from electricity generation [2, 3, 4, 5, 11]
Economically sound	Electricity Intensity (GDP/kWh) [1, 6, 10] Price of Residential Electricity [1, 6, 8, 10]

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[2] [65]
[3] [56]
[4] [57]
[5] [58]
[6] [25]
[7] [63]
[8] [24]
[9] [60]
[10] [59]
[11] [67]

3.3.1 Consumer Engagement

The 'Consumer Engagement' goal is meant to measure how much customers are interested or participating in the Smart Grid. Two metrics are used to assess this goal. The 'Goggle Search' metric measures consumer engagement by identifying how much consumers search for terms related to the Smart Grid. Search terms include "smart grid", "smart meter", and "smart power" and were measured from 2004 up until the time of collection in December of 2014. The data is scaled by the total number of searches within a given geography over the specified time period. This means that the country with the highest score may not have the highest search volume since the number is scaled by the total number of searches within a specified geography [81]. The Google metric is used as a proxy to gauge how much consumers are discussing Smart Grid technology and relevant topics.

The "LEED Professionals" metric is a less direct measure of consumer engagement. It tracks the number of LEED certified professionals in a country. An increasing number of LEED professionals should signal consumers' interest in sustainability and having green buildings. The Smart Grid is also a sustainable idea, and the 'LEED Professionals' metric can serve as a proxy for measuring consumer interest in sustainable ideas.

3.3.2 Robust and Renewable Generation Mix

The 'Robust and Renewable Generation' goal addresses the desire for diverse generation portfolios, which include renewables and are not overly reliant on one generation source. Two metrics are used to capture this dynamic. First, "Percent Renewable" measures the percentage of renewables present in the electricity generation portfolio, measured based on annual generation. The renewable technologies considered here include hydroelectricity, biomass, waste, geothermal, solar photovoltaic, solar thermal, wind, and tidal power.

The second metric is the "Diversity Index," which utilizes the Herfindahl-Hirschman Index (HHI) formula to measure diversity. The HHI is commonly used in the business community to measure market concentration, the opposite of diversity, and it has been used in the energy security literature as measure of diversity [65]. The HHI is written as:

$$H = \sum_{i} g_i^2$$

where "g_i" is the fraction of total supply from source "i". HHI values range from 0 to 1. A score close to 1 represents a concentrated market with little diversity, and a score closer to 0 represents a very diverse market. In this study, ten generation sources are considered in calculating the HHI; coal, oil, natural gas, nuclear, biofuels and waste, hydroelectricity, geothermal, solar, wind, and tidal/wave/ocean power.

3.3.3 Modern Infrastructure and Technically Sound

The 'Modern Infrastructure and Technically Sound' goal is meant to measure how updated an electric grid is, which consist of improving operation, deploying new technology, and enabling new services. Four metrics were chosen to assess this goal. The first is the 'Loss Percentage' metric which is used to determine if daily operations are improving. An electric grid that is modern and technically sound will, ideally, reduce all losses feasible. The "Loss Percentage" metric measures the percentage of transmission and distribution losses in the electric grid. It is written as:

$$\% \, Loss = \frac{L_{T\&D}}{E_s}$$

where $L_{T\&D}$ are the transmission and distribution losses due to the transport and distribution of electrical energy, and E_S is the electricity supply. Electricity supply is defined as the electrical energy supplied from all power stations within a country, including imports less electricity used for pumping and exports.

The second metric is the 'Presence of Electric Vehicles' which is used to determine if new technologies and services are being deployed. There are many new services and technologies that the Smart Grid can enable, but many are not measured or made publically available. However, electric vehicles are one of the most discussed, and the deployment of electric vehicles is measured by multiple sources, making it available to gauge the deployment of new technology. Also, a country with a relatively large share of electric vehicles will have to update its distribution grid to accommodate the increase in load, making the 'Presence of Electric Vehicles' a reasonable proxy for modern infrastructure. The "Presence of Electrified Vehicles (EV)" metric specifically measures the annual market share of electrified vehicles in a nation's vehicle fleet.

The third metric is 'Research Patents', it is also meant to gauge the deployment of new technology but in a less direct way. The "Research Patents" metric measures the number of patent applications per capita filed in a country. The intent of the metric is to gauge the amount of innovation going on in a country. Where innovation is taking place, new technologies can be developed that would be helpful in the development of the Smart Grid.

The fourth metric is 'SAIDI' which stands for System Average Interruption Duration Index. In this paper, it is measured annually, in minutes. SAIDI is used to determine if an electric grid is technically sound by measuring the average duration of outages that consumers experience. In a sound electric grid, outages would be reduced to zero ideally or as few minutes as possible per year. SAIDI is calculated as

$$SAIDI = \frac{\sum Customer\ Inerruption\ Durations}{Total\ Number\ of\ Customers\ Served}$$

3.3.4 Efficient

The 'Efficient' goal is meant to address increasing societal demand for energy and electricity efficiency. An electric grid that is modern and efficient will ideally increase electricity efficiency to the highest percentage feasible. The 'Electricity Efficiency' metric measures the efficiency of a nation's electric grid. Normally, energy efficiency is defined as usable energy/total energy. We have defined electricity efficiency as:

$$EE = \frac{E_C}{E_S}$$

where E_C is the electricity consumption or electricity used, and E_S is the electricity supply or total supplied electricity. Electricity consumption is defined as electricity supply less losses and electricity used by the electricity industry for heating, traction, and lighting purposes.

3.3.5 Social Acceptability

The 'Social Acceptability' criterion addresses societal demands for reduced greenhouse gas emissions. The 'CO_2/kWh' metric measures the total amount of CO_2 emissions emitted per kWh of electricity produced. A modern electric grid that is meeting societal demands for sustainability will reduce CO_2/kWh emissions as much as possible.

3.3.6 Economically Sound

The 'Economically Sound' goal addresses the need for prudent electricity prices. This goal is assessed using the 'Electricity Intensity' and 'Price of Residential

Electricity' metrics. The 'Electricity Intensity' metric measures how economically productive a nation's electric grid is. It is written as:

$$EI = \frac{GDP}{E_S}$$

where *GDP* represents the nation's Gross Domestic Product. It measures for every kWh of energy produced, how much GDP is produced. An electric grid that is modern, but prudent, will maximize the amount of GDP per kWh within feasible limits.

The second metric is the "Price of Residential Electricity" which is a direct measure of the cost of electricity to the average residential consumer per MWh. All prices are in $US and were converted using 2011 purchasing power parity (PPP). In a modern, but prudent electric grid, prices for residential consumers should be reasonable. This is a comparative metric assessing where each country's price is relative to other nations. Higher prices will receive lower scores.

3.4 Smart Grid Assessment

To test the metric system developed in Section 3.3, the Smart Grid progress of 33 OECD countries and the BRICS nations (Brazil, Russia, India, China, and South Africa), excluding the Russian Federation, were evaluated. Data was collected for all 37 countries for each of the eleven metrics. The data was principally drawn from 2012 however, the Google Search metric, LEED Professional certifications and presence of EV data contained the most recent data up to 2013.

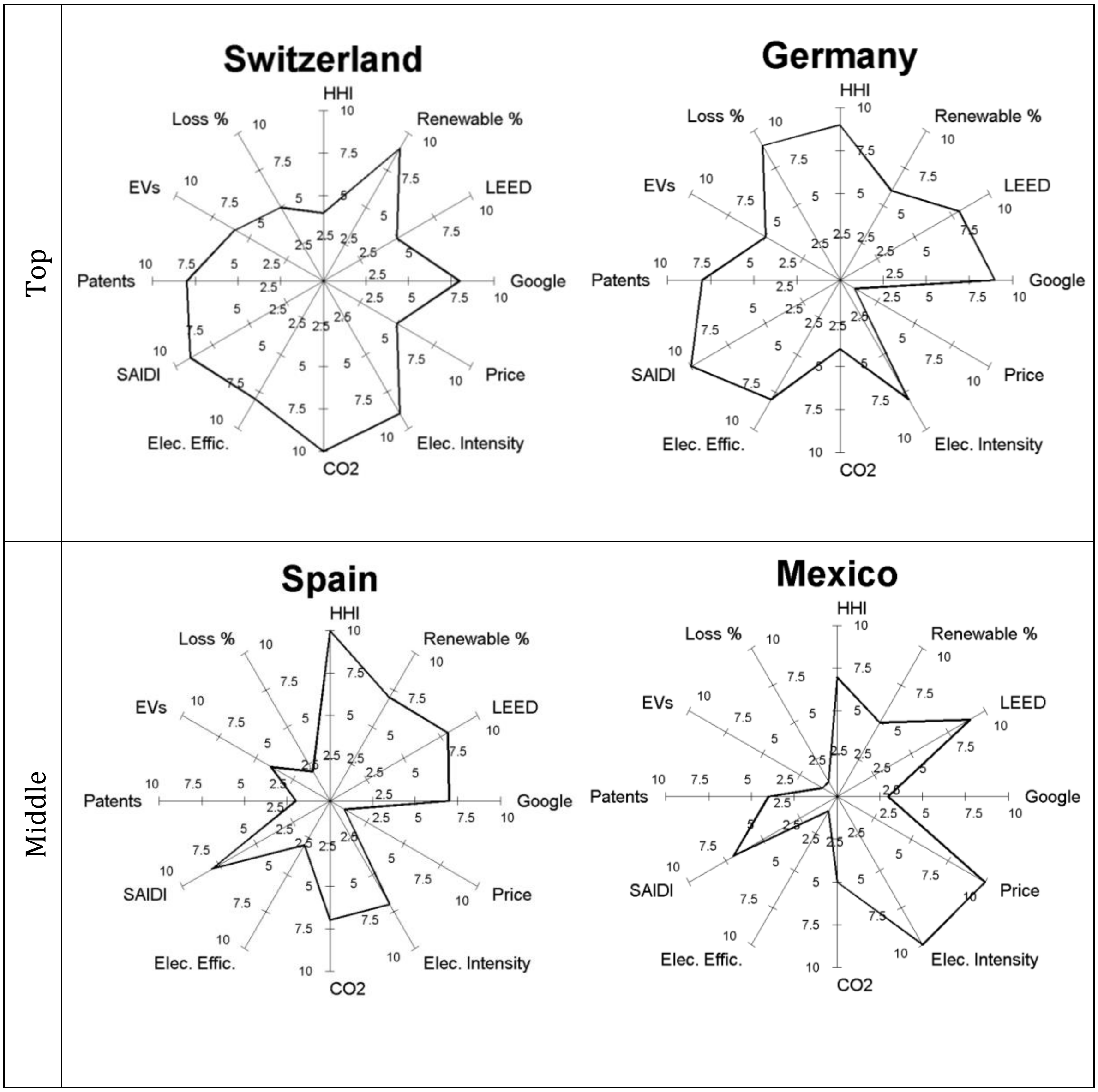
The OECD and BRICS countries were chosen based on availability of data on their respective electric grid and their importance to the global economy. OECD countries tend to focus on updating existing infrastructure while the BRICS nations are building some parts of their respective electric grid for the first time. Both instances offer important insights of how to build better electric grids. The Russian Federation was omitted due to a lack of available data.

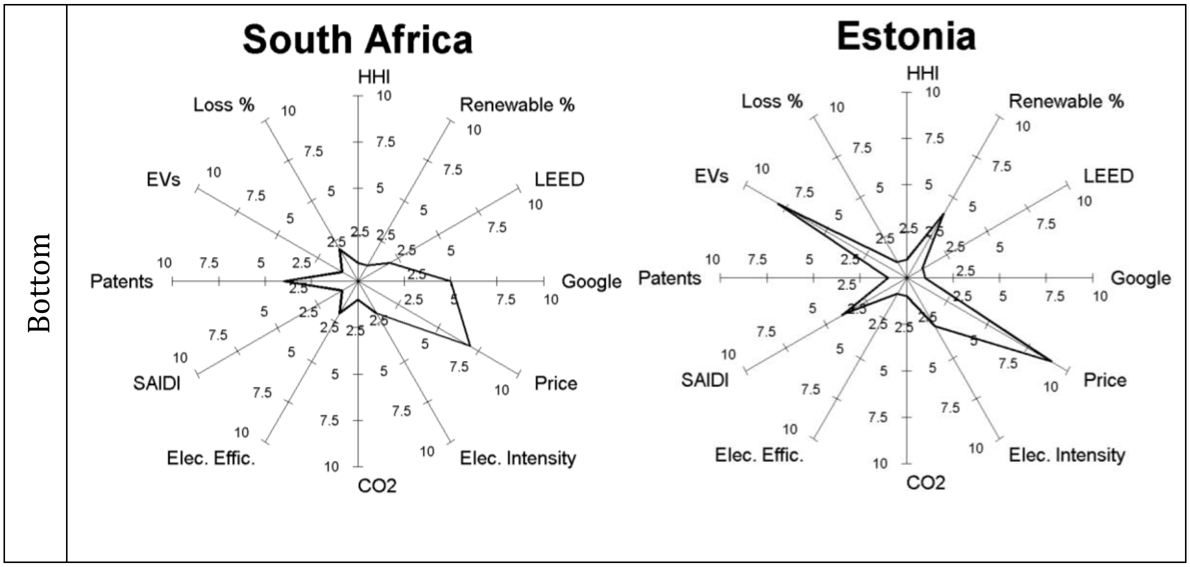
Each metric has its own units. To have each metric on the same scale, each metric was ranked from lowest to highest and separated into deciles. From there, a ranking of 1 to 10 was assigned to each decile with 1 representing a low score and 10 a high score. Table 6 displays each metric, the range of values for the corresponding metric, and what constituted a low and high score. The full set of data can be found in Appendix A.

Table 6: Metric Units and Value Ranges

Metric	Units	Low Score (1)	High Score (10)
Google Search	unit less	0	149
LEED Professionals	# of certifications	0	83,120
Percent Renewable	%	0.8%	100%
Diversity Index	unit less	0.93	0.17
Loss Percentage	%	18.15%	1.56%
Presence of EV's	%	0%	6.1%
Research Patents	%	0%	0.38%
SAIDI	Minutes	10	21,924
Electricity Efficiency	%	80.62%	98.44%
CO_2/kWh	g CO_2/kWh	926	0
Electricity Intensity	(GDP/kWh) *GDP = 2011 Int. PPP	0.73	7.43
Price of Residential Electricity	$U.S./MWh (using PPP's)	$383.43	$90.20

A spider plot was generated for each country to create a visual representation of Smart Grid progress. A sampling of the two top, middle, and bottom performers are showcased in Figure 7. In addition to the visual representation of Smart Grid progress, the total area captured by the spider plot was calculated. Table 7 lists the total Smart Grid metric area captured. The full set of spider plots and their corresponding areas can be found in Appendix B.





*Ranking: (1) Switzerland (2) Germany (19) Spain (20) Mexico (36) South Africa (37) Estonia

Figure 7: Selection of Smart Grid Spider Plots

Table 7: Smart Grid spider plot area

Smart Grid Spider Plot Area			
Switzerland	154.50	**New Zealand**	84.75
Germany	145.25	**Belgium**	84.00
Japan	135.75	**India**	82.00
Finland	135.50	**Greece**	75.25
Korea	135.50	**Slovenia**	74.00
Netherlands	126.00	**Ireland**	73.75
Denmark	125.50	**Norway**	71.25
United States	122.25	**China**	66.00
Iceland	108.25	**Portugal**	65.50
Austria	107.00	**Australia**	65.00
Italy	103.75	**Slovak Republic**	61.25
Canada	101.75	**Israel**	61.00
Luxembourg	101.00	**Brazil**	58.50
United Kingdom	99.00	**Hungary**	43.25
France	97.25	**Poland**	42.50
Sweden	92.75	**Czech Republic**	36.50
Chile	85.50	**South Africa**	20.00
Spain	85.50	**Estonia**	18.50
Mexico	84.75		

3.5 Discussion: Evaluating Smart Grid Progress

3.5.1 Smart Grid Metric System Discussion

The metrics themselves were evaluated to gain an understanding of which metrics had the biggest and smallest influence on the final results. The Spearman's rank correlation coefficient was utilized to determine the significance of each metric in the final spider plot area. It is computed as

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$$

where ρ is the Spearman coefficient, d represent the difference between the spider plot area ranking and the corresponding metrics ranking, and n represents the sample size. The Spearman coefficients for each metric are displayed in Table 8.

Table 8: Smart Grid Spider plot Metric Spearman Coefficients

Metric	Correlation
Google Search	0.400
LEED Professionals	**0.173**
Percent Renewable	0.287
Diversity Index	-0.441
Loss Percentage	-0.438
Presence of EV's	0.467
Research Patents	**0.508**
SAIDI	**-0.629**
Electricity Efficiency	**0.548**
CO_2/kWh	-0.363
Electricity Intensity	**0.142**
Price of Residential Electricity	**-0.186**

The 'SAIDI', 'Electricity Efficiency' and 'Research Patents' metrics have the strongest correlations. Among the countries with the most Smart Grid development, consisting of areas in which they scored high, or in countries with less Smart Grid development, consisting of areas in which they scored low. The 'Electricity Intensity', 'Price of Residential Electricity' and 'LEED Professionals' had the weakest correlations.

Google Search

Top Performers: New Zealand, Korea, Australia, India, United States, and Canada
Worst Performers: Chile, Czech Republic, Estonia, Hungary, Iceland, Israel, Luxembourg, Slovak Republic, and Slovenia

The Google Search metric showed good consumer engagement throughout the countries studied. The top six performing countries greatly outperformed the other countries. The average score among the top performers is more than double the average of the remaining countries showing high consumer interest in the specified Smart Grid search terms. The nine lowest performing countries who received a zero did not search for the specified Smart Grid terms frequently enough to register on the Google trend data. This indicted lower consumer interest in the specified Smart Grid search trends.

A possible limitation of this metric is that it will be biased towards countries that have easy access to the internet and where Google is the top or preferred search engine.

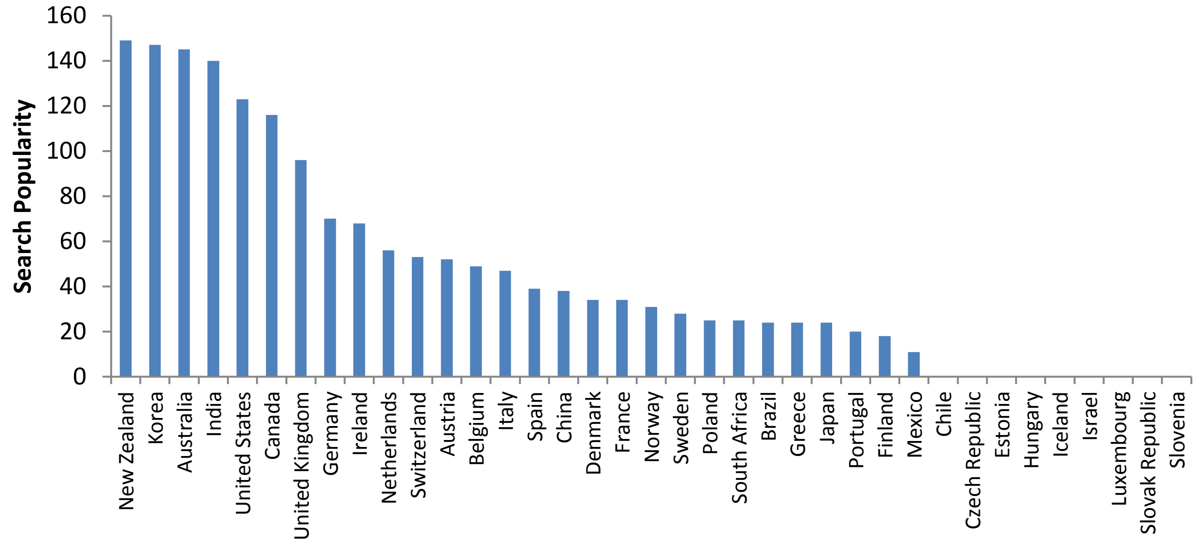


Figure 8: Google Search Ranking

LEED Professionals

Top Performers: US, Canada, Korea

Worst Performers: Estonia, Iceland, Norway

A possible limitation of this metric is that it could be biased towards North America, where the metric began. The top two performers are in North America, and the number of LEED professionals those countries have far outnumbers the other countries studied. This bias should decrease over time as LEED certifications become more popular. The popularity is rising as evident by the high number of LEED professionals in countries far away from North America, like Korea, China, and India. In the future, this metric could be made stronger by scaling this metric by population. At this point, there are not enough professionals for this to be necessary.

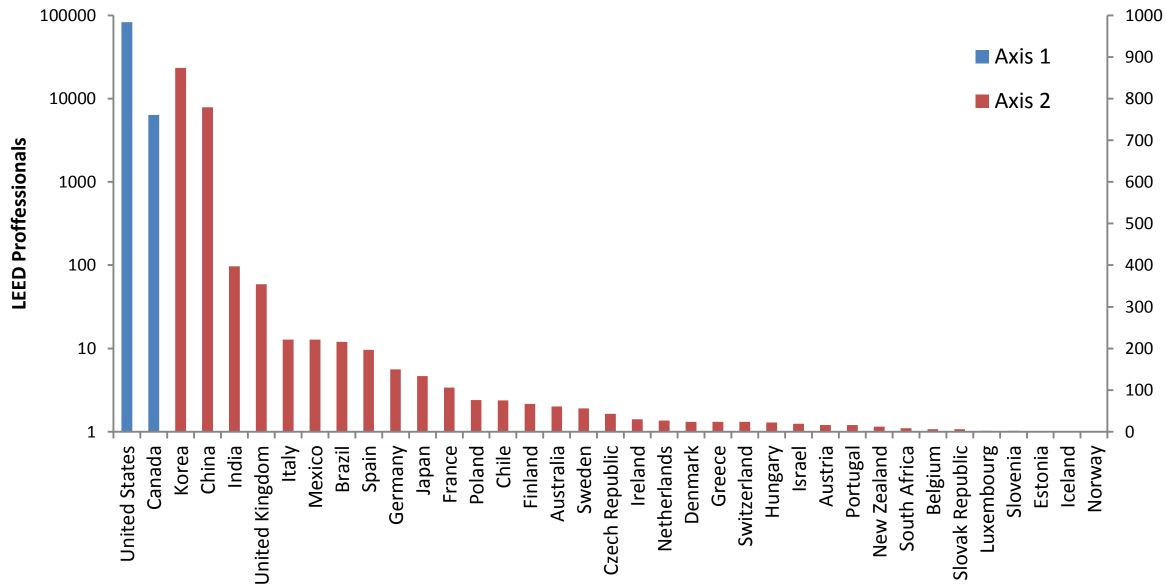


Figure 9: LEED Professionals Ranking

Percent Renewable

Top Performers: Iceland, Norway, Brazil

Worst Performers: South Africa, Korea, Israel

The 'Percent Renewable' metric shows a wide range of renewable penetration across the countries studied. The data trends in an exponential fashion; as you progress past the best performers, the percent of renewables drops quickly. It is of note that all of the countries in the 80th percentile, on average, obtained over 50% of their electricity needs from hydro resources. It was clear that countries with available hydro resources were more likely to score well in this category. However, some of the performers in the 50th percentile do not have abundant hydro resources, but have greatly expanded other renewable sources, like Denmark and Germany. As more countries complete or realize the renewable portfolio standards they set for themselves, there will be a greater variety of renewable sources in the top performers.

A possible limitation of this metric is giving too much credit to a country over reliant on one renewable source. The Smart Grid definition outlined in Table 4 requires generation to be renewable and robust. To account for this shortcoming, countries are also measured for diversity from the 'Diversity – HHI' metric.

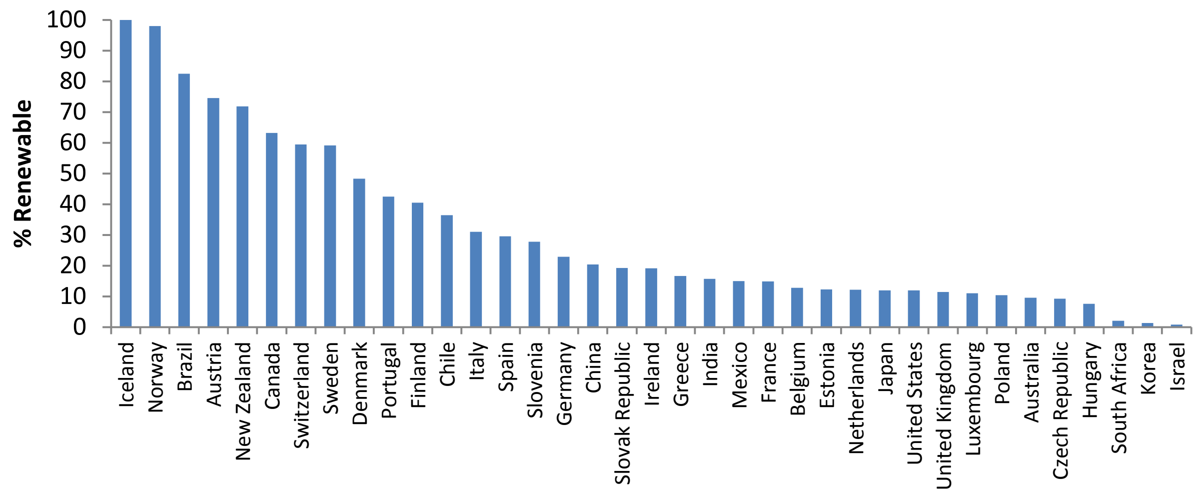


Figure 10: Percent renewable ranking

Diversity Index

Top Performers: Spain, Portugal, Finland

Worst Performers: Norway, South Africa, Estonia

The 'Diversity' metric showcased a wide variety of performance among the countries studied, from very diverse to countries limited to primarily one resource. All of the counties in the 85th percentile had at least 25% of their electricity generation provided by multiple renewable generation sources. While all of the countries in the 15th percentile obtain at least 75% of their electricity generation from a single source, 66% of the time the primary source was coal.

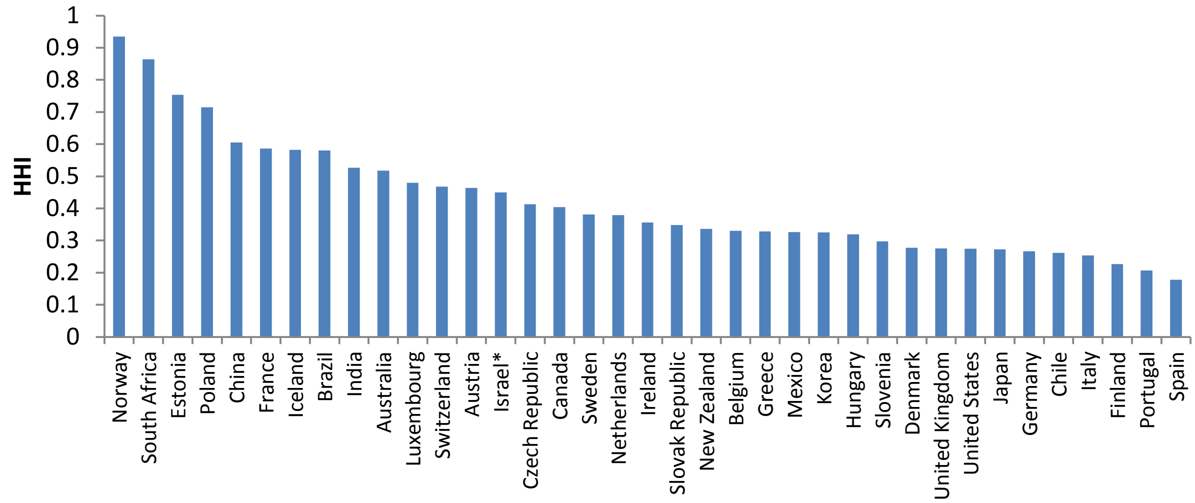


Figure 11: Diversity Index Ranking

Loss Percentage

Top Performers: Luxembourg, Greece, Iceland

Worst Performers: India, Brazil, Mexico

The 'Loss Percentage' metric showed a smaller range/variance from country to country than other metrics did. Overall, many countries are performing well. The average losses were 7% and over 90% over the countries studied that had less than 10% losses. For the two worst performing countries, some of the losses are attributed to widespread electricity theft [82] [83].

This metric could be biased towards countries with smaller landmasses and less dispersed population. However, in the countries reviewed for this study there were smaller landmass countries in the 20th percentile (ex. Estonia, Hungary) and countries of moderate landmass in the 80th percentile (ex. Germany and Finland).

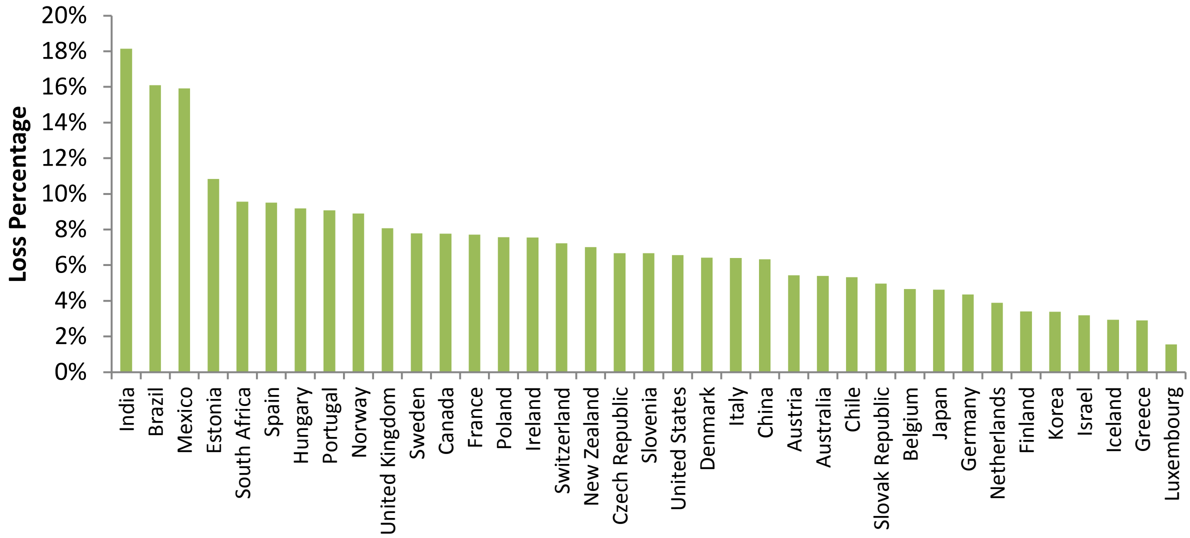


Figure 12: Loss Percentage Ranking

Annual Market Share of Electric Vehicles

Top Performers: Norway, Netherlands, Iceland

Worst Performers: Countries where EV's have not yet reached 0% annual market share

The 'Electric Vehicle' metric breaks down into three categories: countries with over 5% annual market perpetration, countries with 1-0.00% market penetration, and countries with less than 0.00% market penetration. The majority of the countries fall into the second category, where EV's are being purchased, but represent a small portion of the annual car sales. The next major block of countries falls into the third category, where EV sales have yet to gain over 0.00% penetration. These low penetrations can be attributed to the fact that electric vehicles are still in the nascent stage of adoption. They will continue to grow in acceptance and popularity, and this metric will have more importance. As electric vehicles become more standard, then the penetration of electric vehicles will rise, and there will be greater variance among countries.

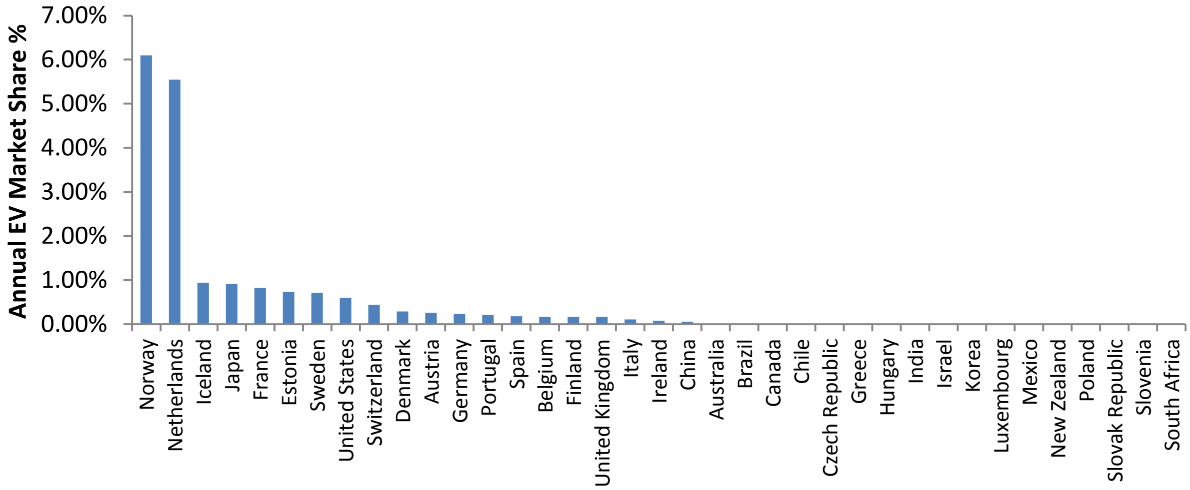


Figure 13: Market Share of Electric vehicles ranking

Research Patents

Top Performers: Korea, Japan, United States

Worst Performers: Slovak Republic, India, Estonia

The ‘Research Patents’ metric shows a wide range of patents per person from the countries studied. The data trends in an exponential fashion; the top performing countries produce significantly more patents per person then countries in the middle and bottom tier. The ‘Research Patents’ metric has one of the strongest correlations to a country with the most development towards a Smart Grid. This signifies that being innovative and producing patents is important to show that a country is involved in creating and implementing Smart Grid technology.

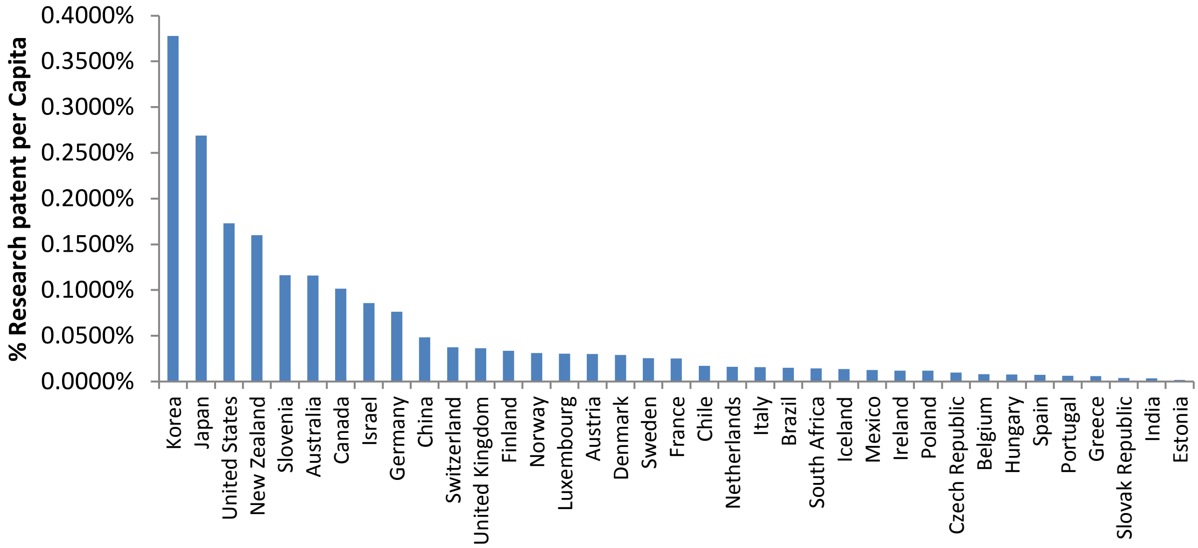


Figure 14: Research Patents Ranking

SAIDI

Top Performers: Luxembourg, Korea, Denmark

Worst Performers: China, Brazil, South Africa, India

There was a wide variety of performance for the 'SAIDI' metric. 87% of the countries studied, on average, had 300 minutes or fewer of interruption per customer. The remaining 13% of countries were far beyond that, with the BRICS countries having the worst performance. India's performance was far worse than all of the other countries studied, with an average interruption time over 90 times greater than the average of all the other countries studied.

The 'SAIDI' metric had the strongest correlation of all of the metrics. This says that having minimal outages correlates strongly to a grid that has been well maintained or updated to the latest Smart Grid technology.

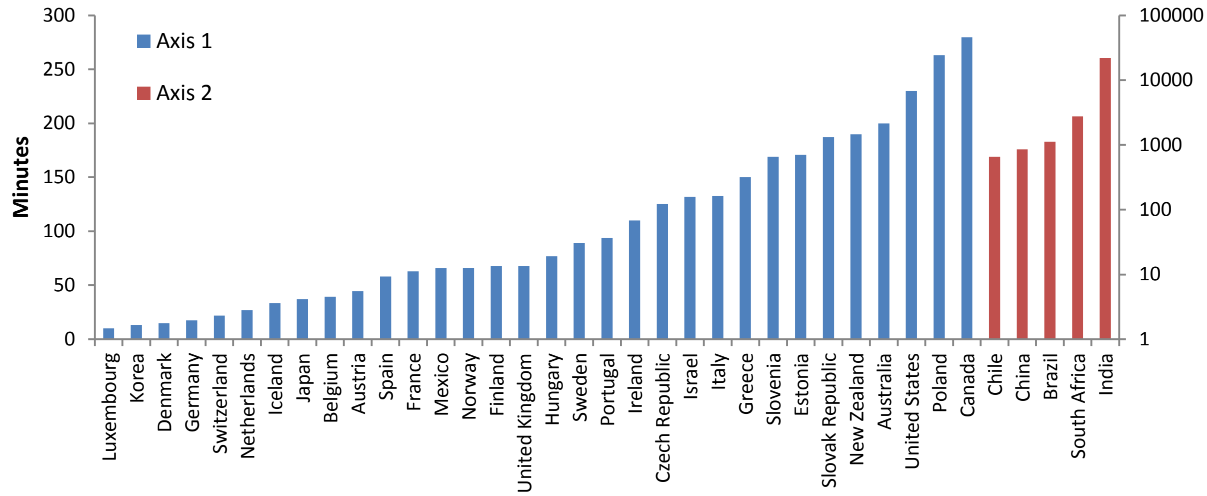


Figure 15: SAIDI Ranking

Electricity Efficiency

Top Performers: Luxembourg, Iceland, Israel

Worst Performers: Mexico, India, Brazil

Most of the countries performed very well in the 'Electricity Efficiency' metric. 65% of the countries studied have an efficiency of 90% or greater. The remaining countries studied had an efficiency of greater than 80%. This metric had the second strongest correlation out of all of the metrics in this study. Countries that performed well in this metric and had a high electricity efficiency were likely to have made progress towards developing a Smart Grid.

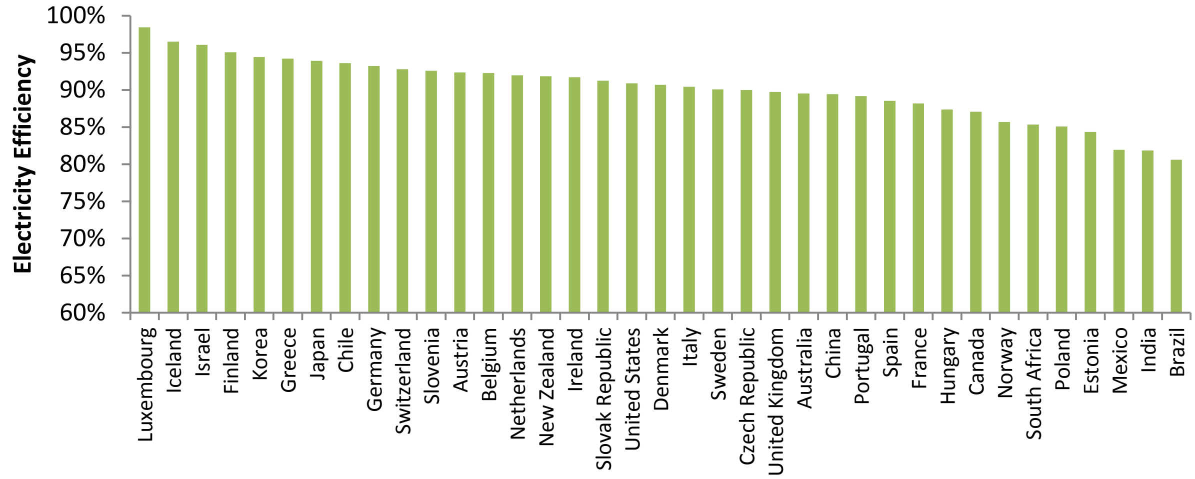


Figure 16: Electricity Efficiency Ranking

CO_2/kWh

Top Performers: India, South Africa, Estonia

Worst Performers: Iceland, Norway, Sweden

The 'CO_2/kWh' metric values varied greatly over the countries studied. For countries in the 70th percentile, the combination of hydro and nuclear sources represented over 50% of their electricity generation. Countries in the 25th percentile have over 50% of their electricity generation provided by coal.

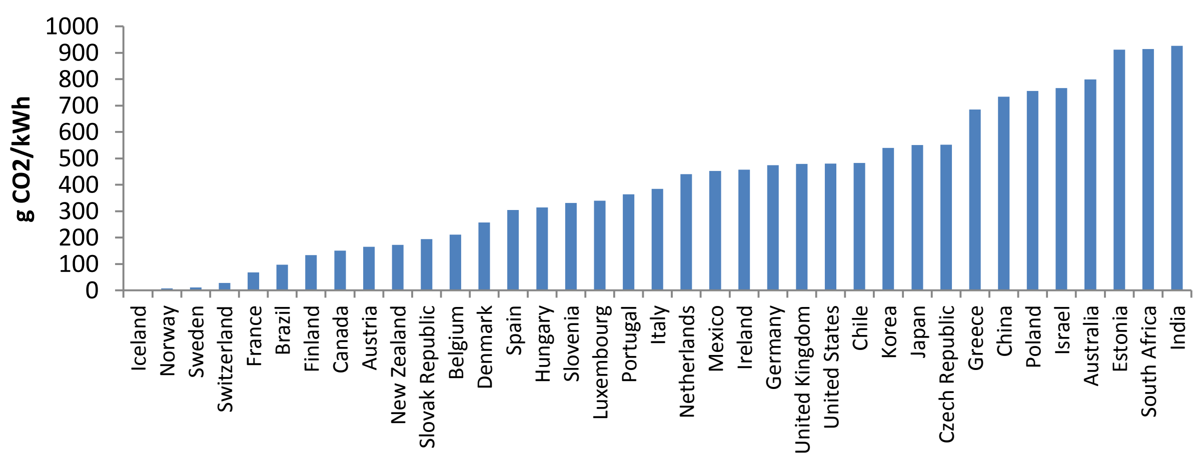


Figure 17: CO_2/kWh Ranking

Electricity Intensity

Top Performers: Ireland, Luxembourg, Mexico

Worst Performers: Norway, Finland, Iceland

Performance for the 'Electricity Intensity' metric was wide-ranging. This metric had the weakest correlation of all the metrics in this study. Countries with the strongest Smart Grid development had varied performance in this metric. Switzerland and Germany (1 & 2) are in the 75th percentile but Finland and Korea (4 & 5) are in the 25th percentile.

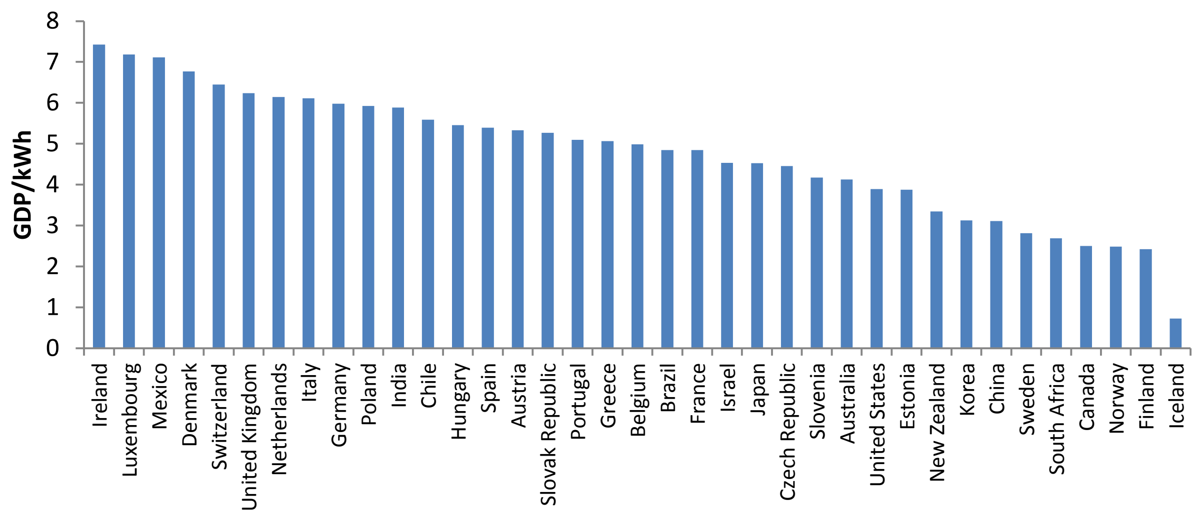


Figure 18: Electricity Intensity Ranking

Price of Residential Electricity

Top Performers: Korea, Mexico, Iceland

Worst Performers: Denmark, Germany, Spain

The residential electricity prices varied greatly between the countries. The countries that scored highest in Smart Grid development had some of the highest residential electricity prices. However, the countries that scored the lowest in Smart Grid development did not always have the lowest prices. This metric had the second weakest correlation. I attribute this to two primary factors. First, prices can be influenced by policy implemented by the government which may make residential prices seem artificially low. Second, countries that are resource rich with abundant coal or hydro resources will have lower prices regardless of the updates they have made to their grid.

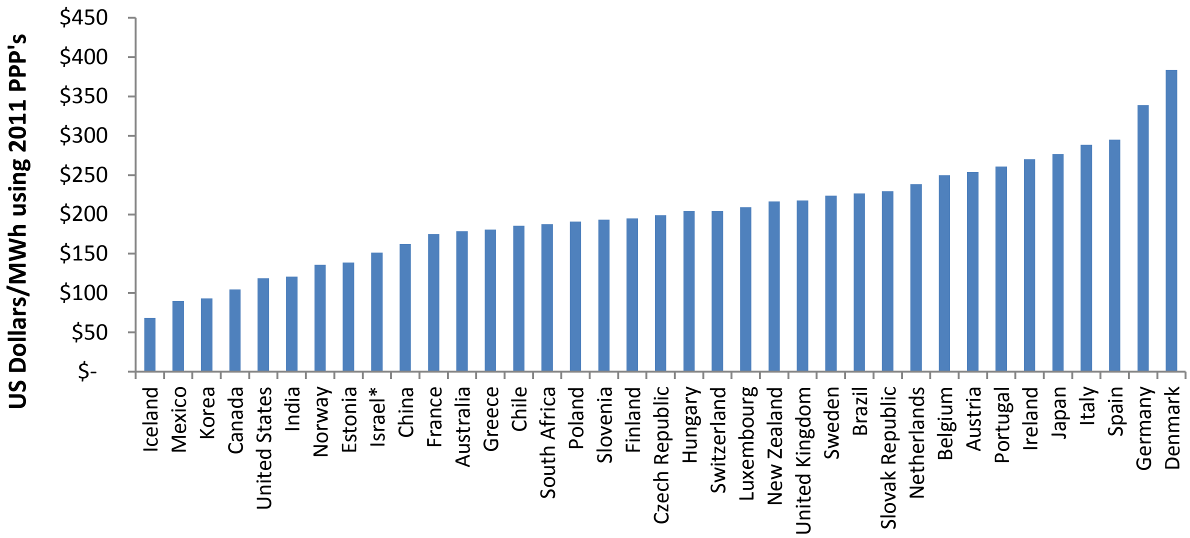


Figure 19: Price of Residential Electricity Ranking

3.5.2 OECD and BRICS Smart Grid Assessment Discussion

Top Performers

Switzerland and Germany had the largest area among the countries studied and have made the most development towards a Smart Grid. Both countries have been very active since the early 2000's creating legislation to improve their electric grid and overall energy use [84] [85]. Germany has enacted several policies and practices that correlate to its high achievement in several of the metrics. For example, Germany passed the Renewable Energy Act of 2000 and the Renewable Energy Sources Act of 2011 which have both contributed to its good score in the

'Percent Renewable' metric [85] [86]. Both pieces of legislation expanded the use of feed in tariffs, set goals to increase the share of renewable energy sources, and made efforts to reduce overall energy consumption. For a country without a significant penetration of hydro resources, Germany scores very well in the 'Percent Renewable' category. Germany also passed legislation and established practices to improve their electricity delivery systems contributing to its high score in the 'Loss Percentage' metric and the 'SAIDI' metric. Germany established the practice of placing their distribution lines underground; almost 80% of Germany's distribution grid is underground [87]. This helps to prevent damage to the lines and outages. Germany also passed the Network Expansion Acceleration Act of 2011 to help expand its transmission network [88]. Both of these contribute to reducing electricity losses and outages experienced by customers.

Middle Performers

Spain and Mexico represent the middle of the pack as far as Smart Grid development goes. Both countries have implemented legislation to develop their electric grid and improve energy use, but lack in certain areas. Spain has made great strides in terms of increasing the penetration of renewable sources, encouraging diversity in their generation, and reducing emissions. Since 1994, Spain has passed a series of laws encouraging the growth of renewable energy sources through feed-in tariffs [89]. With the help of these tariffs, from 1995 to 2012, electricity production from renewable sources doubled in Spain [90]. The rising penetration of renewables contributed directly to Spain's high score in the 'Percent Renewables' metric and helped to increase its score for the 'Diversity Index' metric. As a member of the European Union, Spain also implemented a cap-and-trade market for CO_2 emissions in 2005 [91]. That program, in addition to the legislation aimed at increasing renewable sources in electricity generation, allowed Spain to reduce its CO_2 emissions per kWh from 454 g/kWh in 1995 to 305 g/kWh in 2012 [92]. These programs contribute to Spain's good score in the '$C0_2$/kWh' metric.

Despite Spain's success at increasing renewable generation penetration and reducing CO_2 emissions, they were unable to fulfill legislation/policies related to increasing efficiency in their economy and improving electricity transmission. As a part of the European Union, Spain is under the 2012 Energy Efficiency Directive [93]. An assessment of Spain's National Energy Efficiency Action Plan to meet the Energy Efficiency Directive was rated as "average, with both good and unsatisfactory elements [94]". 70% of the experts interviewed to conduct the assessment did not think that Spain would meet their Energy Efficiency Directive target. Spain's mediocre pursuit of energy efficiency contributes to its low score in the 'Electricity Efficiency' metric. In 2002 at the European Summit in Barcelona, European Union members agreed to have electricity interconnections equivalent to at least 10% of their production capacity by 2005 [95]. As of 2012, Spain's electrical interconnection with France is at 3.5% [96]. Spain has not done a good job at improving or expanding transmission lines leading to high losses and a lower score in the 'Loss Percentage' metric. It is also important to note that the ambitious feed-in tariffs for renewables and changes in Spain's electricity market led to high prices and the resulting poor score in the 'Price of Residential Electricity' metric [96].

Bottom Performers

South Africa and Estonia had the smallest areas among the countries studied and have made the least amount of development towards a Smart Grid. While both countries have not made a lot of development, they do have plans to achieve a Smart Grid. South Africa's Smart Grid initiatives began later than most of the other countries studied in this report. South Africa's Smart Grid initiatives focus on diversifying their generation mix, decarbonizing their economy, and improving the transmission and distribution grid. [97]. To address their aims of increasing renewable energy penetration, South Africa is hosting renewable energy auctions. They hosted their first renewable energy auction in 2010 [98]. To decarbonize their economy, they are pursuing increased renewable generation and an emissions cap [99]. According to the 2013 Integrated Resource Report (IRP) update, South Africa is also considering a carbon tax or a carbon budget as an alternative to the current emissions cap to reach emissions goals, but perhaps at a lower cost. To achieve South Africa's other Smart Grid objectives of improving network availability and network security, they are working to expand their distribution and transmission system. The 2013 IRP Update identified five possible transmission corridors that need to be built to help connect new generation to demand and expand their connection to all consumers [99]. The IRP Update also encourages expanding their distribution network. They would like to "consider a large distributed generation network with more appropriately sized units. These would be smaller sized plants that can be integrated into the distribution networks utilizing their infrastructure and reducing the loading of the Transmission Grid [99]." Reducing the load on the transmission grid would contribute greatly to their goal of improving network availability. Also, switching a significant portion of electricity transmission to the distribution system also helps to improve network security because distribution systems tend to be redundant and provide more routes for electricity to flow. As time progresses and South Africa completes some of the initiatives they have started, their scores in the metric system should improve.

Overall Assessment

Switzerland, Germany and Japan achieved the highest spider plot scores and developed the most. As depicted in their spider plots, each country achieved that score in different ways and the spider plot of each of the top three countries looks very different. Switzerland excels in the 'Percentage of Renewables' and 'CO_2/kWh' metrics but falls short in the 'Diversity Index' and 'Loss Percentage' metrics. Germany and Japan, contrastingly, excel in the 'Diversity Index' and 'Loss Percentage' metrics but fall short in the 'Percentage of Renewables' and 'CO_2/kWh' metrics. This underscores there are many ways to go about achieving Smart Grid progress; there is not, necessarily, one correct path.

The BRICS nations primarily appear on the bottom half of the spider plot area results; however, they are evenly spread across the bottom half. This highlights that their developing country status hasn't kept them from making progress towards achieving a Smart Grid. Developed nations have a higher score on average, but development status is not the strongest indicator for Smart Grid development.

The strongest take away from this Smart Grid analysis is how much more work still could be done. In theory, the Smart Grid spider plot can have a total possible area of 314. The largest area measured was 154.50, less than half of the total possible area. This statistic says that there is still much work to be done. It is not foreseeable that a country's spider plot area will reach the theoretical maximum, given that some of the metrics have competing interest, like prudent prices and installing the latest technology. However, achieving higher scores is clearly feasible since the metrics are scaled to values that have already been achieved by at least one country.

3.6 Conclusions and Policy Implications

The intent of this work was to create a broad system of metrics to measure the large scale Smart Grid progress for countries. There are a plethora of Smart Grid assessments in the literature, but many are technically focused and for specific projects. The Smart Grid assessments that were intended for large scale were still dependent on technical data that was not widely available. This work adds value by creating a broad Smart Grid progress metric to help assess nation to nation progress.

The Smart Grid metric system can help to identify weak and strong areas of a country's electric system development. From there, a nation could decide to work on improving their overall progress, key in on improving weak areas or focus on building on their established strengths. The assessment could be conducted on regular annual or biennial intervals to monitor progress and ensure that Smart Grid programs and initiatives in place are indeed helping the country to reach a smarter electric grid.

In terms of the results taken from the actual Smart Grid assessment, the other significant takeaway from this assessment was that every country we examined still has progress to make. No country studied reached even half of the technically feasible Smart Grid spider plot area. Most countries seem to specialize in pursuing one or two of the six Smart Grid characteristic goals rather than broadly pursuing all six at once. For example, Portugal is a mid-range performing country that has successfully pursued a 'Robust and Renewable Generation Mix' which shows in its high performing scores in the 'Diversity' and 'Percent Renewables' metric. However, Portugal doesn't excel in any of the other five goals.

The intent of this work is to assist countries in assessing their Smart Grid progress. Tracking this assessment over time would indicate their level of Smart Grid progress, areas they are doing well in and areas that could be improved. Evaluating the metrics over time could also help assess the speed at which progress is being made for various nations.

Future work could include adding other valuable metrics when that data becomes standardized and widely publically available. It would also be valuable to conduct a more in depth qualitative study of the countries examined to validate the results found.

CHAPTER 4

ELECTRIC UTILITY BUSINESS MODEL FRAMEWORK

4.1 Motivation

The purpose of this work is to create a business model framework to assist utilities in updating their business model as discussed in Recommendation 6 in Section 2.4.6. The intent of this work is to adapt a common business model framework and utilize business analysis tools to create an electric utility business model framework (EUBMF). The EUBMF will enable utilities to assess their current business model and explore/develop new business models. While existing literature proposes isolated business model options, the EUBMF is a framework for business model development, where the business model is to be discovered.

4.2 Literature Review

A business model is a template for how an organization creates, delivers, and captures value. For many organizations this entails determining their customers' desire and creating a strategy to deliver that product or service using various resources, activities and channels. There are many factors that can influence the success of a business model. As a result of that, business models need to be reviewed regularly to ensure they are meeting the organization's strategic goals, their customers' needs, and factors that affect a business.

In the case of the electric utility industry, the classic business model in the U.S. has been as follows: customers desire affordable reliable electricity; electric utilities provide this by generating electricity with central generators and then deliver the electricity through transmission and distribution lines for which customers provide reciprocal value in the form of monthly revenue.

Many challenges have arisen that can affect the success of that electric utility business model. These challenges include uncertain environmental legislation, declining sales, decreasing profit margins, a shrinking customer base, increasing consumer demand for reliability during storms/emergencies, and rising cyber security concerns. One of the most urgent challenges is a rising production of renewable distributed energy required to achieve sustainability objectives related to the Smart Grid. These installations reduce the amount of electricity that consumers buy from the electric utility and affect the ability of the utility to remain profitable and keep the cost of electricity affordable. To address this loss of revenue, electric utility companies need to review and update their business models. The need to address the issue of diminishing revenue has been echoed by many major players in the electric utility industry [36], [35], [37], [38].

4.2.1 Utility Business Model Literature

Many entities have responded to the call for new utility business models and authored papers with their perspective; these entities range from academics, to regulators, to think tanks, and industry experts. The authors of [100], [101], [102], [103], and [36] discussed business models that address utility's business on a large scale. Other authors were more focused on business models for niche applications. The authors of [104] and [105] focused on business models to incorporate renewable energy. The authors of [106], [107] and [108] focused on energy efficiency. Author [109] focused on business models centered on achieving sustainability. Much of the literature follows the same approach. They begin by discussing the driving force behind why new business models are needed; next, they discuss what a business model is and its core tenets; then they end with two to four business models they believe will help electric utilities succeed in the face of rising challenges. Business model ideas range from a "service" provider ([101], [107], [36]) to renewable energy resource dispatcher ([100], [102], [36]) or a finance resource for renewables and other new technology ([100], [105]). While many of the ideas are innovative and present good arguments for why their business models will be successful, they are usually lone ideas. None of the literature reviewed in this survey presented a framework where utilities could create or discover business models that work for their unique situation. The U.S. utility industry landscape is very diverse with respect to size, ownership (co-ops, municipality, private), regulatory authority, etc. Very few U.S. utilities have the same make-up. With this knowledge, it is important to create custom solutions for each utility's needs versus a one-size fits all approach. This work intends to remedy this problem by creating a utility business model framework that will allow utilities to walk through the business model creation process and create custom solutions suitable to their own objectives and conditions.

4.2.2 Business Literature

Major works related to business model ontology and innovation in business models were studied. Ontology is the theory about how something came into existence, in the case of business model ontology, it is a study of the science of business model formation. Business model ontology was reviewed to better understand how business models are formally defined and created. Baden-Fuller and Morgan [110], Chesbrough and Rosenbloom [111], Casadesus-Masanell and Ricart [112], Teece [113], Zott et. al [114], Osterwalder [115], and Osterwalder et. al [116] served as the foundation for knowledge on business model ontology.

Baden-Fuller and Morgan define a business model as “a set of generic level descriptors of how a firm organizes itself to create and distribute value in a profitable manner [110].” They describe business models as “recipes” that can easily be copied and altered to serve each individual business’s needs. Chesbrough and Rosenbloom define a business model as “the heuristic logic that connects technical potential with the realization of economic value [111].” Through an extended example about the development of Xerox and spinoffs it produced from Xerox PARC, Xerox’s research subsidiary, they stress the importance of altering and fine tuning business models to each business’s needs. The successful spin-offs from XEROX PARC evolved the original XEROX business model to something that worked better for them. Casadesus-Masanell and Ricart define business model in two ways, “a *reflection* of the firms *realized* strategy” and “the logic of the firm, the way it operates and how it creates value for its stakeholder [112].” They make a clear distinction between a business model and strategy. They refer to choosing a business model as a form of strategy. Teece states that a business model “defines how the enterprise creates and delivers value to customers, and then converts payments received to profit [113].” He argues that a business model is intended to be a conceptual model versus a financial model. Amit and Zott define a business model as “the content, structure, and governance of transactions designed so as to create value through the exploration of business opportunities [114].” The content is what is being delivered to customers; governance is defined as who is doing what; and the structure defines the links between the two. Osterwalder defines a business model as “the rationale of how an organization creates, delivers, and captures value [116] [115].” He focuses on defining business models in such a way that they can be used to model business processes and business case simulations.

Osterwalder's work [116] is the foundation for the present work on the Electric Utility Business Model Framework (EUBMF). His work on connecting business models to a generic framework that could be used as a tool to discover new business processes was right in line with the goal of the author. The goal of this work is to create a framework for electric utilities to use to develop new business models, and an adaption of Osterwalder's framework was a great starting point. It was also chosen because it does an excellent job breaking down basic business principles, creates a visually engaging model and is well cited in the literature. Figure 20 shows the business model framework developed by Osterwalder in [116].

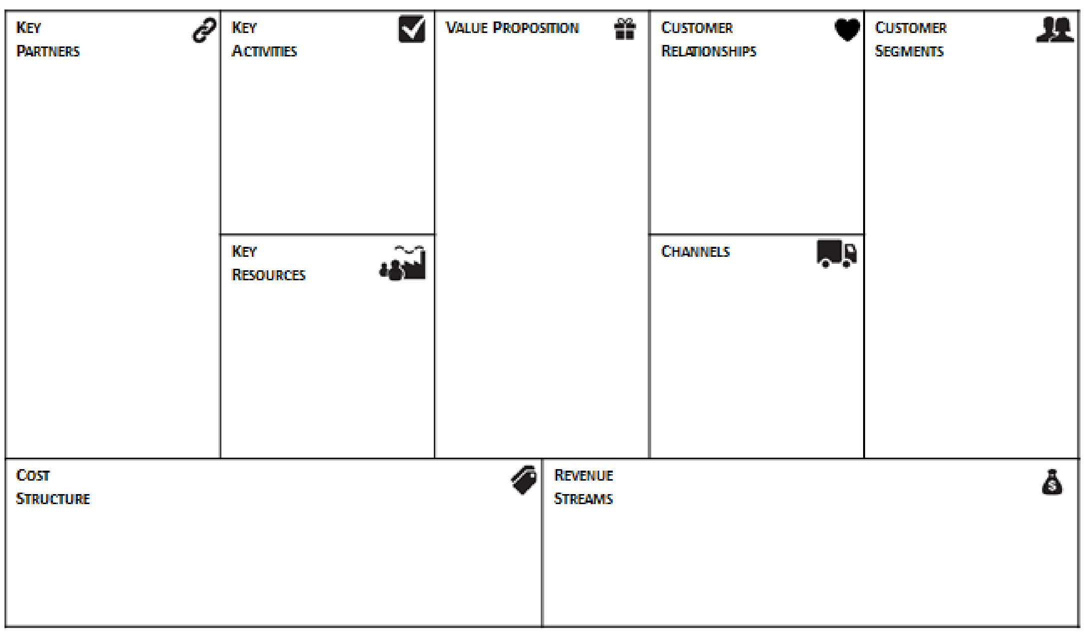


Figure 20: Business Model Canvas (BMC) [116]

Osterwalder defines nine key building blocks that make up the business model framework. Those blocks break out into four key sections. Section one, the heart of the business model, is composed of the value proposition block. The value proposition defines what products and services a business creates for a customer that creates value. Section two, relates to customers. It encompasses the customer segments, customer relationships, and channels blocks. The customer segments block defines the different groups of people an organization serves. The customer relationship block defines what kind of relationship the organization has with each group of customers. The channels block outlines how and what methods an organization uses to deliver the product/service to each customer segment. Section three relates to the interworking's of the organization. It is composed of the key resources, key activities, and key partnerships blocks. The key resources lock describes what assets are needed to make the business model function. The key activities block describes what an organization does to create the product or service delivered to customers. The key partnerships block descries partners the organization works with to make the business model work. The fourth section is related to finances and encompasses the revenues and costs blocks. The revenue block describes all forms of revenue generated and the costs block describes all costs incurred from the business model.

4.2.3 Business Model Innovation Literature

In addition to studying business model ontology, business model innovation was also reviewed; [117], [118], [119], [120] and [121] were the reference texts used throughout this proposed research. Innovation is important in order to learn the best way to adjust to the Smart Grid challenges facing utility companies, in addition to knowing the basics of business model formation.

4.3 Electric Utility Business Model Framework Development

The Electric Utility Business Model Framework was developed in five steps summarized below.

(1) Conduct a literature survey – discussed in Section 4.2

(2) Complete detailed study of the Business Model Canvas from **[116]**

(3) Walk through the BMC for a traditional vertically integrated utility

(4) Walk through the BMC for a deregulated utility

(5) Address shortcomings and opportunities for improvement

After the literature survey was completed and the business model framework by Osterwalder [116] was identified as the inspiration for the EUBMF, a detailed study of the BMC was conducted. The detailed study helped the author to understand the business model generation process and what questions should be asked to generate new ideas.

4.3.1 BMC - Vertically Integrated Electric Utility

The business model canvas creation from [116] was completed for a traditional vertically integrated electric utility. A traditional vertically integrated electric utility owns generation, transmission, and distribution and is regulated by a state governing board like a public service commission; for example, Georgia Power. The goal was to outline and understand the current business model for a traditional vertically integrated electric utility. I printed out a large scale version of the BMC and answered the questions for each block in the BMC. A snapshot of the completed business model canvas can be found in Figure 21. After the canvas had been filled in, I assessed the strength of business model by completing some of the business analyses suggested in the strategy section of [116]. A Strengths, Weakness, Opportunities, and Threats (SWOT) analysis, market and industry force analysis, and a key trends analysis were completed. These analyses revealed some of the same issues presented in the literature [36], [35], [37], [38] like an increasing demand for renewable/distributed energy, increased reliability, and shrinking cost recovery from public utility commissions.

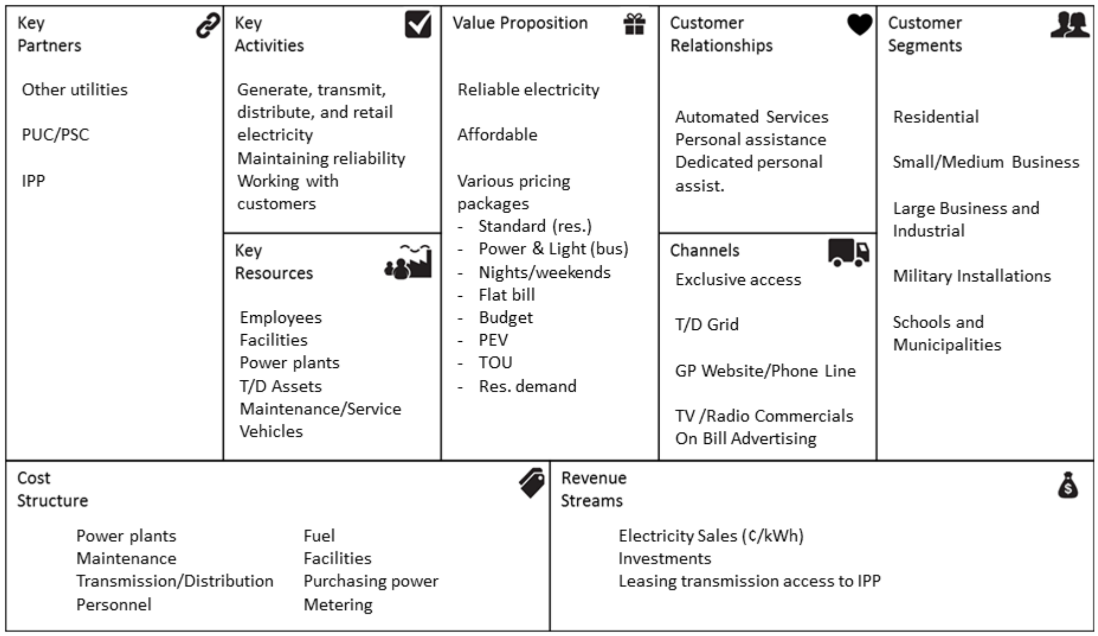
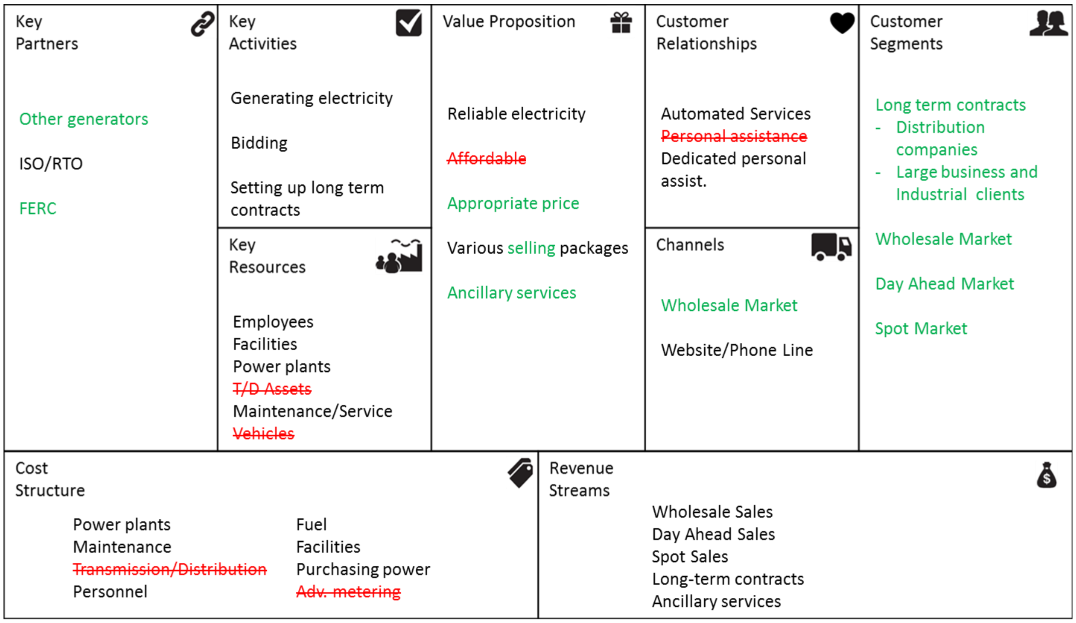


Figure 21: Vertically Integrate Electric Utility Business Model Canvas

4.3.2 BMC - Deregulated Electric Utilities

The business model canvas creation from [116] was completed for a deregulated electric market as well, specifically retail electricity providers and generators. A retail electricity provider provides electricity to retail consumers from power bought in the bulk market. They handle billing and customer interactions. The generators produce the electricity and sell it on the wholesale market. Again, the goal was to outline and understand the current business model for these deregulated utilities. The same analysis conducted for the vertically integrated electric utility was repeated for the deregulated utilities. A snapshot of the completed business model canvases can be found in Figure 22.

Deregulated Electricity Generation Business Model Canvas



Retail Electricity Provider Business Model Canvas

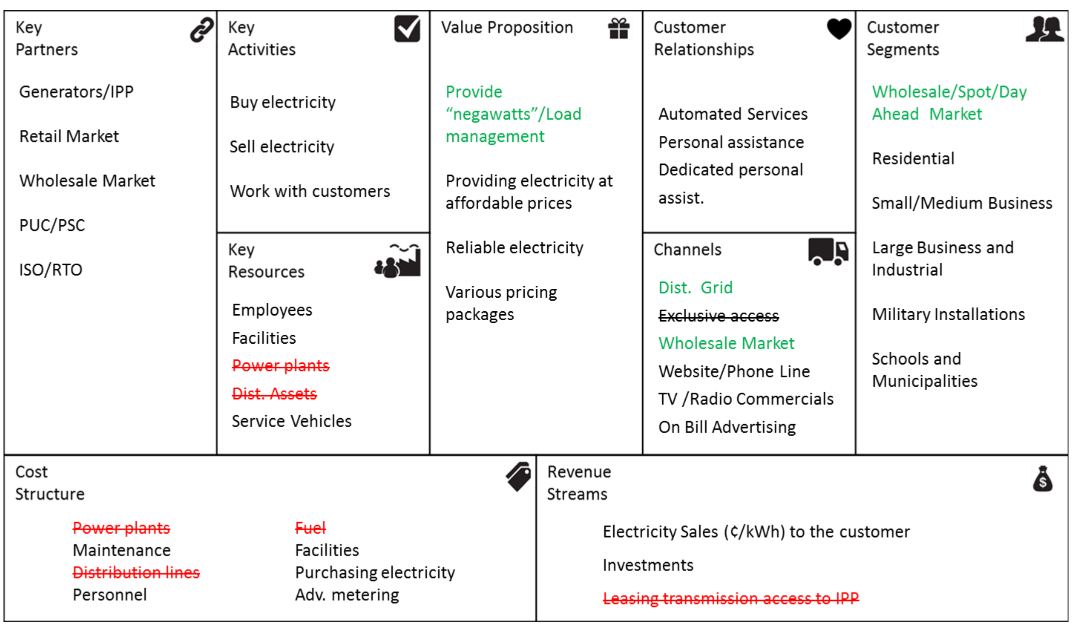


Figure 22: Deregulated Electric Utilities Business Model Canvases

4.3.3 BMC – Shortcomings and Room for Improvement

Upon completing the BMC for regulated and deregulated utilities and reviewing the complementing analyses, several weakness and opportunities were identified that could improve the BMC for electric utilities. The primary shortcoming was a disconnect between the value proposition and the products and services that can actually be offered by an electric utility. Reference [122] introduced the concept of a layered business architecture where future electric utilities will operate across many layers to increase the penetration of distributed generation and address the needs of prosumers – consumers that produce, buy, and sell electricity. As discussed in Section 1.1, these are the exact challenges being faced by electric utilities today; so it is important to incorporate the concept of a utility operating on a variety of levels to deliver services into the business model canvas. Figure 23 displays the layered architecture introduced by [122]. The EUBMF will incorporate a mechanism to account for the various levels/layers future electric utilities will operate on.

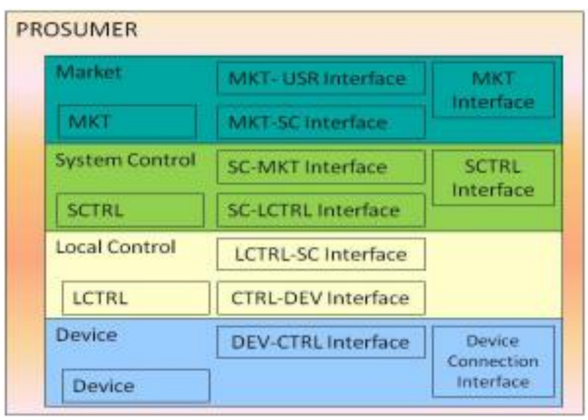


Figure 23: Prosumer-Based Layered Architecture [122] and the Prototype of the EUBMF

The second short coming identified was the inability to incorporate constraints on the utility from outside forces, like investors and regulators.

Customers are an essential component of utility business models, but utilities also have to consider directives from regulators and investors, and those inputs should be considered when creating new business models. The EUBMF will incorporate a new block whose purpose will be to acquire needs and constraints from outside entities.

One opportunity identified to increase clarity was to align/connect each block of the BMC with the appropriate department of an electric utility that would address the questions and concerns of that block. This was suggested by an electric utility insider when they reviewed the EUBMF for ease of use. To further customize the EUBMF, the questions will be altered to focus specifically on electric utilities. Suggestions for responses, concerns, and projects/pilots from other utilities will also be incorporated into the discussion section of each block.

4.4 Electric Utility Business Model Framework

4.4.1 Overview

The Electric Utility Business Model Framework (EUBMF) proposed here was inspired by the "Business Model Canvas" from Osterwalder and Pigneur [116]. It follows the same business model creation process, but the building blocks have been modified to include elements important to the electric utility industry. A picture of the EUBMF and a brief overview of each block are presented below in Figure 24.

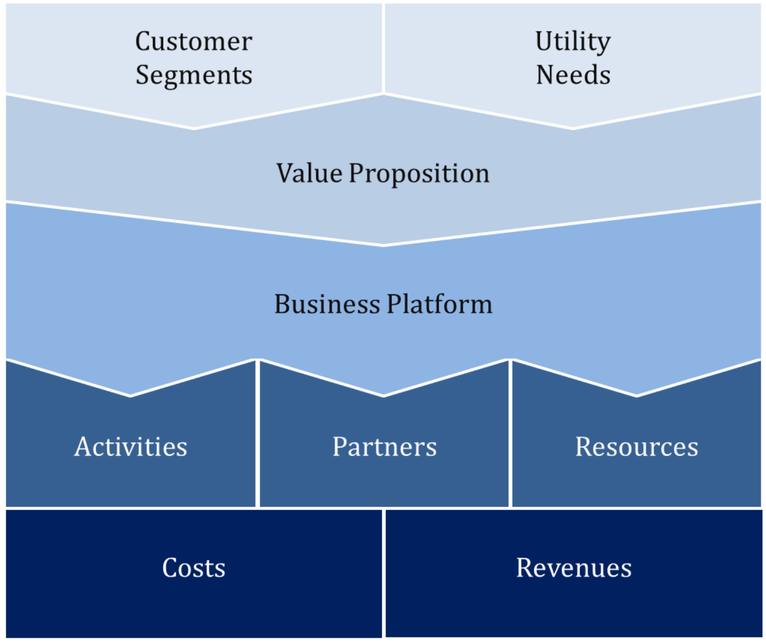


Figure 24: Electric Utility Business Model Framework

1.) Customer Segments

The Customer Segment block describes the various segments of customers the business model serves.

2.) Utility Needs

The Utility Needs block addresses the jobs and demands the utility needs to consider outside of its customers.

3.) Value Proposition

The Value Proposition block describes products and services that will be used to meet the customers and utility's needs.

4.) Business Platform

The Business Platform describes the service outlets electric utilities have to fulfill the value proposition.

5.) Activities

The Activities block describes key activities needed to carry out the value proposition.

6.) Partners

The Partners block describes key partners you will collaborate with to carry the value propositions.

7.) Resources

The Resources block details key assets needed to fulfill the value proposition.

8.) Costs

The Costs block describes cost accrued from delivering the value proposition.

9.) Revenues

The Revenue block describes revenues generated from delivering the value proposition.

The following sections will be written as if it were being presented to an electric utility. The text is presented as if providing instructions to work through creating a business model.

4.4.2 Customer Segments

The Customer Segment block focuses on who the utility is serving. Customers are grouped into segments based on common demographics, needs, or desires. A business model can serve one customer segment or many similar customer segments. If customer segments differ significantly, they can each have their own unique business model to create value for the utility. There are two key steps for the customer segment block:

(1) Identify your customers and their needs.

(2) Segment your customers once you understand their needs.

Task 1: Know the customers in your service territory

When generating new business models, customers are key. It is essential to understand your customer and their needs. Begin by conducting market research in your specific service territory. This research can be gathered by an outside firm, from a survey connected through online billing, or through surveys on physical bills. It is important to gather demographic information, needs, values, and wants. Table 9 lists potential data for each category; it is intended to be illustrative but not exhaustive. It is important to collect as much data as possible to better inform future customer segmentation. Whenever possible, gather research in your specific territory and not general market information about electricity users. The more tailored your customer data is, the better value propositions you can offer your customers.

Table 9: Customer Segment Data

Demographics	Needs/Jobs	Values	Desires
Age	Heat/Cool Home	Being economical	Tech savvy
Household Income	Charge EV	Being efficient	Look cool
Education Level	Use the internet	Caring for the environment	Feel safe
Dwelling Type (i.e. apartment, home, etc.)	Complete household chores/tasks		Be connected
Average electric bill	Cook meals		

Task 2: Segment, segment, segment

Once sufficient customer data is collected, the next step is to segment customers based on common demographics, needs, and attributes. The electricity industry already has common segments that are used by most electricity providers (i.e. residential, small/medium business, large business/industrial, governments and institutions, agricultural), but with more detailed information about consumers, the current segments could be further subdivided. For example, the Smart Grid Consumer Collaborative has been conducting market research on electricity users since 2011 and has created five unique subdivisions inside the residential electric utility segment [123]. **Table 10** showcases each SGCC residential subdivision, their common attributes and what percentage of respondents each division is made up of.

Table 10: SGCC Residential Segmentation Demographics [123]

Residential Segment	Demographics
Green Champions 30%	• Youngest, and higher than average income, despite youth • More likely than most to live in an apartment, but their bill is still relatively high • College educated, working, and living in suburban areas • Early adopters of technology
Savings Seekers 20%	• Many younger than 35; few older than 65 • Lowest income; highest percentage of low-income households (43%) • Three quarters live in single family homes • Average electric bill
Status Quo 18%	• Relatively older age, many retirees • Smaller households • Middle income • Lower than average electric bill • Know little about energy efficiency, and don't think it's important
Technology Cautious 17%	• Relatively older age, retired, few people in household • Second lowest segment in average income • Lower than average electric bill • Knowledgeable about energy efficiency
Movers and Shakers 15%	• Working, college educated • Highest average bill • Highest income • Higher concentration on Pacific Coast, more likely suburban than most • High level of energy efficiency knowledge

These subdivisions could easily be applied to most utilities by adjusting the percent representation through surveying your own territory. If these subdivisions aren't appropriate, a unique set could be created based on the demographics and behaviors of your customers.

A similar segmentation could be done for business and industrial customers as well. For example, businesses that are budget conscious, interested in having a certain percentage of their load met by renewable energy or interested in reduced emissions could be placed in their own segment. Major businesses and retailers like Google [124] and Walmart [125] have already begun requesting such services. These businesses could easily represent unique subdivisions within the business and industrial segments. The possibilities are wide but dependent on the needs and desires of your customers.

It is important to segment as much as possible because breaking down the market will allow electric utilities to better target customers. Therefore, customer segmentation is necessary to fully investigate the product offerings and value streams. The more segments that can be created, the more value streams that will be possible. Not every customer segment identified has to be served, but it does provide the utility with options. Once customer segments have been identified and appropriate value propositions created, then the segments can be prioritized based on a value or a utility identified set of goals.

Takeaway

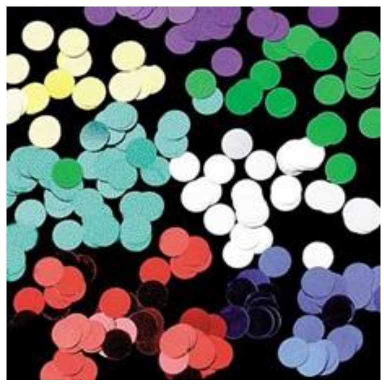
Know your customers intimately and segment them where appropriate to create the maximum number of value streams.

Essential Questions

Who are our customers?

How can they be segmented?

Separate each customer segment and list their needs

Conduct Market Research	Segment	List/Organize
		

4.4.3 Utility Needs

The Utility Needs block focuses on the jobs the utility needs to accomplish outside of their customers. The purpose of this block is to think about influences on the utility not directly coming from customers.

Consideration One: Outside Influence

Most electric utilities have to obey/oblige regulatory agencies, governing boards, investors and legislators. Afore mentioned groups represent influence that must be accounted for in the business model. For example, some regulatory bodies and legislators have put in place requirements on a minimum amount of renewable energy generated, a maximum amount of emissions generated or demands for increased electricity efficiency. These requirements are not directly from the consumer but have a large influence on the way electric utilities conduct business. It is important to have these requirements in mind when creating the value proposition to ensure the utility will be profitable.

Consideration 2: Business Decisions

This category is for major considerations coming directly from the utility. Either internal goals the utility is trying to achieve or major investments the utility is undertaking. The goal is to capture elements that would never directly be asked for by consumers but are essential to operation. For example, planning for new transmission or converting a plant from coal to natural gas.

Table 11: Potential Utility Needs

Outside Influence	Business Decisions
Meet RPS standards	Update power plants to MACT
Meet emission standards	Train new younger employees
Meet efficiency standards	Plan for new distribution lines
Increase shareholder return	

Takeaway

It is important to identify the needs of the utility and ensure they are incorporated into the value proposition. The goal being to match customer needs with utility needs to create value or at the very least, offset utility needs with value created from the customer.

Essential Questions

What are key considerations coming from our governing/oversight body?

Are there any major goals the utility is trying to accomplish?

e.g. safety, reliability, affordability, etc.

4.4.4 Value Proposition

The Value Proposition block describes products and services that will be used to meet customer and utility needs. Once having identified who your customers are, what they desire, and your own needs, you can then brainstorm methods to satisfy these needs.

Task 1: Align with the most important customer jobs

Take the list of needs/jobs and desires for each customer segment and rank them. Once the list is ranked, begin thinking of appropriate products and services for the highest ranking items. After you have listed products and services for the most important priorities, consider the lower ranking priorities as well. List as many 'product and services' offerings as you can. You will revise and refine the list later, but it is good to begin with as many options as possible. Each value proposition is a potential revenue stream.

Task 2: Fulfill needs and wants

Think outside the box and don't just focus on function jobs (i.e. heating a home, cooking meals) that are easy to align products and services with. Think of innovative ways to address consumers social and emotional needs as well (i.e. being tech savvy, feeling connected, being efficient). For example, consumers that have an interest in being efficient could be interested in an energy efficiency audit provided by the utility.

Task 3: Look for alignment between utility needs and customer needs

Once you have generated a list of products and services for each customer segment, compare that to the list of utility needs. Look for overlap. For example, if you have identified a residential customer subdivision and a business subdivision interested in purchasing renewable energy, how can that be aligned with a mandate from regulatory body to produce 20% renewables by 2020.

Takeaway

Address customers most important needs/desires and find a way (when possible) to align utility needs with customer value propositions.

Essential Questions:

Which jobs/desires does each customer segment value most?
What products and services can we create to meet those needs?
Are there lower priority jobs/desires that we can also serve?
Is there a way a value proposition designed for customer needs can also fulfill utility needs?

4.4.5 Business Platform

Now that the “who” (customer segments) and “what” (value propositions) have been identified, it is time to think about how you will deliver the various products and services from the value proposition. The Business Platform block describes the service platforms electric utilities can use to carry out their value propositions.

Task 1: Nuances to traditional service platforms

Electric utilities primarily serve consumers through rate plans and a few additional side services like energy audits or weatherization programs. There is potential to offer new rate plans to consumers like reliability levels, time of use pricing, critical peak pricing, etc. Some of those plans have been available to certain customers segments for a while, but given the rise of new technology, they could potentially be offered to all customer segments.

In addition to new rate plans, there are opportunities to provide new services to customers if they express a desire for those services. Table 12 lists a variety of new services the utility could offer, like providing financing for customer installed solar panels.

Task 2: New service platforms

In addition to the traditional rate and service platforms, there are new avenues utilities can pursue to fulfill customers' needs/desires. As the demand for customer sited distributed generation grows, the utility could provide installation of those sources and then maintenance and technical support further down the line. The possibilities for new service platforms is endless and will be heavily influenced by customer needs/desires. That's why it is important to thoroughly complete the Customer Segmentation block to understand what customers desire so that the utility can deliver and produce value.

Table 12: Potential Business Platforms and Services

Service	Electricity Rate Plans	Hardware	Technical Support and Maintenance	Ancillary Services
Weatherization Tips	Standard Service	Install solar panels	Solar panel maintenance and support	Voltage control
Energy Efficiency Audits	Ultra-Reliability	Install microgrids	Microgrid Physical Support (i.e. fixing hardware)	Load following
Home Security	Renewable Generation	Install backup/storm generation	Backup generation support	System protection
Financing for self-installed dist. generation **[126]**	Reduced Emissions	Install EV chargers	Microgrid Technical Support (i.e. controls/interface to grid)	Spinning reserves
Facilitator to 3rd party **[127]**	Budget/Flat Bill	Install battery storage		Frequency control
Community Solar	Time of Use			

Takeaway

There are many ways to serve customers. Think creatively about fulfilling value propositions, whether that is expanding traditional service platforms or branching into new ones.

Essential Questions

What are new rate plans we can offer to meet the value proposition?

What are new service areas we can branch into to meet new value propositions?

4.4.6 Implementation

The Implementation layer of the Electric Utility Business Model Framework is composed of three components that focus on the tangible components needed to carry out each value proposition on the appropriate business platform.

Resources

The Resources block describes essential resources needed to carry out the value proposition. For utilities, that could include fuel costs, plants, personnel, hardware, new technology, etc.

Activities

The Activities block describes essential activities needed to carry out the value proposition on each platform. That could include generating electricity, providing technical support, installing hardware, etc.

Partners

The Partners block describes essential partnerships needed to carry out the value proposition. This could include manufacturers, third party service providers, finance companies, etc.

Essential Questions:

What key resources do our value propositions require?

What key activities are needed to carry out each value proposition?

Who are our key partners to execute our value propositions?

Who are our key suppliers?

Which key resources are acquiring from partners?

Which key activities do partners perform?

4.4.7 Economics

The Economics layer of the Electric Utility Business Model Framework describes the costs and revenues associated with each value proposition.

Costs

The Cost block describes all major costs incurred to operate a business model. This would include fixed costs, variable costs, current costs, and new costs.

Revenue

The Revenue block represents the cash you can generate from each customer segment. Each value proposition represents a potential revenue stream. What value do customers see in each value proposition? What pricing mechanism should the utility use to collect that value from customers?

Essential Questions

What are the most important costs inherent to the business model?
Which key resources are most expensive?
Which key activities are most expensive?
What are the costs associated with your partnerships?
How do new value propositions change current costs?
What new costs do new value propositions create?
For what value are our customers really willing to pay?
For what do they currently pay?
How are they currently paying?

How would they prefer to pay?

How much does each Revenue Stream contribute to overall revenues?

What pricing mechanism should we use for each value proposition? (ex. volume dependent, fixed price, per service)

4.5 Conclusions

The goal of this chapter was to create a framework to help electric utilities develop new business models to thrive in the changing electricity industry landscape. This work does not seek to recommend a single business model but instead develop a thought framework to help utilities generate custom solutions for their individual needs. To achieve this feat, business ontology literature and proposed electric utility business models were reviewed to provide background for the EUBMF. A deep study and critique of current electric utility business models also helped to inform the EUBMF. From reviewing this material, a framework was created for electric utilities from a generic business model framework. The EUBMF is composed of nine unique blocks, each customized to focus on electric utilities. As a complete model, it will help utilizes walk through the business model creation process and generate new or improved business models specific to their needs and the current market.

CHAPTER 5

ELECTRIC UTILITY BUSINESS MODEL FINANCIAL TOOL

5.1 Motivation

The purpose of this work is to create an electric utility business model financial tool (EUBMT) to assist utilities in updating their business model as discussed in Recommendation 6 in Section 2.4.6. The intent of this work is to use a mathematical model to predict the financial implications of new business models generated from the EUBMF. The EUBMT is an Excel based spreadsheet tool that will enable utilities to assess the financial outcomes of new business models. The tool utilizes Excel to be more accessible to the business community. The EUBMT is intended to be used for policy and planning purposes.

5.2 Overview

The EUBMT expands upon the Georgia Tech – Demand Side Management tool (GT-DSM) [128]. The GT-DSM tool evaluates the financial impact of various energy efficiency business models for utilities in the Southeast. The EUBMT incorporates a broader suite of utility products and services discussed in Section 4. It draws on publically available data from utility integrated resource plans, annual reports, public service commission (PSC) filings, utility securities and exchange commissions (SEC) filings, data available on utility websites and utility projects/pilots.

The EUBMT is split into two sections; one focusing on customers and the other focusing on the electric utility. Inside each section, there are corresponding inputs and sub modules to reflect the business platforms discussed in Section 4.4.5.

The input components of the EUBMT include the basic customer and utility input data from the GT-DSM, program data related to the business models being studied, and scenario data. The sub-modules will focus on the Service, Hardware, and Technical Support/Maintenance platforms. The Electricity Rate and Ancillary Services platforms were left out because electric utilities already have the capability to simulate the financial impacts of new rate plans and ancillary services. A block diagram of the tool overview is shown in Figure 25.

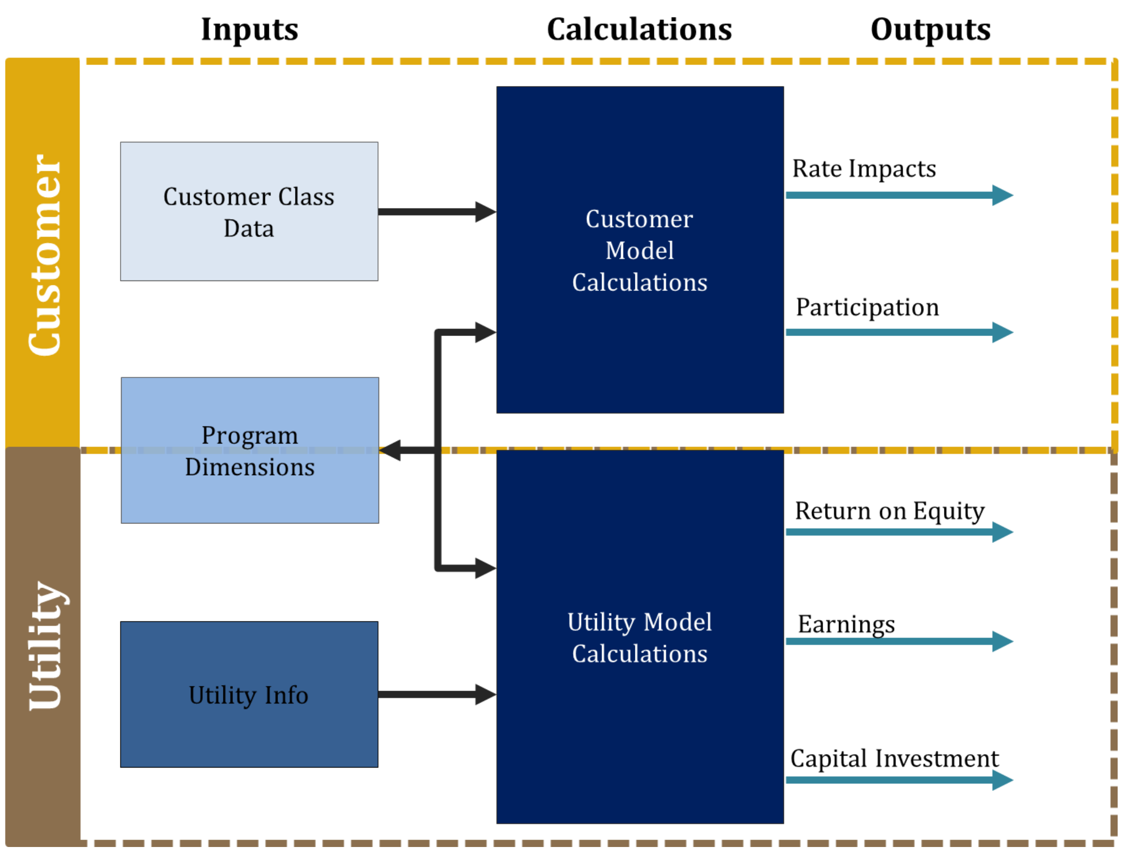


Figure 25: EUBMT Block Diagram

The Customer Sector focuses on how customers will be affected by programs implemented using the new business platforms. Outputs will include the effect on consumer rates ad utility bills. The Utility Sector focuses on how the electric utility will be affected by the new programs implemented. Outputs will include utility earnings, capital investments, return on equity, and economic value added.

5.3 Inputs

5.3.1 Customer Section

Base Information

Residential Customers Residential Iteration Base Inputs			
Name		**Value**	**Units**
Year Zero - Y0		2013	year
Residential Customer Info:			
Sales			
Sales in Y0		25,700,000,000	kWh
Avg Changs in Sales		1.40%	%/year
Demand in Y0		4,889,650	kW
Average Change in Demand		1.40%	%/year
Annual Load Factor		60.00%	%
Customers in Y0		2,062,040	households
Avg. change in number of customers		1.02%	%
Res. Rate Impact Module Fundamental Sub-Module			
Name		*Value*	*Units*
Rates			
Avg Rate in Y0	$	0.12	$/kWh
Variable Rate			
Use Utility RR for Variable Rate?		FALSE	boolean
Avg Variable Cost Rate in Y0	$	0.04	$/kWh
Avg Change in Energy Cost		6.5%	%/year
Fixed Rate			
Use Utility RR for Fixed Rate?		FALSE	boolean
Rate class's share of fixed cost		62.2%	%

Figure 26: Customer Section – Base Information Sub-Module

The first module for the customer section is the Base Inputs. The Base Inputs sub-module is repeated for the residential consumer and commercial consumers. It aggregates basic data about the customer class related to the number of sales that class has at the beginning of the program, the number of customers, and the rates each customer class pays. These inputs are taken directly from the GT-DSM and detailed information about the inputs can be found in the GT-DSM user manual [128]. By default, the sub-module is filled with data from various south eastern utilities in the United States. This data should be updated to match the utility being simulated or utilizing this tool.

Service Platform: Non-Recurring (NR) Service

Service Program			
Non-Recurring Services			
NR Costs			
Program cost per household	$	10	$
Average change in program costs		5.0%	%
Admin costs	$	2	$
Average change in admin costs		0.0%	%
NR Revenues			
Price per service	$	12	$
Average change in price		1.0%	%
NR Parameters			
Program Lifetime		5	years
Particpation in Y1		10	customers
Average change in participation		1%	%
Change in electricity demand/system		-	kW
Energy Savings/system		-	kWh

Figure 27: Customer Section – Service Platform: Non-Recurring

The second module in the Customer Section is the Services Platform. The services platform is split into two sections. The first section is for programs that are non-recurring, like an energy efficiency audit. The Non-Recurring section is split into three segments: costs, revenues, and parameters.

Costs

Program Costs: All costs associated with the program for employees and equipment

Administrative Costs: All costs related to executing the program, such as staff and marketing

% Change: Each cost comes with a percent change to adjust costs over the lifetime of the program.

<u>Revenues</u>

Price per service: This is the price the customer pays to receive the service.

*% change in pric*e: The price per service comes with a percent change to adjust price over the lifetime of the program.

<u>Parameters</u>

Program Lifetime: This is where the duration of the program is specified

Participation in Y1: Expected participation in the first year

% Change in Participation: Expected growth in participation each year

Service Platform: Recurring (RR) Service

Service Program			
Non-Recurring Services			
Recurring Services			
Costs			
Admistrative costs	$	20,000	$
Average change in admin. costs		0.5%	%
Upfront hardware/system investmemt	~~$~~	~~-~~	$
Install costs	~~$~~	~~-~~	"
Incentive/pay out costs	~~$~~	~~-~~	"
Use calculated costs?		TRUE	boolean
Upfront hardware/system investmemt (per household	$	2,250	$
Install Costs (per household)	$	-	"
Average incentive/pay out costs (annually per househo	$	25	$
Ammortized Cost Recovery			
Over measure lifetime		TRUE	boolean
Over set years		~~10~~	years
Revenue			
Hardware/System Fees (per household)	$	850.00	$
Monthly Program Charge (per household)	$	-	"
Grants/Federal-State-Local Incentives	$	5,000,000	"
Energy Sales (per system/household)		$48	
R Parameters			
Program Lifetime		25	years
Particpation in Y1		20,620	customer
Average change in participation		1.5%	%

Figure 28: Customer Section – Service Platform: Recurring

The second section for the Services Platform is for programs that are recurring, like a home security program. The Recurring section is split into the same three segments: costs, revenues, and parameters.

Costs

Administrative Costs: All costs related to execute the program like staff and marketing

% Change in admin costs: The admin costs can be adjusted with a percent change to adjust costs over the lifetime of the program.

The costs below can be inputted in two ways. The user can input overall annual costs or per household costs and allow the tool to calculate the yearly costs. To utilize the per-household costs *"Use calculated costs?"* should be marked true.

Upfront hardware/system costs: All costs associated with purchasing hardware and software for the program

Install Costs: System installation costs

Incentive/pay out costs: Costs associated with paying out incentives to customers for participating in the program

This program allows for costs to be recovered over the lifetime of the program or over a specified number of years. To recover costs over the lifetime of the program *"over measure lifetime"* should be marked true, otherwise it should be marked false and the desired number of years to recover expenses should be indicated at *"over set years".*

<u>Revenues</u>

Hardware/System Fees: Price the customer pays for hardware and system installation

Monthly Program Charge (per household): This is the price the customer pays to receive the service per month

Grants/Federal-State-Local Incentives: Money obtained from outside sources that are used to finance the program

Energy Sales: Revenue the utility receives from selling energy produced from the program.

<u>Parameters</u>

Program Lifetime: This is where the duration of the program is specified

Participation in Y1: Expected participation in the first year

% Change in Participation: Expected growth in participation each year

Hardware Platform

Hardware Program			
Hardware Revenues			
Hardware price per customer	$	9,000	$
Average change in hardware price		0.25%	%
Average labor price per customer	$	2,000	$
Average change in labor price		0.25%	%
Software price per customer	$	-	$
Average change in software price		0%	%
Hardware Costs			
Hardware costs per customer	$	8,000	$
Average change in hw costs		0.25%	%
Labor costs per customer	$	1,085	$
Average change in labor costs		0.25%	%
Admin costs	$	20,000	$
Average change in admin costs		1.02%	%
Hardware Parameters			
Program Lifetime		25	years
Particpation in Y1		2,000	customers
Average change in participation		1.00%	%

Figure 29: Customer Section – Hardware Platform

The third module in the Customer Section is the Hardware Platform. This platform is for hardware installation programs, like installing backup generation. It is also split into three segments: revenues, costs, and parameters.

Revenues

Hardware Price per service: This is the price the customer pays for the installed hardware.

Labor Price per service: This is the price the customer pays for labor associated with installing the hardware or software.

Software Price per service: This is the price the customer pays for the software to accompany the program.

*% change in pric*e: The prices come with a percent change to adjust prices over the lifetime of the program.

Costs

Hardware Costs: The cost the utility pays for hardware associated with the program.

Labor Costs: The cost the utility pays for labor associated with the program.

Administrative Costs: All costs related to execute the program like staff and marketing.

% Change: Each cost comes with a percent change to adjust costs over the lifetime of the program.

Parameters

Program Lifetime: This is where the duration of the program is specified

Participation in Y1: Expected participation in the first year

% Change in Participation: Expected growth in participation each year

Technical Support and Maintenance (TSM) Platform

Technical Support and Maintenance			
TSM Costs			
Annual hardware costs in Y0	$	20,000.00	$
Average change in hardware costs		0.5%	%
Annual labor costs in Y0	$	10,000.00	$
Average change in labor costs		0.5%	%
Admin costs in Y0	$	12,000.00	$
Average change in admin costs		1.02%	%
TSM Revenues			
Annual service charge in Y0	$	50,000	$
Average change in service charge		1%	%
Average fees and extra costs in Y0	$	8,000	$
Average change in fees/costs		1%	%
TSM Parameters			
Program Lifetime		25	years
Particpation in Y1		400	customers
Average change in participation		0.2%	%

Figure 30: Customer Section – Technical Support and Maintenance Platform

The fourth module in the Customer Section is the Technical Support and Maintenance Platform. This platform complements the hardware platform and is meant to provide support to utility or customer installed physical systems, like helping to maintain a backup generator. It is split into three segments: revenues, costs, and parameters.

Costs

Hardware Costs: The cost the utility pays for replacement or upgrades hardware associated with the program.

Labor Costs: The cost the utility pays for labor associated with the program.

Administrative Costs: All costs related to execute the program like staff and marketing.

% Change: Each cost comes with a percent change to adjust costs over the lifetime of the program.

Revenues

Service charge: Annual expected service charges in the first year.

Fees and Extra costs: Annual expected fees and costs from upgraded hardware and software associated with the maintenance program.

% Change: The charges/fess come with a percent change to adjust revenues over the lifetime of the program.

Parameters

Program Lifetime: This is where the duration of the program is specified

Participation in Y1: Expected participation in the first year

% Change in Participation: Expected growth in participation each year

5.3.2 Utility Section

Base Inputs

Utility Sector		
Fundamental Module		
Name	*Value*	*Units*
Rate Base		
Rate Base in Y0	$ 19,475	$ (million)
Annual Capital Expenditures in Y0	$ 1,315	"
Escalation rate of Annual Capital Expenditures	6.5%	%
Costs of Production		
On-peak variable rate	$54.51	$/MW
Off-peak variable rate	$37.53	"
Escalation rate for costs of peak production	~~7.00%~~	% (annual)
Escalation rate for costs of off-peak production	~~7.00%~~	"
Capital Structure		
% Equity	54.0%	%
target ROE	11.15%	"
% Debt	46.0%	"
Cost of Debt	4.2%	"
Operations & Maintenance costs		
O&M costs in year 0	$ 500	$ (million)
Annual escalation rate for O&M costs	1.0%	%
Taxation		
Effective income tax rate	36.7%	%
Depreciation		
Book Asset Depreciation Rate	3.2%	%

Figure 31: Utility Section – Fundamental Module

The module for the utility section is the Fundamental Module. This sub-module aggregates basic utility data such as, the rate base, wholesale electricity rates, debt, and tax information. These inputs are also taken directly from the GT-DSM and detailed information about the inputs can be found in the GT-DSM user manual [128]. By default, the sub-module is filled with data from various south eastern utilities in the United States. This data should be updated to match the utility being simulated or utilizing this tool.

5.4 Calculations

5.4.1 Customer Calculations

The Customer Sector is split into six parts: Rate Impact Module, the Service Platform with Non-Recurring and Recurring portions, the Hardware Platform, the Technical Support and Maintenance Platform, and the Bill Impact Module. Each of these parts is repeated for residential, and commercial and industrial customers.

Rate Impact Module

The rate impact module calculates the change in rates for each customer class as well as tracking the change in the electricity sales. This sub-module is borrowed directly from the GT-DSM and detailed information about the calculations can be found in the user manual [128]. The rates can be calculated in one of two ways. In the first method, the rate in Y0 is specified and then future rates are calculated based on a simple growth calculation as seen in Equation 1.

$$\boldsymbol{x_{t=}x_{t-1}} * (\mathbf{1} + \%\ \boldsymbol{Change}) \quad \mathbf{(1)}$$

where t is the year.

In the second method, the rate can be calculated as a direct product of projected costs and sales as demonstrated by Equation 2.

$$\boldsymbol{rate_t} = \frac{\boldsymbol{cost_t}}{\boldsymbol{sales_t}} \qquad \mathbf{(2)}$$

Service Platform: Non-Recurring Program

The Non-Recurring program sub-module calculates the number of customers participating in the program, total costs, and revenues generated by the program. To calculate the number of participants, the model calculates how many new participants there are for a given year using Equation 3 and then sums all previous years as seen in Equation 4.

$$\boldsymbol{New\ Participants_t} = \boldsymbol{Participants_{t-1}} * (\mathbf{1} + \%\ \boldsymbol{Change\ in\ Participation}) \quad (3)$$

$$\boldsymbol{Total\ Participants} = \sum_{t=0}^{x} \boldsymbol{New\ Participants_t} \quad (4)$$

To calculate total costs, admin costs and program costs are summed. Admin costs in the first year are calculated using Equation 5 and then future admin costs are calculated using the standard growth formula in Equation 1.

$$\boldsymbol{Admin\ Costs_{t=0}} = \frac{\boldsymbol{Admin\ Costs}}{\boldsymbol{Program\ Lifetime}} \quad (5)$$

To calculate yearly program costs, Equation 6 is used. Equation 1 is used to calculate the appropriate yearly program cost per customer.

$$\boldsymbol{Total\ Program\ Costs_t} = \boldsymbol{Program\ Cost_t} * \boldsymbol{Total\ Participants_t} \quad (6)$$

To calculate yearly revenue, Equation 7 is used. Equation 1 is used to calculate the appropriate yearly price per customer.

$$\boldsymbol{Total\ Program\ Revenues_t} = \boldsymbol{Price_t} * \boldsymbol{Total\ Participants_t} \quad (7)$$

Service Platform: Recurring Program

The Recurring program sub-module calculates the number of customers participating in the program, total costs, and revenues generated by the program. To calculate the number of participants, the model calculates how many new participants there are for a given year using Equation 3 and then sums all previous years as seen in Equation 4.

To calculate total costs, all cost subcategories are summed. Admin costs in the first year are calculated using Equation 5 and then future admin costs are calculated using the standard growth formula in Equation 1. There are three ways to calculate the hardware, install, and incentive costs. If the user has marked *"Use calculated costs?"* as true then Equation 8 should be used. If *"Use calculated costs?"* is false then the customer has to decide whether they want to recoup costs over the entire life of the program or over a set number of years. If the user marks "*over measure lifetime"* true then Equation 9 would be used, otherwise Equation 10 would be used.

$$\boldsymbol{Costs_t = Cost_{per\ household} * Total\ Participants_t} \quad (8)$$

$$\boldsymbol{Costs_t = \frac{Total\ Costs}{Program\ Lifetime}} \quad (9)$$

$$\boldsymbol{Costs_t = \frac{Total\ Costs}{Set\ Years}} \quad (10)$$

To calculate total revenues, all revenue sub-categories are summed. The hardware, monthly charge and energy sales revenues are calculated using Equation 11. The Grants/Incentives revenues are calculated using Equation 12.

$$\boldsymbol{Revenue_t = Price/Charge_t * Total\ Participants_t} \quad (11)$$

$$\boldsymbol{Revenue_t = \frac{Total\ Revenue}{Program\ Lifetime}} \quad (12)$$

Hardware Platform

The Hardware platform sub-module calculates the number of customers participating in the program, total costs, and revenues generated by the program. To calculate the number of participants, the model calculates how many new participants there are for a given year using Equation 3, and then sums all previous years as seen in Equation 4.

To calculate total costs, all three cost sub-categories are summed. Admin costs in the first year are calculated using Equation 5 and then future admin costs are calculated using the standard growth formula in Equation 1. The Hardware and Labor costs are calculated using the same process. To calculate those costs, Equation 6 is used and then Equation 1 is used to calculate the appropriate yearly cost per customer.

To calculate total revenues, all revenue sub-categories are summed. The hardware, labor, and software fees are calculated using Equation 11.

Technical Support and Maintenance Platform

The TSM platform sub-module calculates the number of customers participating in the program, total costs, and revenues generated by the program. To calculate the number of participants, the model calculates how many new participants there are for a given year using Equation 3 and then sums all previous years as seen in Equation 4.

To calculate total costs, all three cost sub-categories are summed. Admin costs in the first year are calculated using Equation 5 and then future admin costs are calculated using the standard growth formula in Equation 1. The Hardware and Labor costs are calculated using the same process. To calculate those costs, Equation 6 is used and then Equation 1 is used to calculate the appropriate yearly cost per customer.

To calculate total revenues, both revenue sub-categories are summed. The service charge and fee revenues are calculated using the standard growth formula in Equation 1.

Bill Impact Module

The Bill Impact module is split into five sections. The first section calculates the average usage and electricity bill for the average customer. The remaining four sections calculates the average bill for each service platform and how that bill differs, percent wise, from the average customers bill. The base calculation for average usage and average bill are shown in Equations 13 and 14 respectively.

$$\boldsymbol{Average\ Usage_t} = \frac{\boldsymbol{Electrcity\ Sales_t}}{\boldsymbol{Customers_t}} \quad (13)$$

$$\boldsymbol{Average\ Bill_t} = \frac{\boldsymbol{Average\ Usage_t}}{\boldsymbol{12}} * \boldsymbol{Base\ Rate_t} \quad (14)$$

For the Service Platform: Non-Recurring the avg. participant bill is calculated using Equation 15. Equation 16 is used to calculate the percent difference between the average consumer and a participant of the program.

$$\boldsymbol{Average\ Service: NR\ Bill_t} = \frac{\boldsymbol{Average\ Usage_t}}{\boldsymbol{12}} * \boldsymbol{Base\ Rate_t} + \boldsymbol{Program\ Costs_t} \quad (15)$$

$$\%\ \boldsymbol{Difference} = \frac{\boldsymbol{Base\ Bill - Particpant\ Bill}}{\boldsymbol{Participant\ Bill}} \quad (16)$$

For the Service Platform: Recurring the avg. participant bill is calculated using Equation 17.

$$\boldsymbol{Average\ Service: RR\ Bill_t} = \frac{\boldsymbol{Average\ Usage_t}}{\boldsymbol{12}} * \boldsymbol{Base\ Rate_t} - \frac{\boldsymbol{Incentive\ Costs_t}}{\boldsymbol{12}} + \boldsymbol{Monthly\ Charge} \quad (17)$$

The tool assumes the average monthly bill for the Hardware and TSM platforms will remain the same because we assume the expenses for these programs are handled through a separate billing system. This assumption was made because many of the hardware installations are high costs items that would be paid all up front at once or paid over time using a loan.

5.4.2 Utility Calculations

The Utility Calculation sector is split into four sections. The first section calculates electricity sales, utility fixed costs, and utility variable costs. These calculations were borrowed directly from the GT-DSM and detailed information about the calculations can be found in the user manual [128]. The remaining three sections are repeated for each platform studied in this tool. They include Capital Investment Costs, After-Tax Earnings, and Return on Capital Employed. The appropriate equations for each are shown below in Equations 18 – 20.

$$\boldsymbol{Capital\ Investment\ Costs_t = Total\ Costs_t} \qquad (18)$$

$$\boldsymbol{Earnings_t = (Total\ Revenues_t - Total\ Costs_t) * (1 - Tax\ Rate)} \qquad (19)$$

$$\boldsymbol{Return\ on\ Capital\ Employed_t = \frac{Total\ Revenues_t - Total\ Costs_t}{Total\ Costs_t}} \qquad (20)$$

5.5 Outputs

5.5.1 Customer Outputs

There are two outputs for the Customer Sector. Each output is replicated for each platform studied in this tool. The first output is the “Average Difference in Bill between Participants and Non-Participants from the Bill Impact sub-module. If the values in the graph are negative then the program participants have a lower bill than non-participants. The opposite is true if the values in the graph are positive.

Average Difference in Bill between Participants and Non-participants

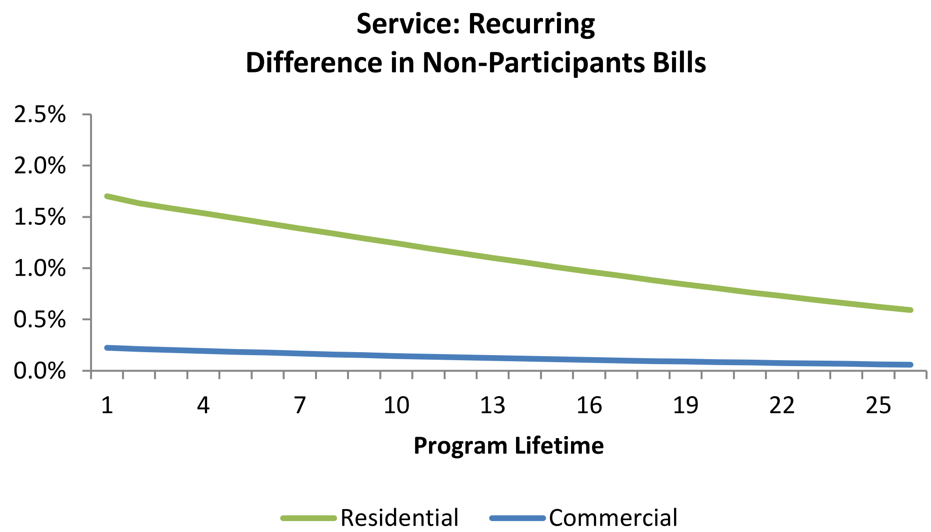


Figure 32: Average Difference in Bills between Participants and Non-participants

Participation

The second output of the Customer Sector is the participation graph. This graph shows the projections of the number of customers, number of participants and non-participants.

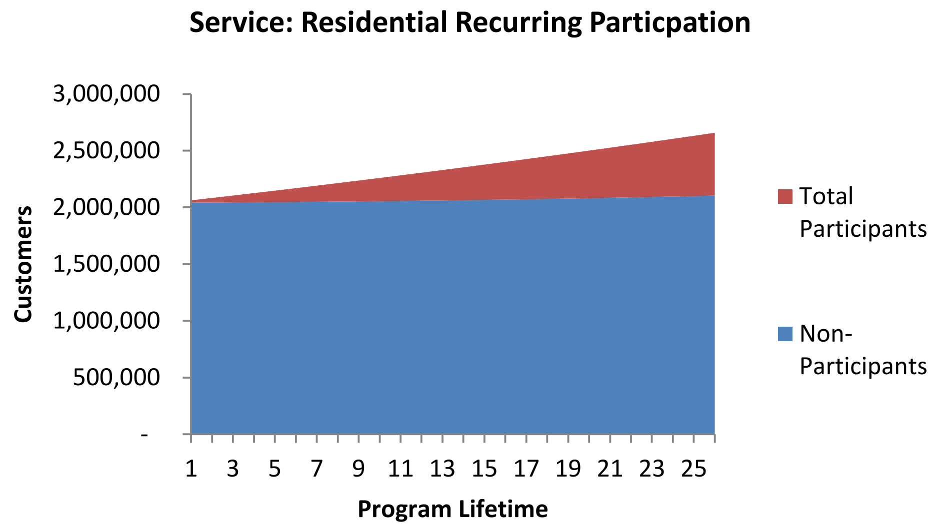


Figure 33: Participation Output Graph

5.5.2 Utility Outputs

There are three outputs for the Utility Sector. Each output is replicated for each platform studied in this tool.

Investment Costs

The first output is the Investment Costs graph. This graph shows the total utility investment cost for each year of the program, including both residential and commercial costs.

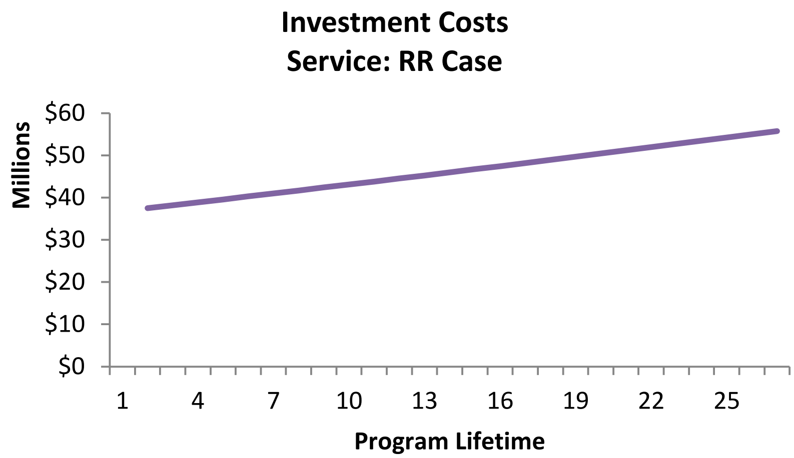


Figure 34: Investment Costs Output Graph

After-Tax Earnings

The second output is the After-Tax Earnings graph. This output displays the profit the utility has earned from the program after taxes for each year of the program.

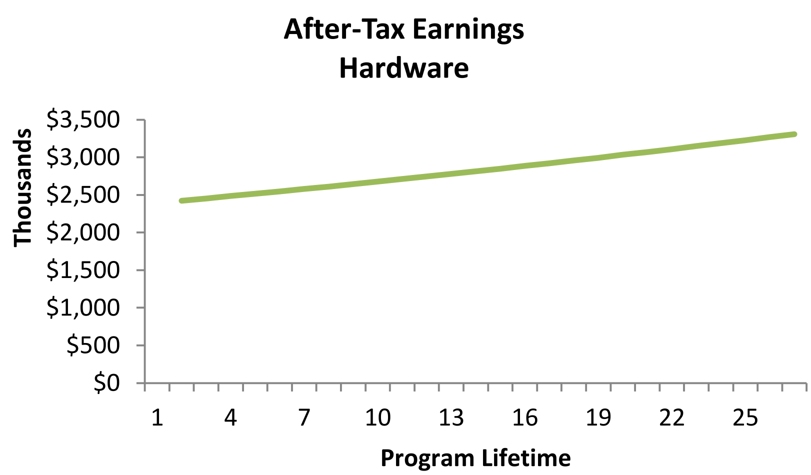


Figure 35: After-Tax Earnings Output Graph

Return on Capital Employed

The third output is the Return on Capital Employed. It indicated how efficiently capital is being used; the higher the return, the more efficient the use of capital.

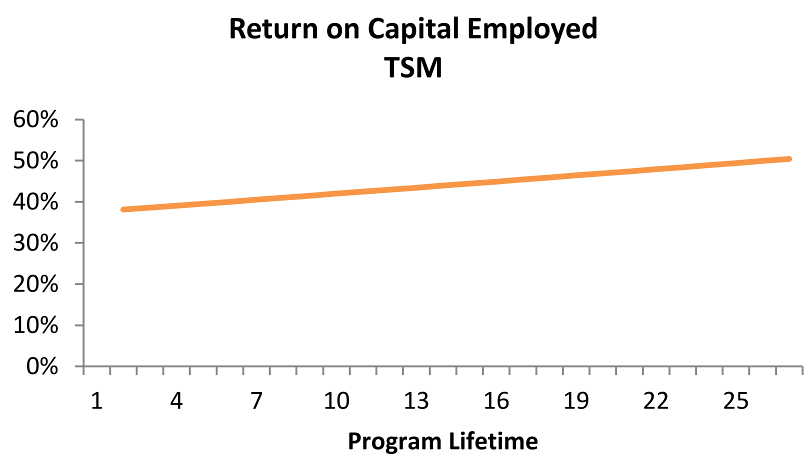


Figure 36: Return on Capital Employed Output Graph

5.6 Conclusions

The goal of this chapter was to develop a tool that could predict the financial implications of new business models generated from the EUBMF. The model is split into two main sections; one focused on consumers and the other focused on utilities. The customer section is split between residential and commercial and industrial customers. The tool collects basic data from the electric utility about itself and its consumers; then collects data about the program/service being executed, and then outputs the potential customer bill impacts, and effect on utility earnings and return on capital.

CHAPTER 6

CONCLUSION

The U.S. electricity industry is in a season of change. There are a variety of opportunities and challenges facing the industry. Issues include aging infrastructure, cyber security concerns, calls for greater sustainability, and a rising demand for renewables and distributed generation. The Smart Grid is developing to meet the afore mentioned challenges and opportunities. The objective of this dissertation was to study and understand U.S. Smart Grid progress, identify problems in Smart Grid development, and create data-driven tools to help utilities and regulators address those problems. Three tools were presented in this research (1) a Smart Grid development metric and (2) an electric utility business model framework (EUBMF) and (3) an electric utility business model financial tool (EUBMT).

In the first segment of this dissertation, U.S. Smart Grid progress was studied and assessed based on a detailed policy review and by gathering feedback directly from industry stakeholders. In that assessment, eight key areas were studied and seven recommendations were proposed to guide the electric utility industry. Those recommendations inspired the creation of three tools to address critical issues.

The first tool created was the Smart grid Assessment Metric system. The goal of the tool was create a system of metrics to measure the progress towards achieving a Smart Grid on the scale of nations or states. The tool consists of six goals with 12 corresponding metrics to measure Smart Grid progress. The tool utilizes both visual and numeric indicators to measure Smart Grid progress. The Smart Grid metric system contributes to the literature by utilizing publically available data, adding new metrics, being adaptable to many countries and utilizing both visual and numeric indicators. The Smart Grid assessment done as a case study after the metric system was developed also offered contributions to the literature. The metric case study revealed that the countries with the most Smart Grid progress employed different tactics revealing that there are many ways to achieve a Smart Grid. The case study also revealed that no country studied received more than half of the possible spider plot area, meaning there is still a lot of room for improvement towards achieving a Smart Grid.

The second tool created was the Electric Utility Business Model Framework. The intent of the EUBMF is to enable utilities to assess their current business model and explore/develop new business models. Most of the electric utility business models in the literature are singular ideas; the EUBMF differs and makes a contribution by creating a framework to create business models. Each business model developed will be unique to the electric utility going through the development process. The EUBMF consists of five layers. The first layer is the Assessment Layer, which is composed of the Customer Segment and Utility Needs blocks. This layer gathers necessary information about customer and utility needs that inform the rest of the business model. The second layer is composed of the Value Proposition block which analyzes how customer needs can be turned into products and services that the utility can deliver. The third layer consists of the Business Platform block which discusses how utilities can carry out the products and services generated in the second layer. The fourth layer is the Implementation layer which consists of the resource, activities, and partners blocks. This layer describes the tools needed to carry out the products and services generated from the value proposition. The fifth layer is the Economics layer which consists of the cost and revenues block. These blocks describe the financial impacts of deliver in the products and services.

The third tool created was the Electric Utility Business Model Finance Tool (EUBMT). The goal of the EUBMT is to test the financial implications of business models developed using the EUBMF. It focuses on the Service, Hardware, and Technical Support and Maintenance platforms. It is split into two major sections, one focused on consumers and the other focused on utilities. The utility inputs basic parameters about customer classes, energy usage, rates, and program data generated from the EUBMF. The EUBMT then outputs what effect the implemented program would have on customer bills, utility earnings, and the ROE of the implemented program.

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