



Original Article

The Energy Trilemma and the Smart Grid: Implications Beyond the United States

Jeannie Oliver and Benjamin Sovacool*

Abstract

This article argues that smart grid technologies enable policy-makers and communities to successfully manage enduring energy policy concerns. It defines what 'smart' energy technologies, grids and policies mean, and then evaluates how the smart grid can enable policy-makers to respond to an emerging energy 'trilemma'. Drawing on case studies from the United States, the article suggests that the automated communications enabled by smart grid technologies significantly benefit each dimension of the energy trilemma: economic, social and environmental. However, successful smart grid implementation requires smart communication beyond technology. Failure to engage with customers through targeted

communication, or to adequately address customers' privacy concerns, risks alienating customers, threatening the value of the smart grid investment. This article concludes that, with smart communication, both technical and human, the smart grid is an important step towards a sustainable energy future for stakeholders well beyond the United States.

Key words: smart grid, energy trilemma, energy security, sustainable development, communication

1. Introduction

Our nation's electric power infrastructure that has served us so well for so long—also known as 'the grid'—is rapidly running up against its limitations. Our lights may be on, but systemically, the risks associated with relying on an often overtaxed grid grow in size, scale and complexity every day. From national challenges like power system security to those global in nature such as climate change, our near-term agenda is formidable. Some might even say history-making.

(U.S. Department of Energy 2014a)

The National Academy of Engineering hailed the electric grid the greatest engineering achievement of the twentieth century (Wulf 2000). The U.S. Department of Energy describes it as 'the largest interconnected machine on Earth, so massively complex and inextricably linked to human involvement and endeavor that it has alternately (and appropriately) been called an ecosystem' (p. 5). Today, in practically every industrialised country in the world, the electric grid continues as the

* Vermont Law School, South Royalton, Vermont 05068, USA. Corresponding author: Benjamin Sovacool, email <sovacool@vt.edu>. The authors acknowledge the support of Vermont Law School's Institute for Energy and the Environment. They express particular gratitude to the Institute's Smart Grid Team, including project leader, Dr Kevin Jones, and research associates, Stephanie Gardener, Jonathan Hart, and Achyut Shrestha. This article draws on the Smart Grid Team's published and unpublished work, including in particular: Kevin B. Jones and David Zoppo, *A Smarter, Greener Grid: Forging Environmental Progress Through Smart Energy Technologies and Policies*, Praeger, Santa Barbara, CA 2014; and Hart, Jonathan (December 2013), *Smart Grid and a 25-Gigaton Reduction in GHG Emissions by 2050*, unpublished article.

foundation for economic development, but there is growing concern among policy-makers that the grid has failed to keep up with the twenty-first century that it helped to create.¹

The grid's aging infrastructure is beginning to strain under the weight of progress and ever-increasing demand. The Congressional Research Service report (Congressional Research Service 2011) on smart grid and cyber security notes that the 'average age of power plants is now over 30 years; most of these facilities were originally designed to last 40 years. Electric transmission and distribution components are similarly aging, with power transformers averaging over 40 years of age, and 70% of transmission lines being 25 years or older' (p. 2). Blackouts are occurring with greater frequency. In America, grid failure costs Americans approximately \$150 billion a year (U.S. Department of Energy 2014a, p. 5). Beyond North America, countries tend to lose 1 to 2 per cent of GDP growth potential due to blackouts, over-investment in backup electricity generators, and inefficient use of resources (United Nations Development Programme 2010). Nigerians for instance live with such persistent power outages that one government official characterised the power supply as 'epileptic'.² The Nepal Electricity Authority supplies electricity to Nepal's capital Kathmandu for less than 8 hours per day, with load shedding accounting for the remaining 16 hours (World Bank 2009). In July of 2012, India suffered an 'unprecedented grid failure' that affected 670 million people—more than half the country's population, or roughly 10 per cent of the world's population, in a single blackout (Harris & Bajaj 2012).

Classically, grid policy focused primarily on economic concerns. The electric grid was modelled to generate more: more electricity, leading to more economic growth, culminating in greater amounts of wealth. However, energy

policy is no longer simply about generating more from an economic perspective, it is also constrained by growing concerns about energy security and the environment: the emerging energy trilemma. In this way, the grid's economic goals have given way to a more complex policy goal—sustainable energy development. As the International Energy Agency stated, '[c]urrent trends in energy supply and use are patently unsustainable—economically, environmentally, and socially. Without decisive action, increased fossil fuel demand will heighten concerns over security of supplies and energy related emissions of carbon dioxide will more than double by 2050. We can and must change our current path. ...' (International Energy Agency 2011, p. 1).

Globally, energy policy-makers have responded with the 'smart grid'. The U.S. Department of Energy explains, '[m]uch in the way that a "smart" phone these days means a phone with a computer in it, smart grid means "computerizing" the electric utility grid.'³ Through smart technology, policy-makers hope to improve the grid's efficiency to prolong the useful life of our current energy infrastructure and defer the need for large capital investments in new transmission, distribution and generation facilities.

The European Union, United States, Australia, China, Japan and Korea, among others, have all invested in the smart grid, including research and development, smart grid pilot and demonstration projects, or simply installing smart meters in homes and businesses.⁴ With many such projects now reaching maturity, it is timely to reflect on their successes and challenges to extract lessons learned and develop best practices for smart

1. See for example, U.S. Department of Energy (2014a) *Smart Grid: An Introduction*, pp. 4–6.

2. '\$85 Billion Needed for Stable Power; Supply Won't Improve Till December,' *Daily Trust*?/All Africa Global Media, 25 June 2008.

3. U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, *Smart Grid*, <<http://energy.gov/oe/technology-development/smart-grid>>.

4. See, International Energy Agency, *Smart Grid Roadmap*, pp. 20–21; The Global Smart Grid Federation (December 2012), *2012 Report* (herein, '*Global Smart Grid Federation 2012 Report*'). <https://www.smartgrid.gov/sites/default/files/doc/files/Global_Smart_Grid_Federation_Report.pdf>.

grid decisions. In its 2012 Report, the Global Smart Grid Federation observed, '[c]reating and sharing international best practices is the best way to maximize consumer involvement, apply both proven and new technologies, and adapt policy and regulatory structures to support this new environment' (Bartels 2012).

This article critically evaluates whether the smart grid is a smart energy policy for the twenty-first century. First, it describes the 'energy trilemma' as an appropriate model for analysing three major energy challenges: economic, social and environmental. Next, it defines what is meant by the 'smart grid' and smart technology, and it evaluates how the smart grid can help resolve the energy trilemma. Drawing on case studies in the United States, the article suggests that successful smart grid implementation requires smart communication beyond technology. Electricity customers play a critical role in accomplishing the smart grid's policy objectives through demand side response. Failure to engage with customers through targeted communication, or to adequately address customers' privacy concerns, risks alienating customers, threatening the value of the smart grid investment. This article concludes that, with smart communication, both technical and human, the smart grid can be a smart energy policy for policy-makers around the world—and an important step towards a sustainable energy future.

2. Concepts

As background, this article introduces two main concepts: the 'energy trilemma' and the 'smart grid'. Specifically, this article will examine how the smart grid impacts each of the three dimensions of the energy trilemma to evaluate whether the smart grid is a smart energy policy for the twenty-first century and beyond.

2.1. The Energy Trilemma

The energy trilemma is rooted in the overarching philosophy of sustainable development.

In 1987, the Brundtland Commission outlined three pillars of sustainable development:

economic growth, environmental protection and social equity (United Nations World Commission on Environment and Development 1987, pp. 1–6, 72–76). The Brundtland Commission emphasised the interdependence between each concept and the need to integrate all three considerations in decision-making (United Nations World Commission on Environment and Development 1987, p. 73). In the energy context, the *Brundtland Report* characterised the goals for sustainable development as economic viability, security of supply and environmental protection—defined more recently as the 'energy trilemma'.⁵ Others have defined the trilemma as a 'three-part set of tensions focused on (i) cost; (ii) infrastructure reliability, and (iii) the environment', concluding that 'ultimately the energy trilemma should not be looked at as a question of dollars and cents, even though cost is one of its key elements' (Sautter et al. 2009).

Various international energy organisations have endorsed the energy trilemma as an appropriate model for energy decision-making in an increasingly carbon-constrained world. The World Energy Council (2012), for example, discusses sustainable energy development by reference to the 'three intertwined dimensions of the energy trilemma: energy security, social equity, and environmental impact mitigation,' (pp. 2, 7) 'entailing complex interwoven links between public and private actors, governments and regulators, economic and social factors, national resources, environmental concerns, and individual behaviours' (World Energy Council 2012, p. 7) Similarly, the International Energy Agency (2011) states, 'there is a pressing need to accelerate the development of low-carbon energy technologies in order to address the global challenges of

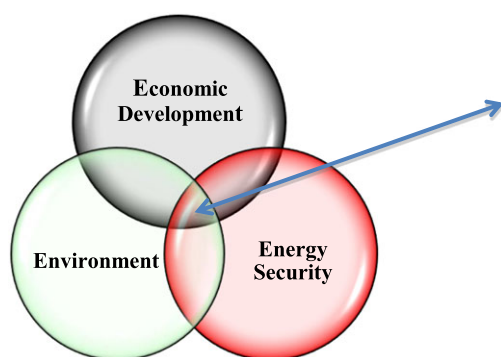
5. The Brundtland Report, in Chapter 7. See also, Patricio Zambrano-Barragan, *The Role of the State in Large-Scale Hydropower Development, Perspectives from Chile, Ecuador, and Peru*, at 10 ('Echoing the Brundtland Report and taking specific aim at the energy sector and its role in the improvement of livelihoods, organizations like the International Energy Agency have defined the challenges ahead as a "trilemma"').

energy security, climate change and economic growth.⁶

Notwithstanding subtle differences in how organisations describe the energy trilemma,⁶ fundamentally the energy-trilemma is characterised by economic, security and environmental concerns.⁷ Sustainable energy development requires policies and decisions that address all three of the interconnected priorities, accepting, however, that specific energy decisions may involve some tradeoff between each dimension.

It follows that the ‘energy trilemma’ is represented diagrammatically below (Figure 1):

Figure 1 The Energy Trilemma The overlapping triangle in this Venn diagram represents ideal sustainable energy development, while the remaining areas show the interdependence and tradeoffs between each of the three dimensions of the energy trilemma



6. The Brundtland Commission refers to economic viability, security of supply and environmental protection; the World Energy Council uses energy security, social equity (including economic and social factors), and environmental impact; the International Energy Agency references energy security, climate change and economic growth, while Sautter, Landis, and Dworkin characterise the trilemma in terms of cost, infrastructure reliability and the environment.

7. This article does not address social equity as an element of the energy trilemma. While the Brundtland Report introduces social equity as one of the three basic requirements for sustainable development, it defines sustainable development more narrowly in the energy context as economic viability, security of supply and environmental protection. Similarly, with the exception of the World Energy Council, most commentators do not include social equity in their discussion of the energy trilemma.

2.2. The Smart Grid

The electric grid is the infrastructure and equipment that carries electricity from power-generating plants to consumers, including, for example, wires, substations, transformers, and switches (U.S. Department of Energy 2014b). The smart grid applies a variety of modern computer technology to the grid to enable the two-way flow of electricity and information.

Smart technologies ‘span the entire grid, from generation through transmission and distribution to various types of electricity consumers’ (International Energy Agency 2011, p. 17). The technology falls broadly into eight categories: (i) wide-area monitoring and control; (ii) information and communication technology integration; (iii) renewable and distributed generation integration; (iv) transmission enhancement; (v) distribution grid management; (vi) advanced metering infrastructure; (vii) electric vehicle charging infrastructure; and (viii) customer-side systems (International Energy Agency 2011, pp. 18–19). Many smart technologies, such as smart meters, already exist and are being actively deployed, while others require further development (International Energy Agency 2011, p. 17). The International Energy Agency describes the ‘smartening’ of the electricity system as an evolutionary process, not a one-time event’ (International Energy Agency 2011, p. 6).

Smart technology achieves seven key outcomes (Pacific Northwest National Laboratory 2010; Hart 2013, unpublished data):

- (i) Two-way real-time communication between utilities and customers via smart meters and data centres enabling smart meters, customers and utilities to identify and address wasteful energy use.
- (ii) Efficient use of heating, ventilation and appliances through smart technologies that communicate with the meter to ascertain the best time to operate.
- (iii) Increased measurement and verification of energy efficiency measures by utilities. By collecting more granular data on customer energy use, utilities can better plan

Table 1 Comparison between Conventional Electricity Grids and ‘Smart Grids’

<i>Goal</i>	<i>Current grid</i>	<i>Smart grid</i>
Resilience and self-healing	Operators respond to prevent further damage, focus is on reaction and protection of assets following system faults	Automatically detects and responds to actual and emerging transmission and distribution problem, focus is on prevention
Information and involvement	Consumers are uninformed and non-participative in the power system	Consumers are informed, involved and active
Quality of energy services	Focused on outages rather than power quality patterns	Quality of energy services is matched to energy end-user demands
Diversification	Relies on large centralised generating units with little opportunities for energy storage	Encourages large numbers of distributed generation deployed to complement storage options such as electric vehicles, with more focus on access and interconnection to renewables and vehicle-to-grid systems
Competitive markets	Limited wholesale markets still working to find the best operating models, not well suited to handling congestion or integrating with each other	More efficient wholesale market operations in place with integrated reliability coordinators and minimal transmission congestion and constraints
Optimisation and efficiency	Minimal integration of limited operational data with asset management processes and technologies and time-based maintenance	Greatly expanded sensing and measurement of grid conditions, technologies deeply integrated with asset management processes and condition-based maintenance

Source: Sovacool BK and MH Dworkin. *Global Energy Justice: Problems, Principles, and Practices* (Cambridge: Cambridge University Press, 2014).

and prepare to meet the demand more efficiently, decreasing losses from inefficiency or inaccurate data, and decreasing the required generation.

- (iv) Shifting load from peak to off-peak times with more efficient generation sources, through demand response. This reduces the stress on the grid, decreases line losses and makes the system more efficient.
- (v) Ability to support electric vehicles (EVs) and perform smart charging to manage when and how EVs are charged so that they do not add to the peak load stress on the grid.
- (vi) Conservation voltage reduction (‘CVR’) and advanced voltage control. CVR entails reducing or increasing the voltage on distribution lines to maximise the efficiency of the grid. By balancing voltage and current to reduce line losses while delivering high-quality electricity, the grid can run more efficiently, components last longer, and energy is delivered to the customer by using less fuel.
- (vii) Support intermittent renewables, such as solar and wind. Smart grid technologies help provide demand response,

distributed storage and energy efficiency to help balance renewable generation into the grid more smoothly.

Put simply, the smart grid is synonymous with automated communication, designed to identify and optimise opportunities for efficiency, and minimise faults. Table 1 compares the smart grid to conventional grid systems.

3. How Does the Smart Grid Address the Energy Trilemma?

Policy-makers advance smart grid as a smart solution to our emerging energy trilemma. This section evaluates the smart grid against each dimension of the energy trilemma, drawing on case study analysis to assess whether the smart grid can achieve its ambitious goal to achieve a cost effective, secure and environmentally sustainable energy future.

Vermont Law School's Institute for Energy and the Environment conducted six smart grid case studies, covering a diverse set of states and projects, including different stakeholders, policies, and local goals and concerns. Table 2

Table 2 Institute for Energy and the Environment Smart Grid Case Studies—Summary

Project	State	Cost	Technology	Lessons Learned
Central Vermont Public Service 'Smart Power' Part of statewide program, 'eEnergy Vermont'	VT	\$63 million. \$69 million federal funding to VT utilities, of which CVP received \$31 million.	Advance Metering Infrastructure ('AMI').	<ul style="list-style-type: none"> • Collaboration reduces regulatory barriers, enables cost sharing, ensures success. • Early and ongoing outreach accelerates customer acceptance, reduces confusion and skepticism, and ensures customers benefit from smart grid technology. • Advanced customer education enhances customer acceptance.
San Diego Gas & Electric.	CA	\$3.5–3.6 billion. \$5 million federal funding.	AMI; Programmable communicating thermostats; remote turn-on, turn-off device for residential meters; time of use rates	<ul style="list-style-type: none"> • Focus on customer experience; maximising environmental impact; minimising impact on utility revenue helps customers to understand 'what's in it for me?'
Pecan Street Inc., Internet Demonstration Project	TX	\$25 million. \$10.4 million federal funding; a \$350,000 private grant; \$14 million investment by project partners.	AMI; smart water and smart irrigation systems; smart appliances; electric vehicles; rooftop solar; home energy storage; home energy networks. Uses Internet for information sharing.	<ul style="list-style-type: none"> • Real time pricing shifts peak loads. • Smart grid must be supported by clearly articulated state smart grid policies to achieve full benefits of smart grid. • Regulatory environment can hinder success: Cost allocation through rate recovery can be controversial; restrictions on advertising real-time pricing hinders demand response potential. • Smart grid backbone infrastructure (communications network) is essential to successful smart grids. • Time of use rates achieve customer satisfaction and end-use efficiency. • Value of customer engagement.
Commonwealth Edison Smart Grid Innovation Corridor Pilot Project	IL	\$800 million (\$720 million AMI, network, installation and vendor costs; \$74 million IT software and hardware integration; \$6 million additional operation and management; \$2 million miscellaneous).	AMI; intelligent substations; integration of plug-in electric hybrid and all-electric vehicles; time of use rates.	<ul style="list-style-type: none"> • AMI; smart grid backbone infrastructure (communications system), time of use rates. • AMI; distribution automation; demand response; pricing study; cyber security.
Salt River Project	AZ	\$114 million. \$56.9 million federal funding.	AMI; smart grid backbone infrastructure (communications system), time of use rates.	
Sacramento Municipal Utility District, 'Smart Sacramento'	CA	\$308 million \$127.5 million federal funding.	AMI; distribution automation; demand response; pricing study; cyber security.	



summarises the six core cases utilised for our analysis.

The following sections of the article extract lessons applicable to smart grid projects globally.

3.1. Smart Economic Policy

Consistent with traditional energy policy, economic concerns remain the dominant dimension of the trilemma. A robust electric grid is essential to a strong economy. Under this dimension of the energy trilemma, the essential question is whether smart grid is a ‘good investment’ in terms of capital expenditure, costs avoided, impact on electricity prices and economic stimulation.

Smart grids are expensive; they require billions of dollars in upfront capital expenditure, together with comprehensive planning and long-term construction. In Canada, for example, the Ontario Smart Metering Initiative invested approximately \$1 billion to install 4.5 million smart meters; and the Grid4EU R&D pilot with six demonstration sites has an estimated cost of 54 million euros (Bartels 2012, p. 28). European nations, as a whole, invested nearly 2 billion euros on smart grid projects in 2012 (Giordano et al. 2013). Our six case studies show that smart grid projects in the United States have been similarly cost intensive. In 2009, the US Congress appropriated \$4.9 billion to help fund the federal smart grid program pursuant to the American Recovery and Reinvestment Act (ARRA). The ARRA fund benefited all but one of our case study projects. The ARRA funds represent just a fraction of the capital needed to roll out smart grid technologies.

Financial constraints are ‘possibly the largest obstacle to fully implementing the smart grid’ (Hart 2013, unpublished data). However, many utilities expect to offset those costs with corresponding savings. The Electric Power Research Institute (2011) in the United States has estimated that fully implementing a smart electric grid will cost between \$1.3 and \$2.0 trillion nationwide, with benefits likely exceeding costs by a factor of three or more—that is, producing \$3.9 to \$6 trillion worth of benefits!

In particular, through increased efficiency, the smart grid will expand the useful life of existing energy infrastructure, avoiding immediate large-scale investment in upgrading transmission and distribution. Peak shifting is another important cost saving. Using traditional grid infrastructure (U.S. Department of Energy 2014a, p. 14):

[w]ithout a greater ability to anticipate, without knowing precisely when demand will peak or how high it will go, grid operators and utilities must bring generation assets called peaker plants online to ensure reliability and meet peak demand. Sometimes older and always difficult to site, peakers are expensive to operate—requiring fuel brought on the more volatile ‘spot’ market ... Compounding the inefficiency of this scenario is the fact that peaker plants are generation assets that typically sit idle for most of the year without generating revenue but must be paid for nevertheless.

By providing customers with detailed information about pricing and loads, the smart grid is expected to achieve significant peak shifting through demand response, avoiding costly peaker plants and expensive fuel.

The efficiency gains through smart grid will also help the economy avoid losses caused by blackouts—which have been increasing in scale and frequency in recent years. In the United States, blackouts are estimated to cost approximately \$150 billion a year (U.S. Department of Energy 2014a, p. 5). According to a study by the National University System Institute for Policy Research, a single blackout in the greater San Diego region cost the region \$97–118 million (DiSavino 2011). Similarly, in 2006 when 250,000 customers in Auckland had their power supply disrupted when a transmission circuit failed, the disruption cost the New Zealand economy approximately NZ\$70 million of GDP (Concept Consulting Group Limited 2008, p. 16).

Other avoided costs include those associated with physical meter reading. The Salt River Project, for example, reports that the benefits of automated meter reading are more than covering the costs of the upgraded grid. As of March 2011, the Salt River Project remotely

addressed over 1.2 million service orders, saved over 401,000 labor hours, avoided 2.0 million driving miles, and conserved 198,000 gallons of fuel. Sacramento Municipal Utility District similarly reports that prior to installing advanced metering infrastructure, it spent more than \$9,000,000 annually on meter reading. The Commonwealth Edison experience, however, warns that not all manual jobs associated with the electric grid can be replaced by smart technology, and the avoided costs should not be overstated. In Illinois, regulations preventing remote disconnection limits the extent to which utilities can recover unbilled and unaccounted for electricity through remote disconnection, or reduce labor hours and fuel costs from suspension of site visits.

Another potential avoided cost is reduction in electricity theft. In Italy, for example, Italy's largest utility, Enel, spent \$3 billion to install 32 million smart meters, but has recouped that cost in just 4 years, saving \$750 million annually in increased efficiency and reduced electricity theft (Hart 2013, unpublished data). The avoided costs associated with electricity theft may be a particularly pertinent justification for smart grid in developing countries. Electricity theft is estimated to cost 45 emerging market countries—such as Brazil, Russia, India, China and South-Africa—a combined total of \$47 billion (Khajuria 2013).

Ultimately, whether smart grids constitute sound energy policy from an economic perspective depends on the particular circumstances of the region, including generation sources and trends in electricity demand. In New Zealand, for example, because generation is dominated by hydroelectricity and other renewable sources, a recent smart grid feasibility study concluded that the smart grid offers fewer benefits in the near term than might be the case in jurisdictions without such a flexible energy supply (Imperial College of London and Meridian Energy Limited 2012, pp. 3–4):

There are likely to be limited power system benefits from a smart grid implementation over this decade. However, future changes in electricity demand are expected, to create a

substantial economic case for the smart grid opportunity in New Zealand. The benefits available from using demand flexibility could reduce New Zealand's required electricity system investment by up to \$3.5 billion in 2030 and up to \$10.6 billion in 2050.

On balance, the International Energy Agency (2011) finds, 'the costs and benefits can be rationalised and defended, ensuring the development of a clean, secure and economic electricity system' (p. 29).

3.2. *Smart Energy Security Policy*

The world faces an uncertain energy future. With increasing demand for energy, aging infrastructure, and climate change concerns, many nations identify energy security as a pressing aspect of energy policy. Enhanced grid resilience and reliability; integration and management of distributed generation and increased energy independence through domestic renewable energy sources; a decentralised grid structure; and integration of electric vehicle supporting infrastructure are each important aspects of energy security advanced by smart grid technology (International Energy Agency 2011, p. 7).

This article has already outlined the reliability and resilience issues posed by our aging grid infrastructure. Smart grid technology improves system efficiency, reliability and resilience through smart communication. Consumers use information communicated through smart meters to modify their demand, shifting away from peak periods, and using electricity more efficiently. The smart grid will also be able to detect and react to unexpected events through self-healing actions, reducing grid interruptions.

The smart grid also supports increased distributed generation integration, decentralising the grid structure. The U.S. Department of Energy reports that the 'grid's centralized structure leaves us open to attack. In fact, the interdependencies of various grid components can bring about a domino effect—a cascading series of failures that could bring our nation's banking, communications, traffic, and security systems among others to a complete standstill'

(p. 9). Smart grid technology can manage intermittency issues posed by distributed energy sources such as wind and solar, and is an essential tool for widespread integration of distributed energy resources. In this way, the smart grid is expected to support a domestic renewable energy market, helping to decrease dependence on imported fossil fuels. The smart grid's ability to support electric vehicles is expected to further support energy independence by displacing reliance on imported fossil fuels in the transportation sector.

One way in which the smart grid is expected to challenge energy security is the increased risk to cyber security. The Congressional Research Service's (2011) report on smart grid and cyber security states, '[t]he information processing attributes which make the smarter grid attractive are the very same attributes which can increase the vulnerability of the electric power system and its critical infrastructure to a potentially devastating cyber attack' (p. 3). In 2010, the National Institute for Standards and Technology (NIST) issued its first guidelines for smart grid cyber security. It identified five specific cyber security threats associated with the smart grid (The Smart Grid Interoperability Panel Cyber Security Working Group 2010, p. 7):

- Greater complexity increases exposure to potential attackers and unintentional errors;
- Networks that link more frequently to other networks introduce common vulnerabilities that may now span multiple Smart Grid domains ... and increase the potential for cascading failures;
- More interconnections present increased opportunities for 'denial of service' attacks, introduction of malicious code (in software/firmware) or compromised hardware, and related types of attacks and intrusions;
- As the number of network nodes increases, the number of entry points and paths that potential adversaries might exploit also increases; and
- Extensive data gathering and two-way information flows may broaden the potential for compromises of data confidentiality and breaches of customer privacy, and

compromises of personal data and intrusions of customer privacy.

Cyber security is an international concern. The International Energy Agency's International Smart Grid Action Network reports a number of international collaborative efforts to address smart grid cyber security concerns, including that by the European Network and Information Security Agency in the EU; coordination between the United States and Korea through the Attached Institute of the Electronics and Telecommunications Research Institute in Korea and the University of Illinois at Urbana-Champaign in the United States; the EU-US Working Group on Cyber-Security and Cyber-Crime; and the European Smart Grid Coordination Group (Miller et al. 2012).

NIST perceived cyber security threats as diverse and evolving, and advocated a defense-in-depth strategy with multiple levels of security because no single security measure could counter all types of threats (The Smart Grid Interoperability Panel Cyber Security Working Group 2010; Congressional Research Service 2011, p. 5). Cyber security issues need to be addressed by policy at the national and state levels; such policy has been made a priority in the United States (Congressional Research Service 2011, p. 21). In addition, utilities need to diligently upgrade both hardware and software systems to stay ahead of security threats (Congressional Research Service 2011, p. 21).

The smart grid's ability to integrate distributed and renewable power generation is likely to counter the risk posed by cyber security, through decentralisation and diversification (Congressional Research Service 2011, p. 21). Taking decentralisation one step further, our research⁸ indicates that micro grids are

8. References to 'our research' in this article includes research by the authors specifically for this article, together with research undertaken by Vermont Law School's Institute for Energy and the Environment's Smart Grid Team, including Kevin B. Jones and David Zoppo, 'A Smarter, Greener Grid: Forging Environmental Progress Through Smart Energy Technologies and Policies', Praeger, Santa Barbara, CA, 2014; and Hart, Jonathan (December 2013, unpublished data) *Smart Grid and a 25-Gigaton Reduction in GHG Emissions by 2050*, unpublished article.

another possible solution to cyber security concerns (Hart 2013, unpublished data):

Micro grids are small electrical grids built for specific locations, such as universities, hospitals, or military bases; they are essentially smaller smart grids that can run independently of the larger grid if needed. In the event of an attack or disruption of the larger grid, micro grids could continue to function by themselves, providing energy to those within the micro grid area.

Micro grids are a special application of smart grid technology. In this way they present similar policy benefits (and costs) as the smart grid generally, while also providing additional local reliability and security of supply for critical community facilities. If cyber security and data privacy concerns can be adequately addressed, the above analysis shows that the smart grid presents many opportunities for advancing energy security.

3.3. *Smart Climate Policy*

The third element of the 'energy trilemma,' environmental protection, reflects a growing concern regarding global climate change and environmental degradation caused by energy development.

International commitment to reducing greenhouse gas emissions makes environmental sustainability an important aspect of energy policy. In the United States, 26 states have adopted renewable portfolio standards mandating that up to 20 per cent of the state's energy portfolio come exclusively from renewable sources by a fixed year; another 4 states have adopted voluntary goals for adopting renewable energy (U.S. Department of Energy 2014a, p. 25). In the Pacific, New Zealand sets a target of 90 per cent renewable electricity by 2030, subject to achieving energy security (New Zealand Ministry of Economic Development 2011, p. 3). And while New Zealand has declined from participating in the Kyoto Protocol's second commitment period under the United Nations Framework Convention on Climate Change (UNFCCC), the Australian government continues to express its commitment to the Kyoto Protocol: 'Australia is

committed to taking strong action on climate change and we are playing our part in the global effort to achieve an ambitious international outcome. Australia has made a 2020 emission reduction pledge under the UNFCCC. Australia has also stated that it is prepared to consider a new commitment under the Kyoto Protocol, following necessary domestic processes.'⁹ The Pacific island nations are particularly vulnerable to climate change,¹⁰ and accordingly, environmental concerns may take greater precedence in energy policy decisions.

In January, the Pacific Northwest National Laboratory (2010) published its comprehensive report calculating the expected reductions in carbon emissions that can be achieved through a smart grid. It estimates that with full implementation of a smart grid by 2030, US energy consumption and carbon emissions could be reduced by 12 per cent (Pacific Northwest National Laboratory 2010, p. 3.3). The estimated emissions reductions include (Pacific Northwest National Laboratory 2010, pp. v, 3.3):

- 3 per cent reduction attributable to the conservation effect of consumer information and feedback systems;
- 3 per cent reduction attributable to the deployment of diagnostic residential and small/medium commercial buildings;
- 1 per cent reduction attributable to measurement verification for energy efficiency programs; <0.1 per cent reduction attributable to shifting load to more efficient generation;
- 3 per cent reduction attributable to its support of additional electric vehicles and plug-in-hybrid electric vehicles;
- 2 per cent reduction attributable to conservation voltage reduction and advance voltage control; and
- <0.1 per cent reduction attributable to penetration of renewable wind and solar generation (up to 25 per cent renewable portfolio standard).

9. <<http://www.climatechange.gov.au/international/negotiations/history-negotiations/kyoto-protocol>>.

10. <<http://www.gcca.eu/regional-programmes/gcca-pacific-small-island-states>>.

Beyond the United States, the International Energy Agency suggests that the smart grid can reduce emissions ‘through feedback on energy usage, lower line losses, accelerated deployment of energy efficiency programmes, continuous commissioning of service sector load, and energy savings due to peak load management. Indirect benefits arise from smart grid support for the wider introduction of electric vehicles and variable renewable generation’ (International Energy Agency 2011, p. 27).

With respect to the potential posed by electric vehicles, dependence on imported transportation fuel is both a security and environmental concern for many nations throughout the globe. The extent to which electric vehicles can help resolve these issues will depend on the degree to which the region depends on imported fuel for transportation, and the alternative sources of energy available to meet the corresponding increase in demand for electricity. The potential for both the environmental and security benefits are greatest in countries such as New Zealand, where electricity generated from renewable resources makes up the majority of the electricity mix (Ministry of Business Innovation and Employment 2014) and which relies heavily on imported oil for transportation.¹¹ On the other hand, in countries such as Australia, which in 2012 boasted relatively modest transportation fuel imports (John Blackburn 2013, p. 8), and whose electricity supply consists primarily of coal and natural gas (International Energy Agency 2012, p. 89), the potential benefits from increased electric vehicle deployment is less pronounced.

In the above ways, the smart grid shows great potential in helping to reduce the impact that electricity has on our global environment.

4. Smart Policy in Practice—Conclusions and Best Practices

The analysis under Section 3 of this article shows that the smart grid has the potential to

address all three dimensions of the energy trilemma: economic, social and environmental. In theory, then, the smart grid represents smart energy policy for those attempting to address the emerging energy trilemma. This section considers smart ‘communication’ practices to enable communities and planners to reap the benefits from the smart grid.

Our research serves a cautionary tale that policy-makers must not overlook the human aspect of smart grid implementation. Much of the smart grid's expected benefits depend on customer participation. In particular, demand response measures dictate load shifting, end-use efficiency gains and reduced demand. Adopting smart grid technologies without also taking deliberate steps to secure customer support for the initiatives will hinder the smart grid's potential to address the energy trilemma.

The case studies highlight two critical barriers to customer acceptance—insufficient communication with customers as to the nature, challenges and opportunities surrounding smart grid, and failure to adequately address customers' privacy concerns.

4.1. Best Practice 1: Communicate with Customers

Our research illustrates the importance of engaging with customers before, during and after the implementation process. In particular, utilities must educate customers about the justifications for smart grid initiatives, including benefits accruing to the individual as well as to society. Public ignorance and/or misconceptions about smart grid technologies can stall smart grid adoption and implementation.

The Californian smart grid experience is particularly illustrative. In 2009, the California state legislature made smart grid deployment state policy.¹² Investor owned utilities were directed to submit smart grid implementation plans to the California Public Utilities Commission¹³ and to deploy smart grid technology

11. Ministry of Business Innovation and Employment, p. 31.

12. West's Ann. Cal. Pub. Util. Code § 8360.

13. West's Ann. Cal. Pub. Util. Code § 8364.

in a manner to ‘maximize the benefit and minimize the cost to ratepayers and achieve the benefits of smart grid technology.’¹⁴ Pacific Gas & Electric’s (PG&E) first attempt to roll out smart meters was met with significant public resistance. By April 2010, the California Public Utilities Commission had received 1,000 consumer complaints about the smart meters (ABC News 2010). Many installed smart meters experienced technical failures—reportedly 9,000 did not communicate energy usage back to the utility, 11,300 did not work at all, and 23,000 were installed improperly (ABC News 2010). Reflecting on the PG&E experience, one commentator asked, ‘is PG&E killing the smart grid?’ (Hertzog 2010):

The news coming from PG&E these days is trending from bad to worse for the Smart Grid and for this country’s citizens. First they created a public relations disaster with their smart meter rollout, which now has its own term called ‘the Bakersfield effect’. PG&E investment in a sensible communications plan and budget could have prevented this problem. The impacts of the Bakersfield effect are widespread. Smart meter rollouts in other utilities are delayed or postponed, and each setback hinders realization of their Smart Grid objectives.

Both the San Diego Gas & Electric and Sacramento Municipal Utility District took active steps to avoid the ‘Bakersfield effect’. Both case studies demonstrate robust communications efforts and attribute their programs’ success to thorough public engagement. San Diego Gas & Electric worked to educate its customers about the environmental and cost benefits of smart meters well before they started to deploy them, including communicating with customers on an individual basis by sending out information and notifications when the utility was preparing to install smart meters. Sacramento Municipal Utility District also allocated resources to educate, inform and enable its customers, and reported high levels of customer satisfaction.

The Central Vermont Public Service (CVPS) case study offers another example of

successful customer outreach. CVPS (now Green Mountain Power) trains call centre technicians to answer and properly route smart grid questions and appoints staff members as smart grid ambassadors in their community. CVPS also developed print and web-based education materials and will use consumer behaviour studies to structure dynamic pricing tariffs. Customers are sensitive to large rate increases, so communicating in advance about how dynamic pricing works and customers’ options is an important aspect of smart grid deployment.

The Australian smart grid experience confirms the importance of customer communication strategy to smart grid projects beyond the United States. In Victoria, a mandatory rollout of smart meters and time-of-use pricing with all costs passed on to consumers was met with extreme negativity, resulting in a temporary moratorium on the rollout (Bartels 2012, p. 15). The recent report by the Australian Auditor General on Australia’s Smart Grid, Smart City demonstration program, also cites customer resistance to smart meter technologies as a key challenge, which ‘contributed to significant delays in rolling out the retail trial and, ultimately, the achievement of lower-than-expected numbers of customers participating’ (McPhee 2014, pp. 16–17).

The smart grid is all about communication. Yet many projects overlook the importance of human communications in implementing technical grid solutions. The US case studies, and recent Australian experience, confirm the importance of customer education and outreach, before and during implementation, for successful smart grid deployment.

4.2. *Best Practice 2: Address Privacy Concerns*

Privacy is an important customer concern impacting willingness to embrace smart grid technologies.

The National Institute for Standards and Technology’s 2010 cyber security report identifies two main categories of privacy concerns: (i) concern that the granular data collected, stored and transmitted by smart meters will

14. West’s Ann. Cal. Pub. Util. Code § 8366.

reveal personal information about customers over time; and (ii) concerns that inadequate cyber security measures surrounding the digital transmission of smart meter data will expose it to misuse (The Smart Grid Interoperability Panel Cyber Security Working Group 2010, pp. 4, 23–24, 29; Congressional Research Service 2012, p. 3). The Congressional Research Service's privacy and security report reiterates the Department of Energy's concern that 'smart meters may be able to reveal occupants' 'daily schedules (including times when they are at or away from home or asleep), whether their homes are equipped with alarm systems, whether they own expensive electronic equipment such as plasma TVs, and whether they use certain types of medical equipment.' (Department of Energy 2010; Congressional Research Service 2012, p. 4)

The US case studies show that utilities are aware of privacy concerns and are taking steps to develop clear smart grid privacy policies for customers. Sacramento Municipal Utility District, for example, has assured its customers that their energy use information will remain confidential, and uses the Department of Energy's Cyber Security plan. Commonwealth Edison states that it is strongly committed to customer privacy and will not disclose customers' personal information without customers' prior approval, except as required by law. Pecan Street Inc. includes developing a cyber security protocol among the five objectives it hopes to achieve through its demonstration project. San Diego Gas & Electric has also committed to protecting customer privacy through a variety of measures, including creating a Chief Privacy Officer position.

Best practice suggests that privacy policies clarify what information is being collected; who owns the information; who has a right to see it; who has a right to use it; and, where information sharing is anticipated, to whom, for what purpose and under what conditions.

Robust privacy policies and smart customer communication strategies will be an important part of the smart grid development. This will help to secure customers' support for smart grid initiatives, thereby empowering the smart grid to achieve its smart energy policy potential.

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