THE SOCIO-ECONOMIC VALUE OF SPECTRUM IN PROVIDING UTILITY SERVICES TO SUPPORT THEIR OPERATIONS

Report by The Joint Radio Company Ltd on behalf of the European Utilities Telecommunications Council

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"Given we are getting regular warnings about the likely frequency of extreme weather events, I think [power network companies] have got to show they have got a proper plan which allows them to respond much more quickly when people are left without power." said Tim Yeo MP, chairman of the UK Parliamentary energy select committee. He added that the power network companies were "analogous to the emergency services" given people were so dependent on a constant supply of electricity.

The Daily Telegraph, London 30 December 2013

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Contents

1 EXECUTIVE SUMMARY

In 2011, the Joint Radio Company Ltd (JRC) conducted a socio-economic study of the use of radio spectrum in supporting utility operations[1]. The report examined the economic value and the additional value to society of incorporating advanced telecommunications into a previously largely passive grid. The "additional value to society" refers to a number of non-marketable benefits which, although not creating wealth, are valued by society. The report concluded that the socio-economic value of a reliable electricity supply is at least 50-150 times the retail price of the electricity supplied.

Urban electricity substation

However, this original report was based largely on historic data covering a period of some 35 years during which time western societies have become increasingly dependent on a reliable supply of electricity to support their standard of living. This report aims to follow up the previous work and apply further analysis to the United States of America (USA), looking at the value of spectrum use to customers, utilities and society as a whole using more recent data.

Because of the increased use of evidence based allocation of scarce resources by governments, much more economic and socio-economic analysis is undertaken to inform policy making. The findings of some of these studies at the macro-economic level estimate:

- The annual cost of power disturbances to the US economy ranges between $119 and $188 billion per year. (Gellings, 2011)
- The societal cost of a massive blackout is in the order of $10 billion per event. [North American Reliability Corporation Report]
- Smart Grids can reduce emissions by 60 to 211 million tonnes of CO_2 per year by 2030. (Gellings, 2011)
- Smart Grids are expected to achieve a 12% reduction in electricity consumption and CO_2 emissions in 2030. [Pacific NorthWest National Laboratory]
- Smart Grid, combined changes in generation and end-use options could reduce by 2030 annual CO_2 emissions from the electric sector by 58% relative to 2005. (Gellings, 2011)

One major element of the socio-economic benefit of applying increasingly intelligent control to the electricity grid is the increased information available to grid controllers during severe weather events. Although much of the evidence in this situation is anecdotal

[1] See (Grilli, 2012)

or subjective, nevertheless, it helps to build the picture of how an intelligent grid can facilitate more rapid restoration of supplies following a storm.

- "During storm, 75% of customers were restored in 9 days and full restoration in 12 days. Resilient communications were vital. In the aftermath of the storm, the only communication network functioning on the Mississippi coast region, one of the worst areas hit, was the utility telecommunications network. Near-full operational telecommunications were restored after just 3 days." (Ball, 2006)
- "Following the storm, the modernised grid had produced a 55% reduction in the duration of outages, avoiding 58 million customer outage minutes. Most customers were restored about 1.5 days earlier than had previously been possible. Outage reductions provided an operational saving of about $1.4 million for the event." (Tweed, 2012)
- During Hurricane Ike in 2008, CenterPoint Energy, the largest electricity provider in Texas, lost power to over 2.1 million customers (over 90%) with restoration taking up to 20 days. Their innovative intelligent grid system has prevented over 7 million customer outage minutes over 2 years and demonstrated a 25% improvement in restoration time. If these improvements could be replicated in hurricane conditions, a very large number of customers would have power restored many days sooner. (CenterPoint Energy, 2008)

Some might argue that this situation can be addressed through economic regulation of the energy sector, but structural issues and the variations in the value of electricity not supplied, added to the near impossibility of preventing all storm damage at an affordable cost undermines this approach:

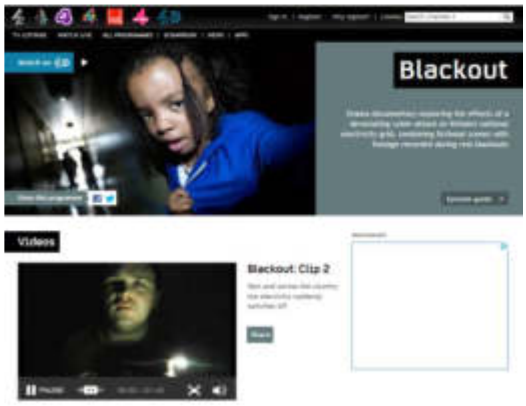
- 'Willingness to pay' increases with time: the WTP to avoid a 4-hour outage is only twice that of a 1-hour outage, suggesting the most costly period of an outage occurs in the first hour. (Bailly, 2000)
- An outage on a weekday during the day time would cause €157 million damage, but the value of the electricity not supplied would only be €2.8 million
    - 57 times the value of unsupplied electricity.
      (de Nooij, Koopmans, & Bijvoet, 2007)
- Sunday daytime would have €80 million welfare costs and €0.45 million cost of electricity not supplied
    - 178 times the value of unsupplied electricity.
      (de Nooij, Koopmans, & Bijvoet, 2007)

How users value electricity also shows wide variations, for example

- Assuming constant electricity prices for residents of $0.1089/kWh, the 'willingness to pay' to avoid outages is between 9 and 31 times the retail value of electricity. (Bailly, 2000)
- Using a composite electricity price of $0.0947/kWh, the 'net lost production cost' for small & medium enterprises is between 813 and 5,903 times the retail value of electricity. (Bailly, 2000)

- 'It is estimated that households create €362 billion a year in leisure value. If everybody were to enjoy leisure at the same moment, a 1-hour interruption would cause a loss of €111 million'. (de Nooij, Koopmans, & Bijvoet, 2007)

The classic economic response would be for those who value electricity more highly to commit additional resources to securing a more reliable supply, but electricity regulation prevents utilities being able to restore supplies based on willingness to pay a premium. There is also a limit to how much individual citizens and organisations can mitigate the effects of wide-spread electricity interruptions. This was graphically illustrated recently by a 'docudrama' on British Television Channel 4 "Blackout" which highlighted the issue that whatever arrangements individuals or businesses may make to prepare for loss of mains electricity. [2] Dependencies on third parties reduce the effectiveness of any provisions; and for unforeseen interruptions to supplies, people will often be trapped at locations away from their home or business location with very limited ability to travel to the place where contingency arrangements have been prepared.



Channel 4 TV Drama: 'Blackout'

The concept of a smart or intelligent grid requires telecommunications to support operations to resolve the energy 'trilemma': security of supply, affordability and sustainability.

Radio spectrum is vital for utilities to be able to support their telecoms operations to ensure reliable supply and rapid restoration after storms.

- The 700 MHz auction in 2008 raised around $5.149 billion at 2013 prices.
- The value of the spectrum is equal to 1.08-1.52% of the EPRI estimate of the total cost of Smart Grid.
- The USA is committed to releasing 500 MHz of government held spectrum to promote the deployment of advanced mobile data networks.

Thus the USA would achieve greater socio-economic gains from providing 20 MHz to Utility Radio and allocating 480 MHz to public broadband than providing all 500 MHz for public broadband services.

Modernising the electricity grid with advanced telecommunications would lead to a number of economic benefits. The investment would create around 40,000 new jobs in total and result in an estimated GDP multiplier effect of 2.5 times the investment, a much higher rate than most other forms of government investment.

[2] http://www.channel4.com/programmes/blackout

An analysis by the Electrical Power Research Institute (EPRI) analysing the gains and costs associated with Smart Grid found that over a 20 year period, a $338-$476 billion investment in modernising the electricity grid would yield a total socio-economic benefit between $1294-2028 billion; a benefit to cost ratio of 2.8-6.0:1. (Lordan, 2004)

The report therefore concludes that there is a compelling socio-economic justification for ensuring that utilities have access to sufficient suitable radio spectrum to enable them to better manage operations of the electricity networks for the benefit of the whole nation.

2 INTRODUCTION

Economies around the world are struggling to achieve growth. Governments see developing the 'digital economy' as a way out of this decline. Public mobile data networks are seen as a key enabler for western-style economies to stimulate growth, whereas emerging economies see an opportunity to leapfrog established nations by skipping fixed broadband networks by migrating straight to mobile data networks; but these radio-based networks need access to suitable and sufficient radio spectrum.

The focus then shifts to repurposing radio spectrum to achieve its greatest value to an economy, a valuable by-product of which is usually a large cash inflow into national exchequers; a potential win-win scenario. Telecoms regulators are therefore selling off spectrum to the organisation that pays the highest price because they believe that represents the greatest economic benefit to the nation in developing a 'digital economy'.

But public commercial mobile data networks are not the only organisations for which increased access to radio spectrum is vital if operational efficiencies and economic growth are to be stimulated. Radio spectrum is an essential ingredient to improving the operational efficiency and effectiveness of a wide variety of functions indispensible to a modern developed economy – transportation, public safety services, security, navigation, etc.

Governments have the unenviable task of migrating from legacy situations where regulators allocated spectrum on a 'command and control' basis to market-based mechanisms to stimulate the most rapid deployment of new technology. But markets have their limitations.

The 'economic benefit' of spectrum represents the value of spectrum to the company using it. The wider benefits are revealed by the 'socio-economic' value to the whole of society from the use of a given amount of radio spectrum. Along with many other sectors, utilities need certainty in terms of their future access to spectrum if they are to serve their communities with reliable, sustainable and affordable energy. The combination of the regulatory framework within which utilities must operate and the longevity of utility asset lives, when married to spectrum regulation where changes are measured in decades create an imperfect market. Under these circumstances, a 'laissez fair' attitude is not in the interests of either consumer-citizens nor commerce.

To provide a rational basis on which to review this situation, in January 2012, the Joint Radio Company Ltd (JRC) published a socio-economic report studying the use of radio spectrum in supporting utility operations[3]. By studying the creation of the Smart Grid - a modernised electricity network - the report examined the economic value and the additional value to society of incorporating advanced telecommunications into a previously largely passive grid. The "additional value to society" refers to a number of non-marketable benefits which, although not creating wealth, are valued by society. This report aims to follow up on the previous work and apply similar analysis to the United States of America (USA), looking at the value of spectrum use to customers, utilities and society as a whole.

[3] See (Grilli, 2012)

2.1 Modernising the electricity grid

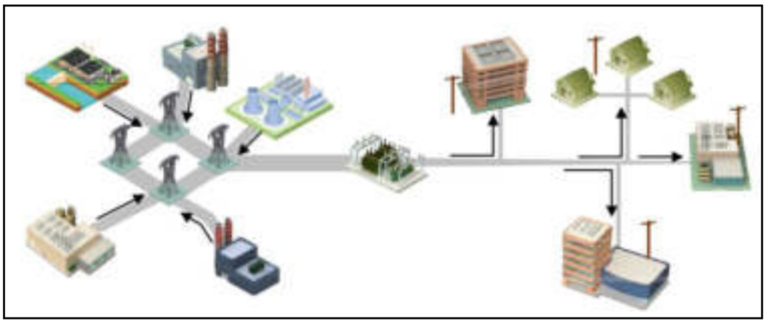


Diagram from Electric Power Research Institute 'Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid', page 1-2: Today's Power System

The idea of a Smart Grid was developed in response to a growing number of changes in the electricity industry that the existing grid was not designed to facilitate.

The current grid was designed to transport a one-way transfer of energy from large generation stations to consumers. The process is centrally controlled and monitored at discrete intervals

Radio spectrum and telecommunications are frequently used throughout the system to provide data for the centrally controlled system and to ensure the safety of those interacting with the grid.

However, recent developments within the industry, changes to government policy and a decline of investment in the grid across the last 2 decades[4] have led to a number of weaknesses emerging.

Modernising and automating electricity distribution offers immense scope for greater reliability and efficiency

Once the power grid was a one-way flow of electricity from a few large generation sites at high voltage down to consumers at low voltage with little need to know anything about the intermediate network. Today the grid must accommodate two-way flows of electricity and data. Increased demand from the digital economy has eaten away the excess capacity on the grid. Meanwhile, government policy shifts away from bulk generation towards distributed renewable generation has complicated the flow of electricity. With higher demand and an ever-increasing number of sources, especially the more sporadic renewable sources such as wind generation and solar panels, more data is required more regularly to manage a more unpredictable grid and prevent failures. In addition, electricity is now traded across the system. Recent events such as the USA and Canada outage on 14th August 2003 and the aftermaths of Hurricanes Sandy, Ike and Katrina have shown the effects of a loss of electricity on the economy and the disruption to people's lives beyond

[4] (Hines, A decentralized approach to reducing the social costs of cascading failures, 2007)

economic damage and how imperative a secure, reliable grid is to mitigating damage and responding to incidents.

Smart Grid is a proposed solution to combat these changed circumstances and emergency conditions. Utilising real-time data collected from all the elements connected, the grid can be monitored and automatically optimised for the conditions it faces. When faced with the current challenges, such measures would make the grid far more reliable as it adapts to the changes in demand and can 'self-heal' when components fail. The Smart Grid would also be better able to facilitate the unpredictable distributed generation with data monitoring so that the grid runs more efficiently and reduces environmental impact. Smart Grid would also be safer from external interactions, monitoring the entire system for potentially unsafe elements, physical attacks, cyber-attacks and damage resulting from natural disasters.

2.2 Study Scope

The purpose of this report is to follow up on the previous study and apply similar analysis for the United States of America. Firstly, in light of recent events and policy decisions, the report reviews new literature and research on the socio-economic value of Smart Grid. This examination focuses not only the economic value of the investment, but also its value to society in minimising outages and the large-scale costs associated. The report examines the opportunity cost of making an allocation of 20 MHz of radio spectrum to 'Utility Radio' and studying how similar spectrum has been sold. Finally, the report considers how the concept of the socio-economic value could be applied to cases where utilities share networks with other users.

3 SOCIO-ECONOMIC VALUE OF A SMART GRID

When looking at the value of a 'Smart Grid' to the United States economy, it is important to consider both the economic benefits and the non-marketable societal benefits. As discussed in other works (Joskow & Tirole, 2007), as well as the former socio-economic report this study is based on, these must be considered in an appraisal of Smart Grid as a number of key functions performed are public goods, such as security, resilience and environment stability. The characteristics of such goods, discussed in the former report, mean that despite having a positive value to society, they will be underprovided in a free market. The issue as it pertains to the electricity network is very well summarised by 'Issues In Science and Technology':

"No Organisation that generates, transmits or distributes electric power wants low reliability. But in a deregulated competitive electricity market, companies have to pay for investments out of revenues they earn. Unless companies can find a way to bill customers for reliability, or unless regulators mandate reliability investments and ensure they are reimbursed, no investment will be made."[5]

Although the benefits are non-marketable, and hence underprovided in a competitive market, these goods clearly have a much wider benefit to society. Therefore, when evaluating Smart Grid, it would be prudent to consider the societal benefits in addition to the monetary value of the system.

3.1 Economic benefits from Smart Grid

A number of reports have already been commissioned in the USA to investigate the value of Smart Grid following the Energy Independence and Security Act (EISA) of 2007 and the American Recovery and Reinvestment Act (ARRA) of 2009. This report considers the conclusions drawn from two reports: '*Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid*' by the Electric Power Research Institute (EPRI) published in 2011, and '*Economic Impact of Recovery Act Investment Grant and Smart Grid Demonstration Projects as of March 2012*' published in 2013 by the United States Department of Energy (DOE). The reports provide credible, wide-reaching, in-depth analysis of the economic costs and benefits relating to Smart Grid. One of the key tools used by most studies on this topic was the Input-Output Model.

3.1.1 Input-Output Model

The Input-Output Model is a widely used method to calculate the total economic impact of an event in an economy. The United States of American Input-Output[6], currently updated for 2002 tables show the output for approximately 500 industry groups that represent the US economy. For each industry group, the model shows the inter-industry demand, sales to other industry to create output, and final demand, sales to households, governments, exports and other linkages.

[5] (Apt, Lave, Talukdar, Morgan, & Ilic, 2004)
[6] (The Bureau of Economic Analysis, 2005)

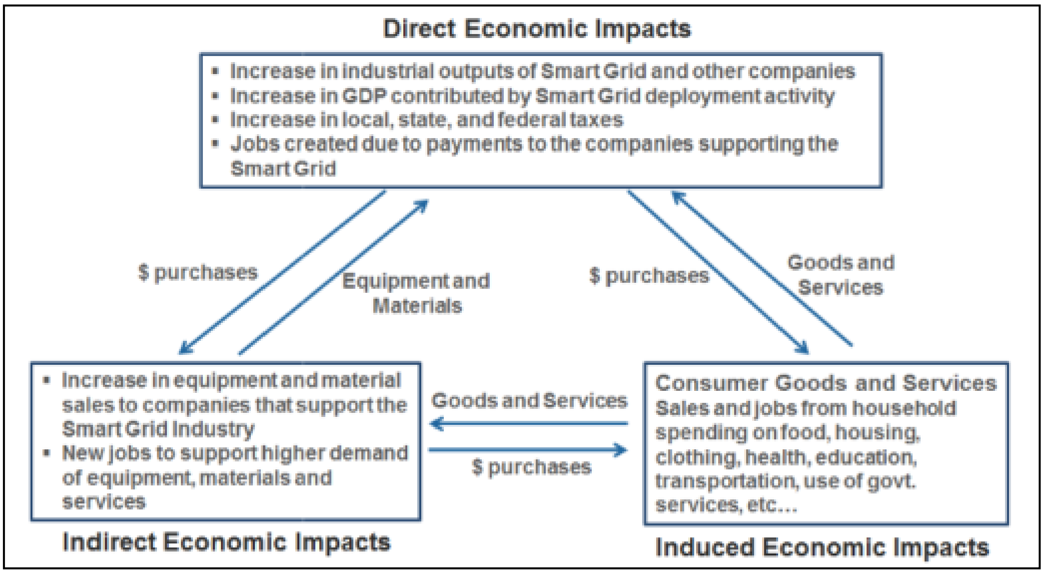


Diagram from US Department of Energy 'Economic Impact of Recovery Act Investments in the Smart Grid', page 8: Schematic of IMPLAN Model: Economic Impact Analysis of Smart Grid ARRA Funding - (Office of Electricity, 2013)

Companies are allocated a North American Industry Classification System (NAICS) code and assigned to an industry based on their primary activity[7]. These tables can then be used for detailed analysis such as how a change in one sector will affect the whole economy or what amount of inputs from each industry are used to create a unit of output. As the model shows the value of the interconnectivity in an economy, it can show Direct, Indirect and Induced effects:

Direct – The economic impact resulting directly from a change. For Smart Grid, examples of direct impacts would be the investment in software, computer systems and the hiring of consultants.

Indirect – The economic impact that exists as firms that received the direct effect interact with other firms that supply them with goods and services in interconnected markets. For Smart Grid, examples of indirect impacts would be computer components and recruitment services.

Induced – The economic impact that results from the expenditure of wages earned from those employed. Examples for Smart Grid would be wages spent on food and real estate (property) by employees.

Whilst the model is a very powerful analytical tool, there are limitations. The use of industry groups and grouping firms based on their main revenue source to create an aggregated figure means the results will be an average-effect, despite the real world impact of one firm not necessarily being the same as another firm in the same industry. Furthermore, the figures are not dynamic and so may not account for changes in technology and increasing or decreasing returns to scale. However, these assumptions

[7] 'Primary activity (generally the activity that generates the most revenue for the establishment)' (The Bureau of Economic Analysis, 2005)

make the model more widely applicable and this type of model is in common use to provide analysis involving interconnected industries

3.1.2 *'Economic Impact of Recovery Act Investments in the Smart Grid' US Department of Energy*[8]

	Total Impact	
	All Vendors	Smart Grid Vendors
Employment (jobs)	47,000	33,000
Labor Income (2010$)	$2.86 Billion	$2.07 Billion
GDP (2010$)	$4.18 Billion	$2.91 Billion
Economic Output (2010$)	$6.83 Billion	$4.79 Billion
State and Local taxes (2010$)	$0.36 Billion	$0.26 Billion
Federal taxes (2010$)	$0.66 Billion	$0.49 Billion

Table 4 from U.S. Department of Energy '*Economic Impact of Recovery Act Investments in the Smart Grid*', page 9: Summary Results

The United States Department of Energy used IMPLAN Input-Output models to examine how the $2.9 billion investment in Smart Grid made in conjunction with the American Recovery and Reinvestment Act 2009 (ARRA) would affect the US economy. This included the Smart Grid Investment Grants (SGIG) and the Smart Grid Demonstration Program (SGDP), from which they reached several key conclusions about the economic impact.

Firstly, the investment would have a large effect on GDP as every $1 invested would boost GDP by around $2.5. This represents a significant GDP multiplier effect, likely due to the high interconnectivity between electricity industries and other industries in the USA. The report outlines a number of GDP multiplier effects associated with alternative government interactions, revealing that Smart Grid would have a greater effect.

However, it is worth noting that when they examine the total economic output of the $2.96 billion investment, the analysis shows only 37% of the total benefit, $2.6 billion, returned as direct benefit.

Type of Activity	Output Multiplier
All Vendors Scenario	2.5
Smart Grid Vendors Only Scenario	2.6
Purchases of Goods and Services by the Federal Government	1.0-2.5
Transfer of Payments to State and Local Governments for Infrastructure	1.0-2.5
Transfer of Payments to State and Local Governments for Other Purposes	0.7-1.9
Transfer of Payments to Individuals	0.8-2.2
Source: ICF/IMPLAN; Congressional Budget Office (CBO)	

Figure 5 from U.S. Department of Energy '*Economic Impact of Recovery Act Investments in the Smart Grid*', page 12: Smart Grid ARRA Support's Impact on Economic Output

Although they state the model overestimates the leakage from the US economy as none of the direct investment went to non-US companies, the scheme was 50% funded by the government. Without the government involvement, it is unlikely the initial investment would have been made.

Secondly, the report indicates that the ARRA Smart Grid program supported 47,000 full time jobs, with 12,000 directly employed, 8,000 indirectly employed and 21,000 employed from the induced effect. This was spread across the entire economy, including 10,000 jobs in professional and technical services, 2,500 jobs in food, drink and restaurant industry, 1,500 in both healthcare and real estate and roughly a further 1,000 jobs in financial

[8] (Office of Electricity, 2013)

services and high-end manufacturing. The report calculated the ARRA impact on aggregate labour income to be $2.9 billion.

The DOE report predicts that Smart Grid will have far reaching positive effects on the US economy, concluding that 'such a large scale investment [full Smart Grid deployment] will continue to contribute significant employment and economic benefit to the US economy'[9]. Overall, the ARRA investment produced 47,000 jobs and a GDP multiplier of 2.5. While these may not scale up when applied to the full Smart Grid deployment, they indicate a large positive benefit. However, the results also suggest that government involvement may be required as the direct benefits do not necessarily create the profit incentive required for private sector investment. The report states the ARRA investment 'must serve as a catalyst to sustain the pace of modernisation, while improving the economic and operational benefits of such investments'[10]. Nevertheless, the DOE predict large benefits for the US resulting from Smart Grid.

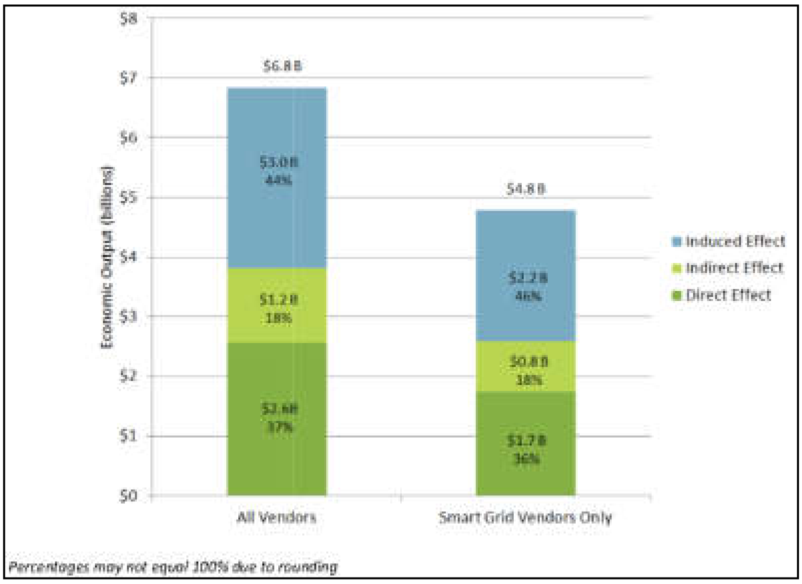


Table 5 from U.S. Department of Energy '*Economic Impact of Recovery Act Investments in the Smart Grid*', page 12: Comparison of GDP Multipliers

3.1.3 *'Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid', Electric Power Research Institute*[11]

The EPRI study follows on from a number of studies previously conducted on Smart Grid, providing a highly detailed analysis of all the benefits associated with a 20 year Smart Grid deployment along with an in-depth cost breakdown – this will be examined later in this report.

As the 2011 study follows up on work previously conducted by EPRI, who have been greatly involved already in estimating the effects of Smart Grid, the report outlines some of the relevant earlier findings[12]:

[9] (Office of Electricity, 2013)
[10] (Office of Electricity, 2013)
[11] (Gellings, 2011)
[12] (Gellings, 2011)

- The previous EPRI study '*The Power Delivery system of the future*' conducted in 2004 had stated Smart Grid would require a $15 billion net investment (this figure has been revised in this more recent report to reflect the newer specifications), over and above investment for load growth and correcting deficiencies with a benefit-to-cost rather of 4:1, with benefits accruing from:
    - Reduced energy losses and more efficient electrical generation
    - Reduced transmission congestion
    - Improved power quality
    - Reduced environmental impact
    - Improved US competitiveness, resulting in lower prices for all US products and greater US job creation
    - Fuller utilisation of grid assets
    - More targeted and efficient grid maintenance programs
    - Fewer equipment failures
    - Increased security through deterrence of organised attacks on the grid
    - Improved tolerance to natural disasters
    - Improved public and worker safety
- EPRI studies show the annual cost of power disturbances to the US economy ranges between $119 and $188 billion per year, with the societal cost of a massive blackout estimated to be in the order of $10 billion per event as established by the North American Electric Reliability Corporation report titled "Final Report on the August 14, 2003 Blackout in the US and Canada"
- Smart Grid is capable of providing significant contribution to the national goal of energy and carbon saving:
- One EPRI report states emissions reduction impact of a Smart Grid is estimated at 60 to 211 million metric tons of CO_2 per year in 2030.

Power Delivery (Improvements/ Benefits)	Attributes	Consumer (Improvements/ Benefits)
O&M Cost Capital Cost of Asset T&D Losses	*Cost of Energy (Net delivered life-cycle cost of energy service)*	End Use Energy Efficiency Capital cost, end user infrastructure O&M, End User infrastructure Control/Manage Use
Increased Power Flow New Infrastructure Demand Responsive Load	*Capacity*	Improved power factor, Lower End User infrastructure cost through economies of scale and system streamlining, expand opportunity for growth
Enhanced Security Self Healing Grid for Quick Recovery	*Security*	Enhanced Security and ability to continue conducting business and every day functions
Improve Power Quality and enhance equipment operating window	*Quality*	Improve Power Quality and enhance equipment operating window
Reduce frequency and duration of outages	*Reliability & Availability*	Enhanced Security Self Healing Grid for Quick Recovery Availability Included
EMF Management Reduction in SF6 (sulfur hexafluoride) emissions Reduction in cleanup costs Reduction in power plant emissions	*Environment*	Improved Esthetic Value Reduced EMF Industrial Ecology
Safer work environment for utility employees	*Safety*	Safer work environment for end-use electrical facilities
Value added electric related services	*Quality of Life*	Comfort Convenience Accessibility
Increase productivity due to efficient operation of the power delivery infrastructure Real GDP	*Productivity*	Improved consumer productivity Real GDP

Table from Electric Power Research Institute '*Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid'* **Page 4-2: Attributes of Types of Improvements Assured in the Value Estimation of the Future Power Delivery System**

- Another report by Pacific Northwest National Laboratory (PNNL) states the full implementation of Smart Grid is expected to achieve a 12% reduction in electricity consumption and CO_2 emissions in 2030
- Another EPRI report estimated Smart Grid, combined with a portfolio of generation and end-use options could reduce 2030 annual CO_2 emissions from the electric sector by 58% relative to 2005.

The report moves on to look at the kind of benefits and costs they feel a fully functioning Smart Grid would provide given set assumptions[13].

The benefits observe the effects on the cost of energy, capacity, security, quality, reliability & availability, environment, safety, quality of life and productivity. Then, using the figures from DOE and EPRI, they estimated values for the benefits of Smart Grid **[Appendix 1]**. Valuing economic, safety and environmental benefits, they concluded that the estimated value of a Smart Grid functioning between 2010-2030 to be in the range of $1,294-2,028 billion, representing a benefit-to-cost ratio for the USA of 2.8-6.0:1.

Although the EPRI report estimates large gains resulting from Smart Grid investment, some of the main components of the benefits, such as demand response and facilitating renewables, are shown in Appendix A to be gains made by society, such as environmental benefits, energy efficiency benefits and avoided generation[14]. Again, this demonstrates great social value, but little profit incentive for the investment, creating a need for government participation.

3.2 CenterPoint Energy Smart Grid

The UTC 2013 conference in Houston provided the opportunity to examine empirical findings on the use of Smart Grids. CenterPoint Energy, who deliver electricity to end-consumers in a 5,000 square mile (8,000 square kilometres) service area in greater Houston, Texas, the fourth largest city in the USA, have constructed a Smart Grid consisting of an Advanced Metering System (AMS) and Intelligent Grid (IG). CenterPoint provided data on costs and benefits from a utility perspective.

The AMS project, costing $640 million, was deployed over a 42 month period and serves 2.2 million customers with Smart Meters connected to the grid via a telecommunication network, allowing data to be easily collected and distributed.

From the perspective of the utility, CenterPoint benefited mostly from gains in operational efficiency, including savings associated with reduced meter reading activities, specifically labour, fleet and equipment costs. Smart Meters also saved consumers $24 million in 2012 alone through the elimination of fees formerly charged for services (such as connections and disconnections) now conducted remotely. The accuracy of month end revenue forecasting has been vastly increased by a reduction in the number of estimated values from 90% to 0.01%. This has boosted investor confidence.

CenterPoint Energy have also seen improvements in resilience and restoration activities resulting from the $138 million deployment of an Intelligent Grid in a portion of their

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[13] (Gellings, 2011)
[14] (Gellings, 2011)

service territory, which enables faster fault locating and remote switching. The modernised system has prevented 7.1 million customer outage minutes in 2012 and 2013, producing a 25% improvement in power restoration.

These improvements are due in-part to the broadband radio communications network. This allows CenterPoint Energy to collect real-time performance data on components of the Smart Grid and facilitates the use of the Smart Meters. In the case of an outage, the capability to use the integrated Intelligent Grid and communications data will enable the operator to locate outages to within 250ft (75 metres) so that response crews can be directed to the fault location, minimising the time required to restore service to customers.

The US Department of Energy recognized the value of CenterPoint Energy's investment in grid automation by awarding the company one of only six $200 million maximum Smart Grid Investment Grants, $150 million of which was used to accelerate the deployment period of AMS from five years to three and $50 million of which helped fund deployment of the Intelligent Grid in a portion of CenterPoint Energy's service territory.

3.3 Economic summary

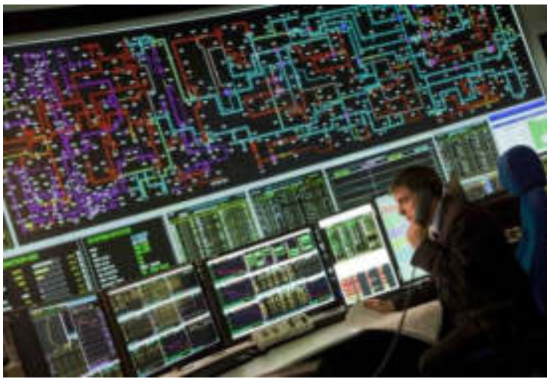
The evidence on Smart Grid suggests that a system servicing the whole of the USA would be of great economic benefit. Both the DOE and EPRI reports suggest that the percolation through the economy could lead to large multiplier benefits, the DOE citing a 2.5 GDP multiplier and EPRI estimating a total economic benefit of 2.8-6.0 times the initial investment. These figures exceed other forms of government action, as outlined in the DOE report.

The reports and the empirical evidence from CenterPoint Energy also provide examples of how the system would create savings for operators through more efficient procedures and better allocation and utilisation of their resources, with broadband radio communications necessary to facilitate the data flows required to function.

However, despite the wider benefit to society, the non-marketable nature of much of the improvements does not provide the profit incentive to make such an investment, exemplifying the public good nature. As such, government intervention would be required to access the large societal benefits.

4 SOCIETAL BENEFITS OF A SMART GRID

Whilst the Smart Grid does confer economic benefits, the majority of the benefits are from societal benefits. These are underprovided in the marketplace as firms would not profit from providing the good or service. When looking at Smart Grid, the main societal benefits are from safety & security, environmental benefits and reliability & interoperability.

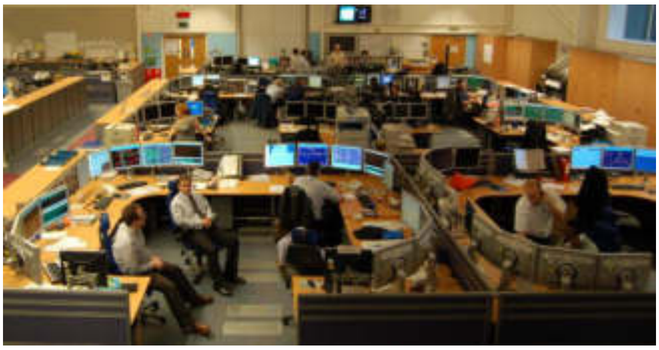


Modern grid control room

4.1 Safety & Security

Through data collection and control capabilities, Smart Grid offers better safety and security in a number of ways. End-users are protected as potentially hazardous and life threatening faults are detected and dealt with sooner using real-time monitoring.

Employees working on the grid are also safer as the monitoring allows pre-emptive action to be taken before dangerous situations develop, using predictive analysis to identify future problems and reacting to mitigate the effects. The self-healing aspect of Smart Grid allows the system to resolve problems and optimise the performance of the grid around the issue. When worker interaction is needed, Smart Grid is able to isolate components and provide better diagnostic data. Other monitoring equipment utilising the broadband capacity of Smart Grid, such as CCTV cameras, would also ensure their safety, monitoring conditions on-site and identifying people interfering with or sabotaging equipment.



Distribution grid control rooms have to ensure they are protected against all credible threats

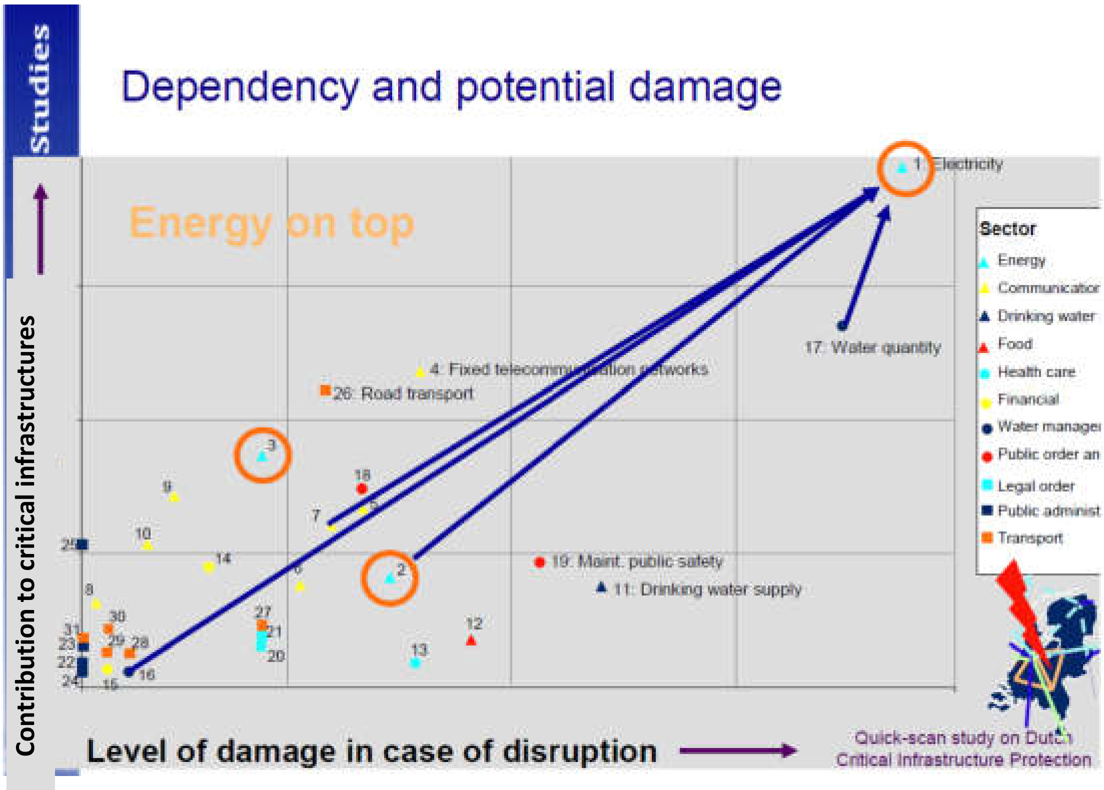
Cyber-Security concerns have become more prevalent in recent years as a result of moving towards a digital economy as many critical infrastructure industries are dependent on electrical power. The chart on the next page shows the dependency of all constituent parts of the critical national infrastructure on a reliable and dependable source of electrical energy as identified in a study on Critical Infrastructure Protection Energy Security by the Hague Centre for Strategic Studies in 2007. As radio communications and data monitoring are essential to creating a functioning Smart Grid, EPRI included a $3,729 million investment in Cyber-Security as part of their cost estimate.

Although Cyber-Security is a growing concern, the grid still needs to be defended from physical threats. EPRI identified a number of current physical threats to the grid[15]:

- System encroachment
  - Vegetation and structural
- Connector splice
- Shield wire lightning strike
- Falling aerial ball marker
- Insulator failure
  - Cracking or contamination
- Phase conductor broken
- Aging foundations and structural damage
- Fallen line
- Vandalism or terrorism

Entrance to a coal fired power station protected by electrified fences and razor wire to defend against intrusion by environmental protestors, measures unimaginable a generation ago

[15] (Gellings, 2011)



No.	Sector	Product or service
1	Energy	Electricity
2		Natural gas
3		Oil
4	Telecommunications	Fixed telecommunication networks services
5		Mobile telecommunication services
6		Radio communication and navigation
7		Satellite communication Incl. GPS & navigation
8		Broadcast services
9		Internet access
10		Postal and courier services
11	Drinking water	Drinking water supply
12	Food	Food supply and food safety
13	Health	Health care *
14	Financial	Financial services and financial infrastructure (private)
15		Financial transfer services (government)
16	Retaining and managing surface water	Management of water quality
17		Retaining and managing water quantity
18	Public Order and Safety	Maintaining public order
19		Maintaining public safety
20	Legal order	Administration of justice and detention
21		Law enforcement
22	Public administration	Diplomacy
23		Information provision by the government
24		Armed Forces / Defence
25		Public administration
26	Transport	Road transport
27		Rail transport
28		Air transport
29		Inland navigation
30		Ocean shipping
31		Pipelines

The chart shows the dependency of all constituent parts of the critical national infrastructure on a reliable and dependable source of electrical energy.

Source: Critical Infrastructure Protection Energy Security, The Hague Centre for Strategic Studies, a TNO Initiative, Eric Luiijf MSc, 10 July 2007.

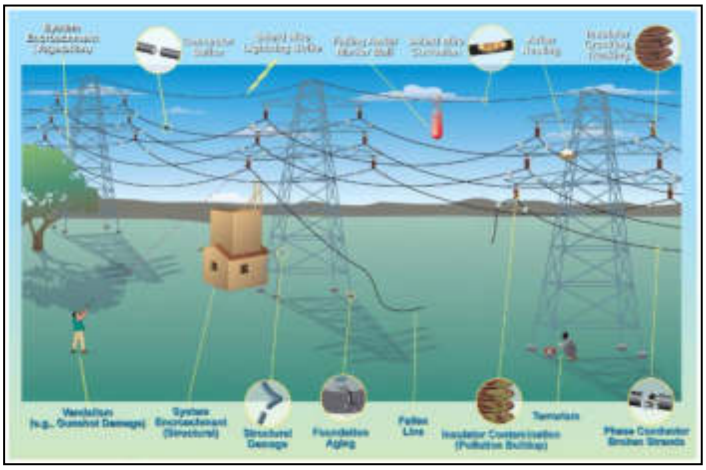


Figure 5-1 from Electric Power Research Institute
'*Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid'*

Page 5-6: Illustration of Sensor Needs for Transmission Lines and Towers

The use of Intelligent Electronic Devices demonstrate how the Smart Grid would be able to offer higher levels of security as it provides data about components within the grid, allowing more informed decisions to be made

The EPRI report on Smart Grids includes an estimated value of the security and safety benefits associated with the system. The estimated value of the safety benefits was given as $13 billion to the US economy while the security benefits were valued at an estimated $152 billion[16].

4.2 Environmental

The modernising of the electricity grid is essential if the USA is to meet their environmental goals. With the DOE pushing for wind generation to account for 20% of electricity generation by 2030[17], the forecast growth of green goods such as domestic electric vehicles[18] and the Renewable Portfolio Standards now adopted in areas of North America[19], the Smart Grid needs to be able to adapt to the changes in supply and demand for electricity in the coming years. Furthermore, the grid itself must contribute to meeting green objectives – reducing losses from within the system and more efficiently allocating resources.

While distributed generation from renewable sources has taken a major role in environmental plans around the World, little consideration had previously been made for the effects on the grid. Recent outages in Europe during 2003 and 2006 highlighted the problem of introducing distributed sources onto a grid designed to handle bulk generation. An investigation by the European Regulators' Group for Electricity and Gas into the cascade outage in 2006, affecting 15 million people, identified the automatic tripping and uncoordinated reconnecting of such generation sources as detrimental to the restoration:

"Generation from renewable energy sources and particularly wind generation are of special concern here. At a national level, incentives are introduced in order to increase generation from renewable sources without creating too many barriers to entry for these units. When decentralised generators begin to represent a significant part of the generation, these generators have to participate to the security of the grid in due proportion"[20]

[16] (Gellings, 2011)
[17] (Gellings, 2011)
[18] (Gellings, 2011)
[19] (Gellings, 2011)
[20] (European Regulators' Group for Electricity and Gas, 2007)

"The uncoordinated behaviour during the disturbance worsened the consequences and introduced a risk for more sever instability."[21]

These statements by the European Regulator serve as a stark reminder that integrating new decentralised generation requires modernisation of the grid. With EPRI predicting a further 135 GW of green generation[22], Smart Grid is essential to a successful environmental program.

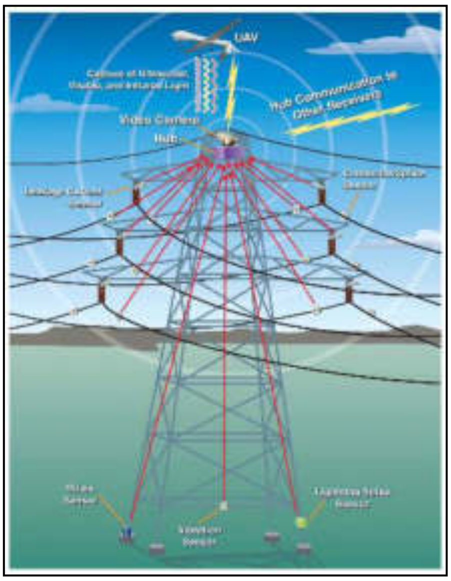


Figure 5-2 from The Electric Power Research Institute '*Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid'***, page 5-7: Image Showing a Single Structure Illustrating Some of the Concepts. EPRI extensively identifies the types of threats that a grid may face, and how protection may be applied using the functionality of Smart Grid. [Appendix 2]**

Smart Grid is not only necessary to facilitate developments in generation, but also the future interaction of customers with the grid. Predicted demand changes such as the growth of electric cars, along with home generation, are likely to strain the current grid. The Energy Information Agency's Annual Energy Outlook 2010 predicted that demand would increase at 1% each year between 2008-2035[23]. The modernised electricity grid would look to manage the system more efficiently to prevent imbalances with built-in features such as demand predicting programs, Dynamic Thermal Circuit Ratings and storage facilities. Smart Meters also have the potential to reduce electricity demand growth. CenterPoint Energy's customers can access smart meter data via the 'Smart Meter Texas' web portal energy analysis tool from Retail Electric Providers (who sell electricity to consumers in the restructured Texas market) and In-Home Displays. 70% of consumers surveyed by CenterPoint who have engaged with these devices or used other means to monitor their usage have taken steps to reduce consumption. The EPRI report estimated the functionality of Smart Grid has the potential to reduce demand growth from 1% to 0.68% per year and the potential to reduce emissions by an estimated 60 to 211 million tons of CO_2 per year in 2030[24].

Environmental benefits can also be made at an operational level. Efficiency gains are made with smart Grid as electricity is transmitted more efficiently, reducing transmission and distribution losses[25] and optimising the use of assets with data monitoring. Automated grid

[21] (European Regulators' Group for Electricity and Gas, 2007)
[22] (Gellings, 2011)
[23] (Gellings, 2011)
[24] (Gellings, 2011)
[25] (Gellings, 2011)

actions have also had benefits with worker patrols, with PECO Energy Company estimating that it avoided 7,500 dispatch crews in 2005 by using an outage management system to confirm if customer-reported outages were accurate[26]. Following the installation of Smart Meters and the advent of electronic service connection and disconnection, CenterPoint have saved over 700,000 gallons (2.65 million litres) of fuel from using electronic readings.

EPRI also established an estimate figure for the environmental benefit of Smart Grid, looking at the ability to facilitate renewable generation, enhance efficient use of electricity and reduce greenhouse gas emissions[27], totalling between $102-390 billion[28]. This has the potential to be one of the key benefits of Smart Grid, but lacks the profit incentive – it is not in the interest of energy companies to reduce consumption. This is similar to most environmental markets, which require government participation to represent true social value.

4.3 Reliability & Interoperability

The resilience of the electricity grid in day-to-day running or under abnormal conditions has been the main driving factor in the move towards Smart Grid. Recent outages in the USA, Europe and India have caused colossal economic loss and devastated lives as society ground to a halt. In the aftermath of natural disasters, the interoperability of energy is arguably even more important as a tool for restoration and saving lives.

Power quality issues, caused by inconsistencies such as drops in voltage or frequency, can lead to momentary outages. Although brief, EPRI estimated that Smart Grid could have an annualised value of close to $5 billion in preventing momentary outages[29]. In cases of power quality issues, the ability of Smart Grid to monitor the network in real-time and make automated 'self-healing' responses has the potential to significantly reduce this cost. CenterPoint Energy found the modernised grid greatly increased the reliability, preventing 7.1 million customer outage minutes in 2012 and 2013, improving restoration by around 25%.

It is not realistic to expect a Smart Grid solution to prevent all outages currently experienced in the USA. In some scenarios, specifically in large scale natural disasters, wide scale outages are likely as components become damaged beyond the ability to isolate or self-heal whilst still delivering electricity. These events often have enormous socio-economic costs attached to them due the prolonged timescale, where there may still be life threatening conditions. Therefore, while Smart Grid may not be capable to prevent the initial outage, the system could dramatically reduce the social costs by limiting the impact and improving restoration.

[26] (Gellings, 2011)
[27] (Gellings, 2011)
[28] (Gellings, 2011)
[29] (Lordan, 2004)

5 OUTAGE MANAGEMENT

5.1 Global perspective

A number of outages across the World in recent years have served as costly reminders of the weakness in outdated electricity grids and how much society depends on them. An outage in Northern and Eastern India in July 2012 saw 600 million people, around half of the population, lose electricity across a 2 day period, causing public transport to cease, traffic to seize up and hospitals to fall back on backup generation during one of the hottest parts of the year[30].

Utility radio towers are often in remote locations

In Europe, major outages occurred in 2003 and 2006. Italy experienced a mass outage in September 2003, when summer tree growth beneath transmission lines between Switzerland and Italy led to almost the entire country losing power for up to 20 hours – affecting around 55 million people[31]. About 110 trains halted across the country, trapping 30,000 people[32], while 3 deaths were attributed to the blackout, which affected domestic lighting and traffic lights[33]. In November 2006, a series of events caused a cascade failure in the Western, South Eastern and North Eastern sub-grids in Europe, blacking out 15 million homes across several countries[34]

In the USA, there have been a number of notable incidents of power outages that have drawn attention to the energy grid, including the 2003 North Eastern Outage and Hurricanes Katrina, Ike and Sandy. Although it is unlikely that the entire loss of power would have been avoided, particularly in the hurricanes, Smart Grid could prove to have societal value from increased resilience during storms, allowing faster restoration of power.

5.1.1 *August 14th 2003: North Eastern Blackout*

The blackout in North East USA and the Canadian province of Ontario that occurred on 14th August 2003 affected an estimated 50 million people, losing 61,800 MW[35]. The event cost, as approximated by most sources, $4 – 10 billion[36], $5.08 -12.70 billion in 2013 USD[37], with ICF Consulting estimating $6.8 – 10.3 billion[38] and Brattle estimating $6 billion[39].

[30] (BBC News, 2012)
[31] (Ortis, 2005)
[32] (BBC News, 2003)
[33] (Hines & Talukdar, Reducing the costs of disturbances to the electric power network, 2004)
[34] (European Regulators' Group for Electricity and Gas, 2007)
[35] (Muir & Lopatto, 2004)
[36] (Hines & Talukdar, Reducing the costs of disturbances to the electric power network, 2004)
[37] Value inflated to 2013 USD from 2003 USD (US Bureau of Labor Statistics, 2013)
[38] (ICF Consulting, 2004)
[39] (Graves & Wood, 2003)

The documentation in *Electrical Blackouts: A systematic Problem*[40] show how an initial failure was exacerbated by a lack of data, both for individual operators and being shared between operators, and the inability to react on data received. The article quotes the concluding remarks from the taskforce charge with investigating the incident:

"Training was inadequate for maintaining reliable operation . . . internal control room procedures and protocols did not prepare them adequately to identify and react to the August 14 emergency."

Additional factors they also identified included: “"inadequate interregional visibility over the power system; dysfunction of a control area's SCADA/EMS [data system]; and lack of adequate backup capability to that system."

The blackout was costly to US business, with the Ohio Manufacturers' Association (OMA) estimating a cost of $1.08 billion to Ohio manufacturers, with all companies reporting a “complete shutdown in operations”[41]. This clearly affected businesses in the area, with another study finding almost 11% of firms were considering their future location following the blackout[42]. A number of businesses suffered severely; Marathon Oil Corporation's Ashland refinery had to evacuate a 1-mile area around the perimeter of the 183-acre complex following an explosion on-site[43], Republic Engineering Products filed for bankruptcy nearly 2 months after the blackout, citing an on-site explosion caused by the blackout as a contributing factor, an businesses in 'Chemical Valley' near Sarnia, Ontario lost an estimated $10-20 million per hour[44].

Residents suffered from the blackout, which started at 4pm EDT, as transport systems jammed, disrupting people either from congestion or other businesses, such as banks, supermarkets, airports, restaurants and entertainment establishments, closing in the conditions.

In scenarios such as the August 14th 2003 blackout, Smart Grid would have been highly valuable. The events preceding the outage show that a lack of data and poorly coordinated responses led to the cascade failure. The real-time data analysis and automated remove responses that Smart Grid is capable of providing would have prevented a large proportion of the damage by balancing the load, if not eliminating the effects entirely.

[40] (Apt, Lave, Talukdar, Morgan, & Ilic, 2004)
[41] (Electricity Consumers Resource Council, 2004)
[42] (Electricity Consumers Resource Council, 2004)
[43] (Electricity Consumers Resource Council, 2004)
[44] (Electricity Consumers Resource Council, 2004)

5.1.2 August 2005: Hurricane Katrina and Hurricane Rita

Some mitigation measures are relatively simple, such as mounting critical infrastructure a few metres above ground

Hurricane Katrina, followed by Hurricane Rita soon after, is on record as the most costly natural disaster to have befallen the USA. The cost of Katrina was estimated at $108 billion[45] in 2005, roughly $129 billion in 2013 USD[46], causing an estimated 1200 deaths[47] and widespread flooding, including around 80% of New Orleans.[48]

The economic damage from the storm largely came from damage to key industries such as tourism, which did not recover until 2010[49], and port operations (including oil)[50]. The direct and indirect costs of the inoperability of the Port of New Orleans in the following 7 months are estimated to have costs in the order of $62.1 billion[51]. Meanwhile, 115 offshore oil platforms were missing, sunk or went adrift[52] and several oil and gas refineries remained unusable for more than a week, contributing to an estimated 3 million barrels/day contraction in US petroleum production[53]. This reduced total US petroleum output by around 19%[54]. The effect on domestic fuel prices was so severe that the US government released fuel reserves onto the market to lessen the supply shock.[55]

The fuel inflation was just one element of the costs to residents of the storm. New Orleans suffered greatly as the population fell from 458,000 prior to Katrina to a low of 137,000 four months after Katrina[56], with employment down 40% in September 2005 compared to one year earlier[57]. Half of the 1.3 million evacuees from the metropolitan area could not return within the first month of the aftermath, with many key workers remaining away longer[58] with concerns about public health and the infrastructure[59]. Many residents throughout the region suffered great disruption to their normal lives, with 300,000 homes destroyed or made uninhabitable[60].

Billy Ball, senior Vice President of Transmission Planning and Operations for Southern Company during Katrina, described the hurricane recovery as "one of the biggest

[45] (Blake, Landsea, & Gibney, 2011)
[46] Value inflated to 2013 USD from 2005 USD (US Bureau of Labor Statistics, 2013)
[47] (Blake, Landsea, & Gibney, 2011)
[48] (Dolfman, Wasser, & Bergman, 2007)
[49] (Gordon, Moore II, Park, & Richardson, 2010)
[50] (Dolfman, Wasser, & Bergman, 2007)
[51] (Gordon, Moore II, Park, & Richardson, 2010)
[52] (Gordon, Moore II, Park, & Richardson, 2010)
[53] (Gordon, Moore II, Park, & Richardson, 2010)
[54] (Amadeo, 2012)
[55] (Amadeo, 2012)
[56] (Gordon, Moore II, Park, & Richardson, 2010)
[57] (Gordon, Moore II, Park, & Richardson, 2010)
[58] (Gordon, Moore II, Park, & Richardson, 2010)
[59] (Dolfman, Wasser, & Bergman, 2007)
[60] (Amadeo, 2012)

operational challenges" in the history of the Southern Company[61] as 65% of the Southern Company distribution system was damage, including 9,000 poles, 2,300 transformers and many high voltage wires[62]. Before the storm, $7 million was spent on securing equipment and logistical support[63], including bringing in additional workers and living facilities to house 11,000 workers. Southern Company's total cost to restore service operations in Mississippi was estimated to be more than $250 million[64], nearly $300 million in 2013 USD.

During the restoration operation, that saw 75% of customers restored in 9 days and full restoration in 12 days, resilient communications were vital. In the aftermath of the storm, the only communication network functioning on the Mississippi coast region, one of the worst areas hit, was the utility telecommunications network[65]. Due to the high interoperability requirements for the network, near-full operation telecommunication ability was restored just 3 days after Katrina[66].

While Smart Grid would clearly be unable to prevent the storm damage to the distribution network, the importance of resilient communications in restoration operation is clearly demonstrated. Significant amounts of the social cost to residents and economic costs to key industries could be avoided if power could be restored faster, allowing pumping and maintenance equipment to be deployed sooner and resume normal service quicker.

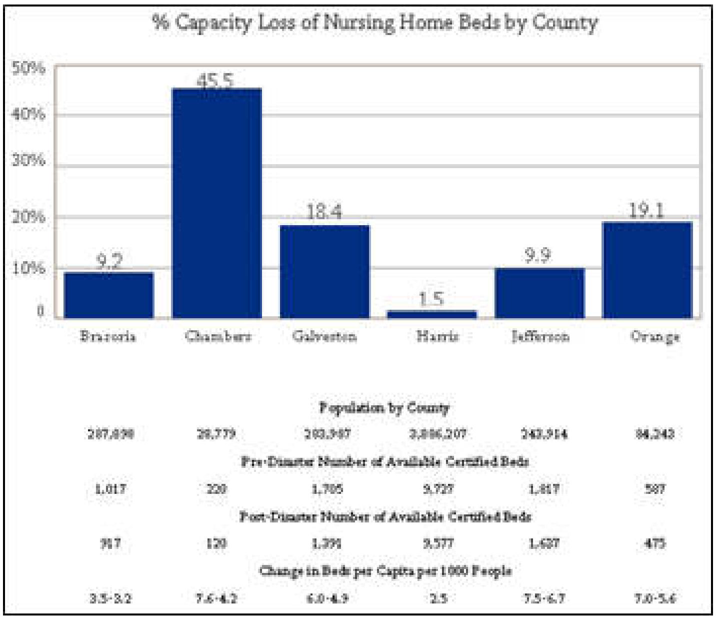
5.1.3 *September 2008: Hurricane Ike*

Hurricane Ike was a category 2 hurricane that hit Texas in 2008, costing the United States $29.5 billion[67], $32 billion in 2013 USD[68]. Throughout the Gulf region, the storm is said to have directly claimed 103 lives[69] although as many as 64 further deaths were attributed to Ike in Texas indirectly though causes such as electrocution, carbon monoxide poisoning and health conditions[70]. CenterPoint Energy, the largest electricity provider in Texas, lost power to over 2.1 million customers (over 90%) with restoration taking up to 20 days[71]. If the 25% improvement in restoration achieved thus far with the company's Intelligent Grid could be replicated in hurricane conditions, a very large number of customers would have power restored many days sooner.

Modern electricity substation in Houston

The storm caused a great deal of economic damage, with some stating the total economic damage for the next 12 months could be close to $142 billion[72] **[Appendix 3]**. The storm

61 (Ball, 2006)
62 (Ball, 2006)
63 (Ball, 2006)
64 (Ball, 2006)
65 (Ball, 2006)
66 (Ball, 2006)
67 (Blake, Landsea, & Gibney, 2011)
68 Value inflated to 2013 USD from 2008 USD (US Bureau of Labor Statistics, 2013)
69 (Berg, 2009)
70 (Berg, 2009)
71 Figures computed from (CenterPoint Energy, 2008)
72 (Texas Engineering Extension Service, 2011)



Federal Emergency Management Agency 'Hurricane Ike Impact Report', page 6: Percentage Capacity Loss of Nursing Home Beds by County

closed 19% of the USA refining capacity[73] and caused $710 million damage to the University of Texas Medical Branch (UTMB)[74] which continued to run at a $40 million a month loss after the storm[75]. As shown in the tables, agriculture, fishing and tourism industries suffered too as a result of the storm. The wide spread destruction to small businesses raised concerns that they would not reopen[76], damaging the recovery.

Large infrastructural damage was a concern as it would hamper the immediate restoration and future economic recovery of businesses, particularly following the recent down turn in the US economy. The State of Texas identified $53.7 million worth of repairs to roads and bridges, $78.1 million to remove debris and $2.4 billion for infrastructural repairs to navigable waterways, ports and coastlines.[77] As with Katrina in 2005, port operations were a key economic driver for the region. It was estimated the City of Galveston lost 85% of their base business.[78]

The residents in some of the more remote areas suffered greatly – an area of Oak Island was left with only 50 of the 350 houses there, 25 of which were uninhabitable[79]. The repair cost for housing was estimated to total $3.4 billion.[80] Vital services throughout the area were damaged, with five hospitals in the area still closed in October and one running at restricted capacity[81]. Nursing homes suffered too, a particular concern given the vulnerable nature of the inhabitants, as the total number of available beds fell by nearly 10% for the area, Chambers County suffering the most with a 45% reduction[82]. Child care, another vulnerable service, was seriously affected, with 68% suffering damage to the facilities, 12% of which indicated they were unlikely to reopen[83].

[73] (Bloomberg, 2013)
[74] (Federal Emergency Management Agency, 2008)
[75] (Federal Emergency Management Agency, 2008)
[76] (Federal Emergency Management Agency, 2008)
[77] (Federal Emergency Management Agency, 2008)
[78] (Federal Emergency Management Agency, 2008)
[79] (Federal Emergency Management Agency, 2008)
[80] (Federal Emergency Management Agency, 2008)
[81] (Federal Emergency Management Agency, 2008)
[82] (Federal Emergency Management Agency, 2008)
[83] (Federal Emergency Management Agency, 2008)

Contaminated water and debris scattered from buildings and the coastline posed significant health risks. Furthermore, 34 people were admitted to already struggling health care services having suffered carbon monoxide poisoning from using backup generators inside[84].

As with Katrina, a lack of power prevented a faster restoration. The FEMA impact report states that "A significant problem after the Hurricane was a lack of power with no backup generators in place"[85]. Ensuring a resilient power supply is vital to maintaining key public services, such as medical, fire and police services and safe re-establishment of infrastructure to the area.

5.1.4 October 2012: Hurricane Sandy

Hurricane Sandy, a 'Frankenstorm' measuring 1,100 miles in diameter[86] recently hit New York, having passed through the Caribbean. The storm is thought to be the second costliest storm in US history at estimated $80 billion[87], $81.4 billion in 2013 USD, having killed 130 people[88].

Although not as powerful as previous storms that have hit the USA, the size of Sandy meant the damage was widespread. Within 24 hours of Sandy making landfall, 8 million customers lost power. The infrastructure, which is not as prone to hurricanes as that in Texas or Louisiana, suffered from high winds and the storm surge. The 7 subways under the East River flooded during the storm as did a number of tunnels for the road network[89]. 5 of the 14 waste water treatment plants for the city of New York were in Mandatory Evacuation Zones designated before the storm due to their low-lying geography, causing further health risks as they flooded[90]. The storm famously closed the New York Stock Exchange for 2 days – the first time it has closed in 30 years[91]. 111 homes were also destroyed by a fire fuelled by the high winds at Breezy Point, Queens as flooding kept fire fighters away[92].

Restoration following Sandy was a significant challenge, given the size of the storm. Major public network providers were unavailable, a number of power stations had been affected and a period of snow and further rain followed, hampering efforts and exacerbating the outage situation. An important part of the restoration effect for PSG&E was the Mutual Assistance Group (MAG) which shares resources across operators at time of crisis. $2.5 million was spent on the MAG, bringing in 70,000 additional workers[93] and utilities were declared first responders following Sandy, giving them priority access to scarce resources.[94] Although PSG&E managed to re-establish 1 million of the 1.9 million customers who lost power due to Sandy in the first 3 days, a further 10 days were needed to reach 95% restoration[95]. PSG&E spend $250 – 300 million in their restoration operations.

Hurricane Sandy, with the following bad weather and wide geographical effect, has led to a number of proposals aiming to improve resilience in energy networks, including a possible

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[84] (Dorell, 2008)
[85] (Federal Emergency Management Agency, 2008)
[86] (Linder, Peach, & Stein, 2013)
[87] (Johnsson & Chediak, 2012)
[88] (Abel, Bram, Deitz, & Orr, 2012)
[89] (New York Times, 2012)
[90] (New York Times, 2012)
[91] (BBC News, 2012)
[92] (New York Times, 2012)
[93] (Sandalow, 2012)
[94] (Sandalow, 2012)
[95] (The Associated Press, 2012)

$3.9 billion investment from New Jersey Board of Public Utility into harden utility infrastructure. Smart Grid and Smart Meters would be of great benefit in mapping downed lines and outages in these scenarios, as well as using automated processes to reduce damage to capital. This would vastly cut down the time taken to get a scale of the damage, especially in bad conditions. Charlie Fisher, head disaster management consulting group Witt Associates, views as vital to faster restoration:

"One of the most significant factors in the length of a restoration effort is how long it takes you to get that initial assessment of the damage... I've seen it take 4 days or longer."[96]

Using Smart Grid, the network would be able to communicate the status of components sooner, allowing for targeted patrols to efficiently restore power where it is not able to 'self-heal'. Furthermore, Smart Meters would be able to identify where power had been restored on the grid but homes remained without power due to other faults.

Electricity networks are becoming increasingly complex

5.1.5 July 2012: EPB Chattanooga

The functionality of Smart Grid under adverse conditions was proven in July 2012, when Tennessee was hit during a 'derecho' (a widespread, long-lived, straight-line wind storm). EPB Chattanooga had installed a Smart Grid in early 2011, as well as full Smart Meter rollout for their 170,000 customers[97].

The Smart Grid included 1,200 automated switches[98] in the distribution grid which allowed remote, automatic responses to prevent failures and enable self-healing – a key feature of Smart Grid. Following the storm, it was found that the modernised grid had produced a 55% reduction in the duration of outages, avoiding 58 million customer outage minutes[99]. It was also found that most customers were restored about 1.5 days earlier than had previously been possible[100]. The outage reductions provided an operational saving to EPB of about $1.4 million for the event[101].

Although the value is unknown, there would also be large social and economic benefits attached to preventing such a large number of outage minutes. Many people did not lose power or only suffered momentary outages, considerably reducing disruption as the majority of businesses would be able to remain open and consumers could continue with their arrangements. Also following on from the storm, the reductions in restoration time would have reduced the social impact. Retaining electrical supplies would also have been

[96] (Johnsson & Chediak, 2012)
[97] (Tweed, 2012)
[98] (Tweed, 2012)
[99] (Tweed, 2012)
[100] (Tweed, 2012)
[101] (Tweed, 2012)

crucial to first responders, allowing them to operate more efficiently during dangerous conditions.

There would also have been great economic benefit as more businesses could reopen following the storm. Other storms have shown damaged or inaccessible infrastructure to be some of the most damaging and costly elements of storms as they hamper restoration attempts and prolong disruption, which can overwhelm affected businesses. Maintaining power during a storm is greatly beneficial to society and the economy as underground and over ground trains can operate and airports remain open. Equipment designed to protect people, such as street lights and traffic lights, continue to work – preventing fatalities that have been seen previously.

Although results are likely to vary in stronger conditions such as hurricanes, the evidence from EPB supports the view that Smart Grid could have a role in reducing the impacts of natural disasters on society and the economy. The data also supports CenterPoint's findings that a Smart Grid can dramatically reduce outage minutes and even suggest that the effect is greater under adverse conditions.

5.2 Valuation of an Outage

When looking at socio-economic value of resilience and interoperability in preventing outages, it is important to examine and evaluate the costs of the outage to all users. As the examples from the USA show, the outages had a significant effect on residents as well as businesses, although this can be over looked. To perform a complete analysis, therefore, this must also be incorporated.

The previous study had estimated the value of reliable electricity to be found in the range of 50-150 times the retail value of electricity. This report will consider results of other reports studying this field and how they compare with the previous findings.

Outage Scenario	Season	Day-of-week	Length and Time	Pre-notification
C1	Summer	Weekday	4 hrs: 5p.m.-9p.m.	No
C2	Winter	Weekday	4 hrs: 10a.m.-2p.m.	No
C3	Summer	Weekday	4 hrs: 11a.m.-3p.m.	No
C4	Winter	Weekend	4 hrs: 11p.m.-3a.m.	No
C5	Summer	Weekday	1 hr: 1p.m.-2p.m.	No
C6	Summer	Weekday	8 hrs: 9a.m.-5p.m.	No
C7	Summer	Weekday	4 hrs: 11a.m.-3p.m.	Yes-2 hours
C8	Winter	Weekend	4 hrs: 11p.m.-3a.m.	Yes-72 hours

Table ES-2 from Hagler Bailly 'Volume 1: SCE 2000 Value of Service Reliability Study', page ES-8: Outage Scenarios for Commercial, Industrial and Agricultural Premises

5.2.1 *'Volume 1: SCE 2000 Value of Service Reliability Study', Hagler Bailly*[102]

The report from Hagler Bailly looked to establish the Value of Service (VOS) reliability for the customers of Southern California Edison Company (SCE). The VOS was calculated for 3 user groups: Residents, Small and Medium sized Commercial, Industrial and Agricultural premises (SMP) and Large sized Commercial, Industrial and Agricultural premises. The study examined a given set of scenarios, testing the effects of time of year, time of day and pre-notification, though not weather conditions[103]

The analysis of Residents' VOS looked at their willingness-to-pay (WTP) to avoid outages in given scenarios. The WTP is used as there is no accurately or precisely direct market for the benefits to residents, which include avoiding food spoilage costs, hassle, safety or annoyance due to lack of lights or discomfort. The results found that the WTP of residents was higher for evening periods, when they are most likely to be home. The WTP also increases with time, although the WTP to avoid a 4-hour outage is only twice that of a 1-hour outage, suggesting the most costly period of an outage occurs in the first hour.[104]

For any given scenario, the most important factor determining WTP was the presence of an individual in the household with health conditions, since loss of power could be severely detrimental to their health. Other important determinants were the reliance on electricity for climate control, factors relating to the likelihood that some is home during the outage including someone working from home and the presence of young children[105].

[102] (Bailly, 2000)
[103] (Bailly, 2000)
[104] (Bailly, 2000)
[105] (Bailly, 2000)

Below (adapted) Table ES-4 from Hagler Bailly '*Volume 1: SCE 2000 Value of Service Reliability Study*', page ES-12: Average Residential Willingness-to-Pay Estimates by Outage Scenarios

Outage Scenario	Mean WTP (weighted) (Unweighted Standard Error)			$/Unserved kWh : Retail electricity $/kWh
	$/Event	$/Annual MWh	$/Unserved kWh	
R1. Summer Weekday, 5 p.m. – 9 p.m., No Pre-Notification	7.64 (0.89) n=457	1.41 n=457	1.75 n=457	16
R2. Winter Weekday, 10 a.m. – 2 p.m., No Pre-Notification	5.86 (0.73) n=448	1.05 n=448	2.45 n=448	22
R3. Summer Weekday, 11 a.m. – 3 p.m., No Pre-Notification	6.18 (0.89) n=456	1.12 n=456	1.84 n=456	17
R4. Winter Weekend, 11 p.m. – 3 a.m., No Pre-Notification	5.57 (0.67) n=447	0.97 n=447	2.51 n=447	23
R5. Summer Weekday, 6 p.m. – 7 p.m., No Pre-Notification	3.77 (0.37) n=452	0.64 n=452	3.43 n=452	31
R6. Summer Weekday, 1 p.m. – 9 p.m., No Pre-Notification	8.35 (0.75) n=453	1.41 n=453	1.01 n=453	9
R7. Summer Weekday, 5 p.m. – 9 p.m., 2 Hour Pre-Notification	5.21 (0.45) n=444	0.87 n=444	1.19 n=444	11
R8. Winter Weekday, 10 a.m. – 2 p.m., 72 Hour Pre-notification	3.52 (0.37) n=440	0.61 n=440	1.47 n=440	13

Assuming constant electricity prices for residents of $0.1089/kWh[106], the prices show an estimated WTP of between 9 and 31 times the retail value of electricity.

The study defines an SMP as a business premise with an annual electricity consumption of less than 2.5 million kWh. These premises comprised of 14% manufacturing, agriculture, mining or construction, 24% retail sales, eating or drinking places, wholesale or warehouse and 61% service or other business types including agricultural pumps[107]. The results showed that consumption did not vary significantly across business types, but did across power usage groups. The cost of outages to SMPs was calculated using three methods: WTP, Net Lost Product (NLP) and Idle Factor Cost (IFC)[108].

NPL = [Value of lost production, sales or services + restart cost + damage to equipment/building + cost to run backup] – [Lost production sales or service recovered + material savings + fuel savings +labour savings]

IFC = Salaries/wages paid + damage/spoilage to materials + restart costs + overhead expenses + damage to equipment/building + cost to run backup

[106] Price taken from (U.S. Energy Information Administration, 2013)
[107] (Bailly, 2000)
[108] (Bailly, 2000)

NPL and IFC represent contingent valuations of lost product, valuing the market value of goods. Whilst residents would not be able to provide a market value of the benefits they gain from avoiding outages, SMPs could be able to from their records.

Although these values should equal the WTP, the study found they do not. The contingent values while costing each component, does not capture annoyance, lost value of leisure or other non-monetary factors. On the other hand, WTP requires participants to accurately value an unfamiliar hypothetical situation. Due to these limitations, the study provided each set of figures. Despite differences in the values they returned, all measures found higher usage groups to place higher value on electricity than lower usage groups. However, higher WTP was more consistently related to higher Annual Revenue than the other measures[109], suggesting an income effect - ceteris paribus, greater Annual Revenue creates a higher VOS. The study also found that 15% of SMPs have backup generation, with 74% of these respondents stating they were to ensure safe shutdown[110].

[109] (Bailly, 2000)
[110] (Bailly, 2000)

Below (adapted) Table ES-9 from Hagler Bailly '*Volume 1: SCE 2000 Value of Service Reliability Study*', page ES-21: Average Small/Medium Commercial, Industrial and Agricultural Premises Value of Service Estimates by Outage Scenarios

Outage Scenario	Dollars Per Unserved kWh (weighted) (weighted S.E.)			$/kWh unserved : Retail Electricity $/kWh		
	WTP	NLP	IFC	WTP	NLP	IFC
C1. Summer Weekday, 5 p.m. – 9 p.m., No Pre-Notification	13.94 n=499	245 (59) n=618	206 (55) n=647	147	2587	2175
C2. Winter Weekday, 10 a.m. – 2 p.m., No Pre-Notification	14.07 n=508	168 (26) n=579	122 (22) n=619	149	1774	1288
C3. Summer Weekday, 11 a.m. – 3 p.m., No Pre-Notification	11.82 n=511	141 (26) n=569	87 (15) n=613	125	1489	919
C4. Winter Weekend, 11 p.m. – 3 a.m., No Pre-Notification	12.09 n=489	171 (41) n=566	188 (56) n=590	128	1806	1985
C5. Summer Weekday, 1 p.m. – 2 p.m., No Pre-Notification	18.91 n=506	559 (152) n=577	412 (77) n=611	200	5903	4351
C6. Summer Weekday, 9 a.m. – 5 p.m., No Pre-Notification	11.26 n=505	88 (13) n=560	74 (10) n=587	119	929	781
C7. Summer Weekday, 11 a.m. – 3 p.m., 2 Hour Pre-Notification	10.86 n=510	146 (27) n=548	137 (25) n=579	115	1542	1447
C8. Winter Weekend, 11 p.m. – 3 a.m., 72 Hour Pre-notification	17.52 n=486	77 (16) n=524	69 (15) n=547	185	813	729

Using the total electricity price of $0.0947/kWh[111], the WTP has an estimated value between 115 and 200 times the retail price of electricity, the NLP between 813 and 5,903 times and IFC between 729 and 4,351 times.

The Large Premises are defined as a business premise that has an annual electricity consumption of more than 2.5 million kWh. Due to the size of the businesses involved, only contingent value data was reported as it was considered WTP estimation would be inaccurate[112]. The results found that the data on VOS was heterogeneous for Large Premises. The report suggests this is likely due to the greater diversity affecting outage costs such as product or service provided, types of process or operation at premise, hours of operation, equipment at site, square footage, annual revenue and electricity consumption[113].

It was also found that only 6% of the total Large Premises generated their own electricity, with 9% of premises in retail/food/service/other business and 3% (2%) in manufacturing/agriculture/mining/construction (continuous manufacturing). It was also

[111] Price taken from (U.S. Energy Information Administration, 2013)
[112] (Bailly, 2000)
[113] (Bailly, 2000)

found that about 44% had a form of emergency back-up, with 74% in retail/food/service/other business, 30% in continuous manufacturing and 3% in manufacturing/agriculture/mining/construction. Continuous manufacturing premises were found to have lower net costs, on average, than other businesses. The report proposed that this is due to having made investment in equipment to cope with outages or cost-effective solutions[114].

Below (adapted) Table ES-12 from Hagler Bailly '*Volume 1: SCE 2000 Value of Service Reliability Study*', page ES-27: Average Large Commercial, Industrial and Agricultural Premises Net Costs by Outage Scenarios

Outage Scenario	Average Net Costs (weighted) (Unweighted Standard Error)			$/Unserved kWh : Retail electricity $/kWh
	$/Event	$/Annual MWh	$/Unserved kWh	
C1. Summer Weekday, 5 p.m. – 9 p.m., No Pre-Notification	104,634 (28,179) n=92	0.0111 (0.0025) n=90	36 (10) n=90	380
C2. Winter Weekday, 10 a.m. – 2 p.m., No Pre-Notification	108,248 (25,324) n=89	0.0126 (0.0024) n=89	34 (8) n=89	359
C3. Summer Weekday, 11 a.m. – 3 p.m., No Pre-Notification	104,102 (25,178) n=89	0.0115 (0.0023) n=89	30 (8) n=89	317
C4. Winter Weekend, 11 p.m. – 3 a.m., No Pre-Notification	75,915 (25,189) n=89	0.0060 (0.0014) n=89	44 (16) n=89	465
C5. Summer Weekday, 1 p.m. – 2 p.m., No Pre-Notification	63,020 (23,805) n=95	0.0154 (0.0073) n=95	79 (29) n=95	834
C6. Summer Weekday, 9 a.m. – 5 p.m., No Pre-Notification	1,568,094 (746,721) n=94	0.3788 (0.1693) n=94	256 (119) n=94	2703
C7. Summer Weekday, 11 a.m. – 3 p.m., 2 Hour Pre-Notification	181,643 (86,910) n=94	0.0499 (0.0291) n=94	55 (27) n=94	581
C8. Winter Weekend, 11 p.m. – 3 a.m., 72 Hour Pre-notification	14,256 (3,533) n=94	0.0021 (0.0005) n=94	7 (2) n=94	74

Using the $0.0947/kWh cost used for SMPs, the estimated cost of an outage is between 74 and 2,703 times the retail price of electricity. It is worth noting that scenario C6, the loss of an entire working day, would cost about $1.6 million per Large Premise.

5.2.2 *'The value of supply security, the cost of power interruptions: Economic input for damage reduction and investment in networks', M. de Nooij, C. Koopmans & C. Bijvoet*[115]

Nooij, Koopmans and Bijvoet produced this study in response to the increasing attention being paid to secure energy supplies following the Californian Energy Crisis in 2000 and

[114] (Bailly, 2000)
[115] (de Nooij, Koopmans, & Bijvoet, 2007)

2001 and outage and power quality issues in Europe in 2003. It aimed to establish why supply interruptions differ on a case-by-case basis; look at the consequences to residents, firms and governments; and estimate the costs of outages using a production-function approach.

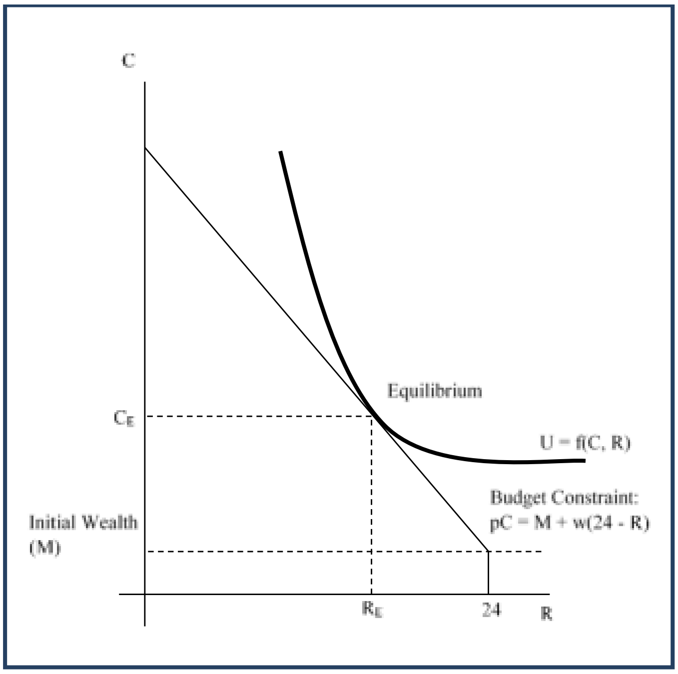
The report initially looks at how outages vary, which affects the cost and makes establishing specific values difficult:

- Different types of users may be affected with different consequences, such as industrial plants, financial service or hospitals.
- The perceived reliability level. The report reasons that in areas of low outage risk, there will be less investment in backup measures, making outages more costly.
- The season, day of week and time of day of the interruption.
- The length of the outage affects costs. Some damages occur instantaneously (i.e. loss of computer files, some after a period of time (i.e. food spoilage) and some are proportional to the length (i.e. lost working hours).
- Whether there is notification, which allows people to take preventative measures.
- Whether interruptions are structural, so people may prepare, lowering costs but increasing frequency, or random occurrence.
- The source of the outage. A network failure affects producers and consumers mean prices remain stable, whereas a shortage of supply increases prices, transferring wealth to producers.[116]

The report does not investigate the effect of prior notification, as this does not occur in Dutch energy markets. In the examples of US outages however, the effects of pre-notification, also discussed in the Hagler Bailly report, would be applicable to hurricane scenarios. This would reduce the cost of an outage, although it is certain to be overwhelmed by the additional cost of the weather and outage time of a natural disaster.

For firms and governments, a supply outage leads to a loss of production as output halts and costs rise due to effects such as worker overtime and replacing spoiled raw materials and ruined capital. This report calculates the damage caused by an electricity interruption to a firm as 'equal to the value added it would normally have produced during that period'[117]. The report also assumes when applying the production-function approach that all activity is halted[118].

[116] (de Nooij, Koopmans, & Bijvoet, 2007)
[117] (de Nooij, Koopmans, & Bijvoet, 2007)
[118] (de Nooij, Koopmans, & Bijvoet, 2007)



The Becker Model: Showing trade off between consumption and leisure time for workers

The consequences to households, such as lost possibility to use leisure time, lost goods and potential effects of lost heating (or cooling), are also assumed to be all lost during an outage. To value to leisure lost, the report uses a Becker Model (1965).

The Becker model states that people gain utility (welfare) from a combination of goods (bought with income) and time (leisure). Both have diminishing returns. Marginal utility households are those wanting neither to have a lot of consumption with no free time or plenty of free time but no consumption. Since a household starts with free time (and any income in addition to working), they will trade free time for income to consume goods (i.e. get a job). This means that given a marginal rate of substitution (MRS) between consumption and time (i.e. a wage rate), there is an optimum allocation of consumption (C) and leisure time (R) for each household given their utility function (U=f(C,R)). At the optimum allocation, the marginal utility of consuming goods and marginal utility of leisure time are equal.

Welfare and electricity usage of households, firms and government (2001)

	Electricity demand[a] (gW h)	Electricity use as percentage of total electricity use	'Value' (million euros)[b]	'Value' as percentage of total 'value'	'Value' of lost load (/kW h)[c]
Agriculture	2889	3.3	11,261	1.5	3.90
Energy sector	−72,361	–	22,910	3.0	−0.32
Manufacturing	34,009	38.4	63,441	8.4	1.87
Construction	750	0.9	24,791	3.3	33.05
Transport	1577	1.8	19,587	2.6	12.42
Services	24,944	28.1	198,126	26.1	7.94
Government	2389	2.7	80,040	10.5	33.50
Firms and government[d]	66,558	75.1	397,246	52.3	5.97
Households	22,100	24.9	362,055	47.7	16.38
Firms, government and households[d]	88,658	100	759,301	100	8.56

Source: Netherlands Central Bureau of Statistics (CBS), Netherlands Bureau for Economic Policy Analysis (CPB); own calculations.
[a] Electricity demand is the quantity of power taken from (or supplied to) the grid.
[b] For households this is the value of leisure time, while for businesses and for the government this is value added.
[c] For the energy sector per delivered kW h.
[d] Excluding the energy sector.

Table 3 from M. de Nooij, C. Koopmans & C. Bijvoet

'The value of supply security, the costs of power interruptions: Economic input for damage reduction and investment in networks', page 287: Welfare and electricity usage of households, firms and governments

The report uses this to provide a valuation of Leisure time (R): 1 hour of leisure is of equal value to 1 hour from working. For this model to be applied, the assumption of Well-behaved labour markets, where labour can choose exactly how much time they want to work and how much time they want leisure for a given wage rate, is made in this report[119]. For the Dutch economy, the report finds:

[119] "This method assumes a well-functioning labour market, in which individuals are more or less free to choose the number of hours they work. This seems justified for the Netherlands, where about 40% of the working population works part time (employees have the legal right to work part time). Furthermore, most employees (83.4%) are satisfied with their working hours;

'it is estimated that households create €362 billion a year in leisure value. If everybody were to enjoy leisure at the same moment, a 1-hour interruption would cause a loss of €111 million'.

Combining the figures gained for the value of leisure and lost production, the report finds the Value of Load Lost (VoLL), which expresses the cost of a lost kWh, is €8.56/kWh. Given the assumption of a constant price of €0.18/kWh[120] this provides a valuation of 47.56 times the retail price of electricity. While €8.56/kWh is the weighted average for usage by households, firms and governments Table 4 details the VoLL for 9 specific time periods during the day in Table 4[121], and Table 5 shows the average cost of a 1-hour outage per person for each period[122].

Below (adapted): Table 4 from M. de Nooij, C. Koopmans & C. Bijvoet 'The value of supply security, the costs of power interruptions: Economic input for damage reduction and investment in networks', page 288: Value of lost load for nine periods

Value of lost load (VoLL) for nine periods in 2001 (€/kWh)			
Day	**Time of day**	**VoLL (€/kWh)**	**VoLL/Retail price of electricity**
Weekdays	Day (08.00-18.00)	8.0	44
	Evening (18.00-24.00)	8.9	49
	Night (24.00-08.00)	2.7	15
Saturdays	Day (08.00-18.00)	8.7	48
	Evening (18.00-24.00)	12.5	69
	Night (24.00-08.00)	3.9	22
Sundays	Day (08.00-18.00)	10.3	57
	Evening (18.00-24.00)	12.5	69
	Night (24.00-08.00)	3.9	22
Average		7.4	41

Looking at the amount of damage an outage causes in an hour compared to the value of electricity not supplied shows significantly larger welfare costs. The report states an outage on a weekday during the day time would cause €157 million damage, but the value of the electricity not supplied would only be €2.8 million – the welfare costs being 57 times the value of unsupplied electricity. Similarly, weekday evenings would have a welfare cost of €101 million and electricity not supplied cost €0.91 million (111 times) and Sunday daytime would have €80 million welfare costs and €0.45 million cost of electricity not supplied (178)[123]. This shows that the costs of interruptions far exceed the monetary cost to providers, again demonstrating that large social gains are to be made but providers cannot afford to initiate the investment.

only 5.5% would like to work more and 11.1% to work less (Netherlands Bureau of Statistics)." (de Nooij, Koopmans, & Bijvoet, 2007)

[120] (de Nooij, Koopmans, & Bijvoet, 2007)

[121] (de Nooij, Koopmans, & Bijvoet, 2007)

[122] (de Nooij, Koopmans, & Bijvoet, 2007)

[123] (de Nooij, Koopmans, & Bijvoet, 2007)

5.3 'Guidelines of good practice on estimation of costs due to electricity interruptions and voltage disturbances', Council of European Energy Regulators[124]

The CEER report follows the growing interest in Europe of cost-estimation for a loss of power. The study's objective was to review current examples of cost-estimation analysis that had been completed in order to:

- Provide a set of recommendations for National Energy Regulatory Authorities (NRAs) and other interested bodies develop nation-wide cost-estimation studies.
- Highlight possible problems in order to improve future studies and make results comparable.

The study advocates survey-based and case-based approaches to valuing electricity quality issues. These issues include availability (continuous supply), technical properties (voltage quality) and speed and accuracy of customer requests handled (commercial quality), and how the cost-estimation of an outage would vary based on customer type, time of occurrence, interruption duration, frequency of occurrences and other factors[125].

The report identifies the costs that must be estimated for a total socio-economic analysis, including social and private, monetary and non-monetary, and direct and indirect factors so as to account for all linkages and effects. These could include consequences which might extend far beyond the reaches of the affected zone, with supply-chain interruption for national and international business. This might include costs and inconvenience associated with the failure of a public transport network impacting businesses, people who can no longer use the network and those stranded either at end-locations or in-transit.

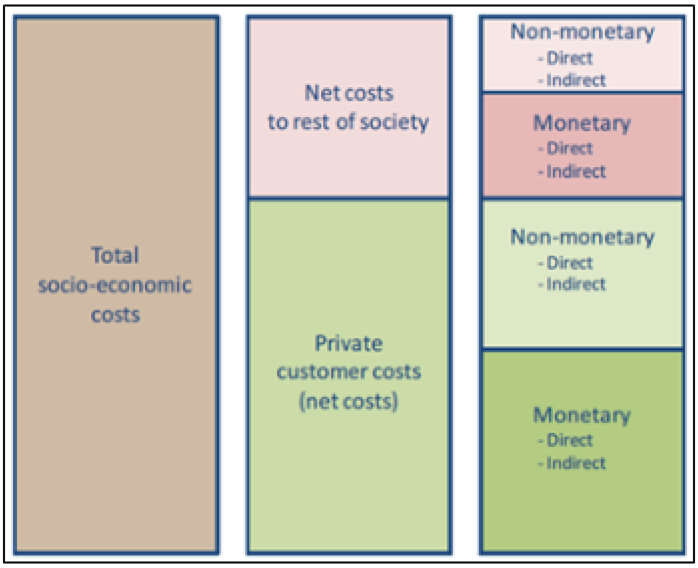


Figure 1 from Council of European Energy Regulators 'Guidelines of good practice on estimation of costs due to electricity interruptions and voltage disturbances', page 14: Total socio-economic costs of electricity interruptions and voltage disturbances

As part of conducting a thorough investigation, the report suggests a range of groups that should be surveyed as well as appropriate methods to do so, although adjustments should be made to compensate for social differences where necessary:

[124] (Bertazzi, Fumagalli, Lo, & Schiavo, 2010)
[125] (Bertazzi, Fumagalli, Lo, & Schiavo, 2010)

- Suggested User Groups[126]:
- Household
- Commercial services (without infrastructure)
- Public Services (without infrastructure)
- Industry (without large customers)
- Large customers
- Infrastructure

[126] (Bertazzi, Fumagalli, Lo, & Schiavo, 2010)

Table 5 from Council of European Energy Regulators 'Guidelines of good practice on estimation of costs due to electricity interruptions and voltage disturbances', page 26: CEER recommendations on use of cost-estimation method

Valuation Method[127]	Description
Direct Worth method	Customers are asked to estimate expenses incurred due to a hypothetical or experienced interruption. Usually have to specify costs for several proposed scenarios.
Contingent Valuation	Respondents are presented with a hypothetical or experiences scenario, then are asked their willingness-to-pay to avoid or willingness-to-accept compensation for the event so they would be indifferent to its occurrence.
Conjoint Analysis	Respondents are asked to choose between two scenarios, or rank a series of options
Preparatory Action method	Respondents choose from a list of hypothetical actions to reduce consequences of interruption with the value of purchases and currently installed equipment an estimate of the cost
Preventative Cost method	Estimates the cost at the value of the measures taken to prevent/counteract consequences of an event
Direct Worth case study	Estimated costs based on real experiences and hypothetical scenarios, intensive analysis of representative groups of customers.

The report outlines the valuations that it finds most appropriate as well as the need for normalised figures to perform comparisons. The report suggests that findings are presented in €/kWh rather than absolute values, so outages of different lengths can be compared[128].

		Households	Commercial services	Public services	Industry	Large Customers	Infrastructure
Cost-estimation Method	Survey-based	A	A	A	B		
	Case-based				A	A	A

A – Alternative A
B – Alternative B

Table 13 from Council of European Energy Regulators 'Guidelines of good practice on estimation of costs due to electricity interruptions and voltage disturbances', page 46:
Comparison of survey results for Norwegian surveys conducted "1990-1991" and "2001-2002".
The normalised costs refer to a 1-hour interruption.
The numbers show a dear increase in the costs associated with interruptions that supersedes the general inflation

The report considers other studies completed recently in Europe looking at the costs of outages, with an Italian and Norwegian report providing further figures for the value of lost electricity. The Italian report, conducted in 2003, evaluated the willingness-to-pay and the willingness-to-accept of different using groups to establish a valuation, citing €10.8/kWh for households and €21.6/kWh for businesses[129].

[127] (Bertazzi, Fumagalli, Lo, & Schiavo, 2010)
[128] (Bertazzi, Fumagalli, Lo, & Schiavo, 2010)
[129] (Bertazzi, Fumagalli, Lo, & Schiavo, 2010)

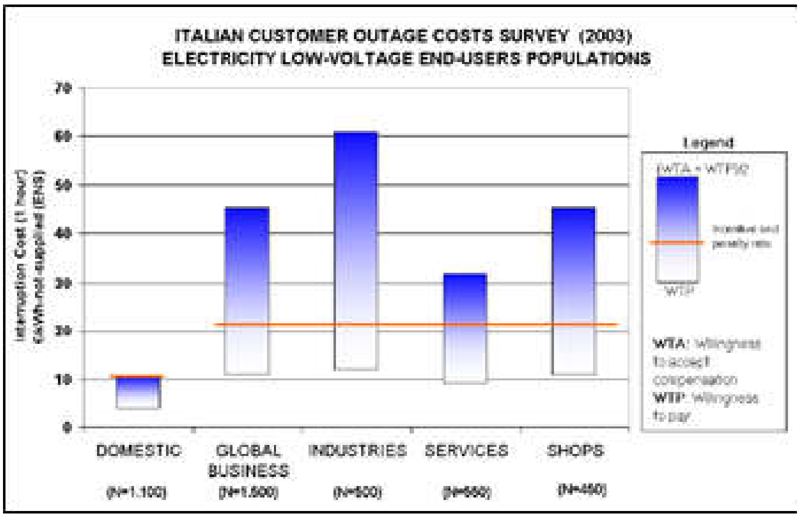


Figure 4 from Council of European Energy Regulators 'Guidelines of good practice on estimation of costs due to electricity interruptions and voltage disturbances', page 34: Treating the volatility in survey results, Italian interruption cost survey

Assuming a price of €0.1982/kWh[130], this gives households a valuation of 54.49 times the retail price of electricity, and 108.98 times for businesses.

The Norwegian report compares findings in a 1991 and a 2001 study on the value of electricity to different consumer groups using willingness-to-pay (WTP) and Direct Worth (DW) figures.

The findings show an increase in the valuation above the rate of inflation between 1991 and 2001. Assuming a constant price of NOK 0.5236/kWh[131], the values for different customer groups range between 9 times the value of electricity and over 380 times.

Customer Group	Estimate	1991 [NOK/kWh]	2001 [NOK/kWh]	Relative increase	$/Unserved kWh : Retail electricity $/kWh
Industry	DW	68.6	123.0	1.8	235
Commercial	DW	47.8	201.5	4.2	385
Large Industry	DW	19.3	23.8	1.2	45
Agricultural	DW	1.4	16.6	11.9	32
Residential	WTP	3.0	5.0	1.7	10

5.3.1 Value of reliability & interoperability

With the results of the value of secure electricity supplies from other studies conducted, the 50-150 times the retail value of electricity, established in our previous report, would appear to encapsulate the effect, although there is a high level of uncertainty and variation in the results due to the range of variables in an outage situation. Whilst the Hagler Bailly report generated some significantly higher values with the IFC and NLP calculations, these appear to be inconsistent with the common ranges found elsewhere using willingness-to-pay. This may suggest that these calculations incorporate costs to businesses that the

[130] Using average 2003S1 and 2003S2 prices (Eurostat, 2013)
[131] Price of electricity in 2000 taken at NOK 0.421/kWh (page 245) and inflated to 2001 figure using CPI 'Electricity, gas and other fuels' component (page 249) at a rate of 24.374% (Statistics Norway, 2003)

businesses either do not identify or do not count as costs from an outage[132]. However, such outliers also suggest the possibility of extreme values resulting from some outage scenarios – again supported in our previous report.

The results of the other studies show that, while a general estimation of the cost of an outage can be made, each individual case will vary massively on a range of variables for both the outage and the affected area. As an example, the data in 'The value of supply security, the costs of power interruptions: Economic input for damage reduction and investment in networks' shows how the willingness-to-pay valuations can deviate greatly when adjusted for time of day.

Furthermore, the evidence from case studies analysing the effects of hurricanes on the US economy combined with the findings of the security of electricity supplies reports suggest that adverse weather conditions add value to the amount people would be willing-to-pay to have resilient electricity during an event and to avoid the lengthy restoration phrase that follows, although this value to society is part of a number of very large social costs faced.

The findings from the August 14th 2003 outage and the examples from Europe and India also show significant socio-economic damage. In these scenarios, Smart Grid could be used to mitigate the effects, in these examples, almost entirely.

5.4 Total benefits of Smart Grid

Modernising the electricity grid using advanced telecommunications and computerised processes looks to have great benefits for the US economy, with an estimated GDP multiplier of at least 2.5 times the investment. Furthermore, Smart Grid has great socio-economic value at it facilitates the growing demands on the grid while also reducing the threat and costs associated with outages and disruptions to supply.

Experimental photovoltaic installation.

In their 2011 report studying the value of Smart Grid to the US economy, EPRI estimated the total economic benefit of Smart Grid would be between $1294 – 2028 billion to the US economy over a 20 year period between 2010 and 2030[133]. This report also feels that there is significant value to be found in the USA from the use of Smart Grids in more efficient recovery operations following natural disasters, as highlighted by the EPB Chattanooga case study.

However, it is important to note that a number of the benefits, while valuable to society, may not generate sufficient revenue for operators, removing the profit incentive for the investment in Smart Grid systems. Government involvement may therefore be necessary to achieve a socially optimal allocation of resources.

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[132] It could be that firms do not included insured costs in their estimations as having paid insurance to protect against damage (which is included in standard production costs), the business only suffers the inconvenience of the time it takes to replace insured loses, rather than the cost.

[133] (Gellings, 2011)

5.5 Cost of Smart Grid

The previous report had established an estimated cost for Smart Grids in the USA at $165 billion based on the EPRI evaluation in 2004 with benefits totalling $638 – 802 billion, giving a benefit-to-cost ratio of 3.87-4.86:1[134].

Summary of Estimated Cost and Benefits of the Smart Grid

	20-Year Total ($billion)
Net Investment Required	338 – 476
Net Benefit	1,294 – 2,028
Benefit-to-Cost Ratio	2.8 – 6.0

Figure 5-1: Table 1-1 from Electric Power Research Institute 'Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid', page 1-4: Summary of Estimated Cost and Benefits of the Smart Grid

In the 2011 report, EPRI updated their figures to reflect an expansion in the functionality associated with Smart Grid associated with demand response, facilitating renewable generation, the electric vehicle market, energy efficiency gains, Advanced Metering Infrastructure (AMI), distributed generation and storage[135]. While this adds additional functionality to the Smart Grid, increasing the socio-economic benefits it has also increased the cost components.

The updated work estimated that a function Smart Grid would require an investment of between $338 – 476 billion across the next 20 years over and above the investment to meet electric load growth[136].

5.6 The Value of Smart Grid

The EPRI report offers a complete analysis of the expected total economic impact of Smart Grid, with the US Department of Energy 'Economic Impact of Recovery Act Investment in the Smart Grid' supporting the findings[137]. The benefit-to-cost ratio of 2.8-6.0:1 shows how Smart Grid could be of great socio-economic value while the case studies for outages demonstrate the important role of the increased functionality; utilising data communications an automated computer management and response to drastically cut the costs and time involved.

CenterPoint Energy's automated metering system with remote connects and disconnects has saved consumers approximately $24 million dollars annually in customer fees and has improved restoration capabilities by around 25%, avoiding 7.1 million customer outage minutes in less than two years.

The findings by EPB Chattanooga show similar improvement, with even greater utilisation and benefits during adverse conditions. However, it also demonstrates that companies are unlikely to invest in improving the reliability of electricity supplies without government support.

134 (Lordan, 2004)
135 (Gellings, 2011)
136 (Gellings, 2011)
137 (Office of Electricity, 2013)

6 RADIO SPECTRUM IMPLICATIONS

Although utilities make extensive use of copper and fibre based communications systems – and in the case of electricity, communicating down the electrical supply cables in some instances, radio also plays an essential role. Radio is valuable in this role because:

- the communications network can be independent of the assets being managed;
- radio is flexible and can be deployed more quickly than fixed assets;
- if radio services are interrupted, they can usually be restored more quickly than wired systems; and
- radio is more cost effective in many applications.

Radio systems need spectrum in which to operate. Some services may be able to operate in licence-exempt bands designed for short range devices (SRDs), but no protection is available for services in unlicensed bands if they suffer interference. For greater certainty of communication and protection from interference, licensed spectrum must be obtained.

6.1 The cost of radio spectrum

Radio spectrum is undeniably important to running a Smart Grid. UTC outline the essential need to have 'secure, resilient and reliable communication, specifically in parts of the country where 4G wireless broadband networks are currently not available and may never exist'[138]. Smart Grid will require telecommunications as much as computerisation to successfully monitor and control the electricity network and provide communications for personnel working on the grid.

Smart Grid communications are necessary for the day-to-day functionality and the administrative savings to be made, as shown by CenterPoint Energy, UTC citing regular functions in the Critical Infrastructure Industries (CII) as 'voice and data, mobile applications, monitoring and control of remote facilities, the extension of circuits to areas unserved by commercial carriers, security, video surveillance and emergency response'[139]. Furthermore, the communications are highly valuable during a crisis. During the wind storms in Tennessee in 2012, EPB showed how remote automated processes could significantly reduce both the initial damage and the costs and time required in recovery. In severe hurricanes, this has the potential to reduce impact, reduce costs and save lives.

In Europe, the European Utility Telecom Council (EUTC) is proposing a portfolio of spectrum to address their requirements, including a total of 16 MHz of licensed spectrum in the vital 400 MHz to 3 GHz space. Canadian utilities have been granted access to 30 MHz of spectrum in the band 1800-1830 MHz for intelligent electricity networks. The public safety community (PPDR - Public Protection and Disaster Relief) within the European Committee for Posts and Telecommunication (CEPT) have proposed a minimum allocation of 20 MHz of spectrum for mobile broadband communications. Various technologies are contemplated, including 4G technologies such as Wimax, CDMA and LTE.

[138] (Patterson, 2013)
[139] (Richards, 2013)

EUTC Spectrum Proposal

Europe - multiple small allocations within harmonised bands:

- **VHF spectrum (50-200 MHz)** for resilient voice comms & distribution automation for rural and remote areas. [2 x 1 MHz]
- **UHF spectrum (450-470 MHz)** for SCADA & automation. [2 x 3 MHz]
- Lightly regulated or deregulated shared spectrum for smart meters and mesh networks (870-876 MHz).
- **L-band region (1500 MHz)** for more data intensive smart grid, security and point-to-multipoint applications. [10 MHz]
- **Public microwave & satellite bands (1.5-58 GHz)** for access to utilities' core fibre network or strategic resilient back-haul.

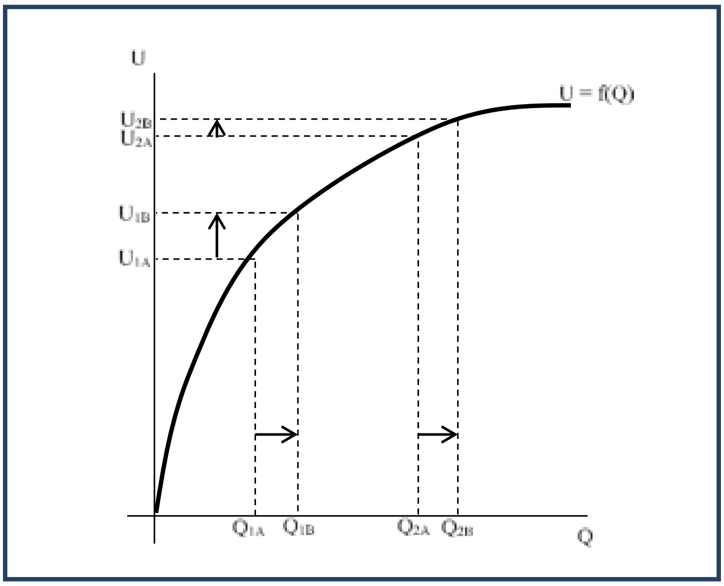
For the purposes of this analysis, it has been estimated that the functionality of Smart Grid could be facilitated within 20MHz of spectrum, utilising 4G technology. It has also been suggested from industry that this could be allocated to 'Utility Radio Operations'. Similar to radio astronomy, maritime and aeronautical, this would be a designated range of spectrum reserved for the use of utilities companies. The benefit of such an allocation would be that utility companies could build interoperable communications to industry standards and not have concerns about 3rd party management. This provides a guarantee that will allow companies to make efficient investment decisions in appropriate technologies by removing the uncertainty in current spectrum-based planning[140].

Current policies in the US have moved to expand the amount of spectrum made available to digital data, following the launch of 4G public communications networks and plans for high speed internet. In recent developments policy makers have proposed to auction a significant amount of spectrum, around 500 MHz, for use by the digital data community[141]. Whilst considerations have been made for first responders in the 700 MHz band, no such plan has been made for utilities.

Were Utility Radio Operations to receive an allocation of 20 MHz of spectrum, it is likely that it would come from resources currently being allocated to the digital data community. This creates an opportunity cost: The cost of providing 20 MHz of spectrum to Utility Radio Operations is the loss of 20 MHz of spectrum to other uses, in this case mobile public broadband.

The stakeholders that would lose out from the allocation to Utility Radio Operations would be: the government treasury, who lose revenue from the non-auctioning of spectrum; the public broadband providers, who lose an input resource used to create their product; and public broadband customers, who lose out on goods and services that will not be sold.

[140] (Stoll, 2013)
[141] (U.S. Department of Commerce, 2013)



Graph showing Diminishing Returns in Utility for increases in Quantity

Since the 1990s, governments have found spectrum auctions to be a very lucrative method of deciding spectrum allocations, hypothesising that those who would produce the most would bid the most. However, oligopolistic traits in the telecommunications market have been one flaw in the allocation theory, as specifications are repeatedly added to auctions to try create mechanisms that '…promotes competition and innovation in telecommunications markets'[142] and prevent hording. Another issue has been treating the market as a set of homogenous providers. As discussed in the previous socio-economic report, this is not the case with utilities.

From allocating spectrum to Utility Radio Operations rather than selling it at auction, the government treasury would miss out on the revenue from the sale. An auction in 2008 (Auction 73) sold a 22 MHz allocation (Block C: 746-757 and 767-787 MHz) of 10 license. The auction raised a total final bid of $4,747,769,000 for Block C, with Verizon Wireless gaining 7 licences for $4,741,807,000, Triad 700 gaining 2 for $4,907,000 and Small Ventures receiving the last for $1,055,000[143]. Updating this to 2013 figures using the CPI, the value of this spectrum to the government treasury is around $5.149 billion[144]. This represents the opportunity cost to the government treasury had it been allocated to Utility Radio Operations. The value of the spectrum is equal to 1.08-1.52% of the EPRI estimate of the total cost of Smart Grid. While a small value in comparison, the spectrum is essential to creating the grid.

Evaluating the producer and consumer welfare is more problematic. Ofcom, the UK telecommunications market regulator, estimated the total net economic benefit to the UK economy of radio spectrum use in 2006 to be £42.4 billion[145]; about $96.75 billion in 2013 USD[146]. If scaled up for the USA population, this value becomes $484 billion[147]. The USA Input-Output for 2002 put a value the total commodity output of telecommunications at $410 billion, $532.94 billion 2013 USD, although this will incorporate many other elements.

142 (U.S. Department of Justice, 2013)
143 (Federal Communications Commission, 2013)
144 Value inflated to 2013 USD from 2008 USD (US Bureau of Labor Statistics, 2013)
145 Ofcom. 2006. *Economic Impact of the use of radio spectrum in the UK*. [ONLINE] Available at: http://stakeholders.ofcom.org.uk/binaries/research/spectrum-research/economic_impact.pdf. [Accessed 17 September 13], page 4
146 Exchange rate of £1=$1.97 for 30/11/2006
and Value inflated to 2013 USD from 2006 USD (US Bureau of Labor Statistics, 2013)
147 USA population of 313.9 million and UK population of 62.74 million

Although these figures are very approximate estimations, it does provide a sense of scale for the value of Smart Grid. Additionally, there are diminishing returns to consider. This states that the rate of welfare gain (U) decreased as the quantity (Q) increases (Diminishing Marginal Utility $\frac{dUdQ}{} < 0$). In respect to the telecommunications market, this means that the welfare gain to society from providing multitudes of additional spectrum for digital data are decreasing per additional unit provided. Conversely, the relative lack of spectrum in the utilities networks mean that large gains in social welfare can be made with the use of few resources.

Smart Grid, and the first responders network FirstNet, are examples of this. In these cases, policymakers can see larger social welfare gains to be made from an allocation to these areas rather than the smaller marginal gains from allocating it to yet more public broadband.

Given that 20 MHz for a public broadband network would struggle to provide enough capacity in an urban environment but could support the entire Smart Grid requirements for spectrum, there is a strong argument that the USA would have greater socio-economic gains from providing 20 MHz to Utility Radio Operations and allocating 480 MHz to public broadband to enable the modernisation of the electricity grid rather than providing all 500 MHz to public broadband.

6.2 The Case for Sharing Spectrum

Whilst a Utility Radio allocation would be preferred by industry, this solution would face some difficulties which may hamper progress. As outlined previously, spectrum has become a scarce resource following the boom in demand for digital data generated by the growth in mobile devices[148]. Providing spectrum to utilities does not provide the same financial incentives to governments as auctioning spectrum to fulfil the desires for mobile data.

An alternative to building bespoke private networks would be for utilities to share spectrum with other network users. A solution such as this would alleviate the issues around finding spectrum at auction and the risks involved for utilities when bidding. However, this involves some trade-off, since utilities would no longer be sole users, that may limit functionality and degrade the quality of service.

6.2.1 Public Safety Networks

Public Safety networks operating in the 700 MHz and 4.9 GHz bands have been identified as a possible sharing solution[149]. In February 2012, congress passed the Middle Class Tax Relief and Job Creation Act[150], leading to the creation of FirstNet: A broadband network for first responders.

The FirstNet service provides a potential opportunity for sharing, with discussions about shared access already taking place. Charles Dowd, Deputy Chief of the New York Police Department, stated that "The ability to set partnerships with utilities, and they become almost a first responder or a second responder in support of first responders, is going to be

[148] (Stoll, 2013)
[149] (Richards, 2013)
[150] (Kilbourne, 2013)

hugely helpful"[151], foreseeing operational benefits from coordinated responses during a crisis. There are further cost and logistical benefits to be found from the partnership, with utilities having the expertise and infrastructure necessary to build interoperable national radio networks while FirstNet have access to spectrum.

However, while a sharing system on FirstNet would create benefits, there would also be limitations. The main concern with sharing with groups such as first responders is primary use. Given the need to use the networks for day-to-day operations and emergency situation for both parties, potentially with both users dealing with the same emergency, establishing which is the primary user and which is the secondary user is both essential and difficult. Telecommunications are vital to both users in coordinating resources in dangerous situations, so deciding how the prioritisation should be designated in the sharing agreement , along with preventing interference, have been key issues highlighted so far in sharing public safety spectrum[152]. Resolving these issues would enable an alternative solution of utilities sharing with public safety.

6.2.2 Commercial Network Providers

Another alternative would be for utilities to approach a commercial carrier to manage their utility telecommunication networks. Commercial providers would aim to reduce the cost of building and maintaining the network. While reducing the cost would be a benefit, key issues face commercial providers about the quality of service they would be able to provide.

Firstly, the utility networks need to provide full coverage of their asset base with 99.999% availability, something that has proven to be commercially unviable for public mobile. Current utility networks are built to cover the entire geographic area with overlap redundancy, power redundancy, strict maintenance schedules and emergency group talk functions[153]. Despite the poor financial case, a commercial provider would have to provide a network that fulfilled all of these criteria. As such, a commercial provider is unlikely to be able to provide the same quality of service at a reduced cost.

Another issue is interoperability during adverse conditions. Maintaining and re-establishing communications during crises has always been fundamental in recovery plans for utility providers. The recent emergence of a report by the FCC on the impact of the June 2012 Derecho casts a certain amount of doubt as to whether commercial operators would provide sufficient resilience. The report found that during the storm, a significant number of 9-1-1 call systems were not functioning properly. The report states that at least 17 9-1-1 call centres had been affected, serving 2 million people, with one centre estimating to have not received 1,900 calls[154]. The commercial providers, which included: Verizon, Frontier, Centurylink and AT&T[155], suffered these failures largely due to loss of power to cell sites and disabled transport equipment[156], with the service remaining down in some places for several days[157].

[151] (Utilities Telecom Council, 2012)
[152] (Kilbourne, 2013)
[153] (Utilities Telecom Council, 2009)
[154] (Federal Communications Commission, 2013)
[155] (Federal Communications Commission, 2013)
[156] (Federal Communications Commission, 2013)
[157] (Federal Communications Commission, 2013)

While commercial operators may be able to reduce the costs associated with building a network, the evidence suggests that this is at the expense of the quality of service. While sufficient for commercial operators, it is unlikely to be acceptable to support utilities.

7 CONCLUSION

From the evidence available, this report finds a very compelling socio-economic case for the investment in Smart Grid. Current data suggests that the use of radio spectrum in providing reliable utility services has great socio-economic value to the US economy, with society valuing reliable electricity significantly above the market rate. This value is estimated to be around 50-150 times the retail price of electricity, although the value will vary due to characteristics of the agents and the conditions of the outage. Some agents may have significantly greater values.

The modernisation of the electricity grid with advanced telecommunications would lead to a number of economic benefits. The investment would create around 40,000 new jobs in total and result in a GDP multiplier effect estimated at 2.5 times the investment, a much higher rate than most other forms of government investment. Installed systems, such as the one utilised by CenterPoint Energy, show that the investment would enable providers to increase their quality of service and reduce operational costs.

Although there are great benefits associated with Smart Grid, the system does not necessarily prove the right profit incentive for operators. A considerable amount of the value found in Smart Grid is accumulated by improvements in living standards for society. This study examined how households would benefit from the improvements in safety & security, environmental benefits and reliability & interoperability, including a variety of electrical outage case studies, though providers would not receive monetary benefit to cover the cost of providing them. While there is a large positive socio-economic impact for the USA, government partnership may be required for investments to be undertaken.

Energy saving doesn't always have to be complex

The EPRI report, which offers a complete analysis of the gains and costs associated with Smart Grid, found that over a 20 year period, a $338-$476 billion investment in modernising the electricity grid would yield a total socio-economic benefit between $1294-2028 billion; a benefit to cost ratio of 2.8-6.0:1.

The report also examined the spectrum requirements necessary for modernising the grid. Smart Grid in the USA is expected to be able to operate in 20 MHz of radio spectrum, using 4G components. Currently, the US government is expected to soon auction more spectrum to satisfy the growing demands of the digital data community, the amount estimated to be around 500 MHz.

Using the results of Block C in spectrum auction 67 in 2008, disregarding the effects of diminishing returns and changes in the market, the requirements for Smart Grid would require an estimated $5.15 billion of spectrum. Given the large benefits of Smart Grid, there is a convincing argument that if 500 MHz of spectrum were to be made available for release, there would be greater socio-economic value achieved if, rather than auctioning the entire amount, 96% of the spectrum was auctioned by the government, with 20 MHz retained for Utility Radio Operations.

If an allocation for Utility Radio Operations was not made available, there are also options for sharing spectrum, the current focus being on first responder networks and commercial providers. Although there are benefits and limitations for both potential sharing agreements, a resolution with first responders is more likely, despite the priority issues. In the case of sharing with a commercial provider, it is doubted as to whether they would be able to provide sufficient quality of service for utilities at any great benefit.

Overall, Smart Grid has the potential to provide large socio-economic value to the US economy, utilising advanced telecommunications to modernise the existing utility infrastructure. Government involvement may be required in the investment and in the spectrum allocation due to the proportion of social benefits involved and the conditions imposed on providers. However, dedicating resources to this underappreciated sector over other spectrum-demanding industries would stimulate enormous economic and societal benefits for the USA.

<u>Appendix 1:</u> Table 4-5 from Electric Power Research Institute *'Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid'*, page 4-7 – 4-10: List of Smart Grid Benefits

Benefit Category	Benefit Sub-Category	Benefit	Included in Original Estimate?	Estimated Value 2010-2030 $Billion Low	Estimated Value 2010-2030 $Billion High	Reference
Economic	Improved Asset Utilization	Optimized Generator Operation		–	–	not included
		Deferred Generation Capacity Investments		→	→	Appendix A
		Reduced Ancillary Service Cost	X	→	→	included below
		Distributed Generation		–	–	not included
		Storage		48	89	Appendix A
		PEVs as Storage & Load Control		11	11	Appendix A
		Energy Efficiency	X	→	→	included below
		Demand Response		–	–	not included
		Enhanced Energy Efficiency*		–	–	not included
		Reduced Ancillary Service Cost		–	–	not included
		Reduced Congestion Cost	X	→	→	included below
	T&D Capital Savings	Distributed Generation		27	27	Appendix A
		Storage		23	65	Appendix A
		Demand Response		192	242	not included
		Energy Efficiency	X	→	→	included below
		Enhanced Energy Efficiency*		1	3	Appendix A
		Deferred Transmission Capacity Investment	X	→	→	included below
		Deferred Distribution Capacity Investment	X	→	→	included below
		Reduced Equipment Failures	X	→	→	included below

Benefit Category	Benefit Sub-Category	Benefit	Included in Original Estimate?	Estimated Value 2010-2030 $Billion Low	Estimated Value 2010-2030 $Billion High	Reference
Economic	T&D O&M Savings	More Effective Use of Personnel		–	–	not included
		Economic Benefit of Added Personnel		–	–	not included
		Operations Savings from AMI		4	4	Appendix A
		T&D Efficiency	X	→	→	included below
		Reduced Distribution Equipment Maintenance Cost	X	→	→	included below
		Reduced Distribution Operations Cost	X	→	→	included below
	Theft Reduction	Reduced Electricity Theft		–	–	Not included
	Energy Efficiency	Enhanced Energy Efficiency*		0	2	Appendix A
		Electrification (Net Reduced Energy Use)		–	–	Appendix A
		Reduced Electricity Losses	X	→	→	included below
		Productivity Increase	X	→	→	included below
	Electricity Cost Savings	Reduced Electricity Cost	X	→	→	Included below
		Automatic Meter Reading		91	91	Appendix A
		Customer Service Costs (Call Center)		2	2	Appendix A
		Storage		115	199	Appendix A
		Enhanced National Productivity	X	→	→	included below
		Reduced Restoration Cost	X	→	→	included below
		Speed of Restoration		–	–	not included

Benefit Category	Benefit Sub-Category	Benefit	Included in Original Estimate?	Estimated Value 2010-2030 $Billion		Reference
				Low	High	
		Storage		2	20	Appendix A
		Reduced Sustained Outages	X →			included below
		Reduced Major Outages	X →			included below
		Accessibility	X →			included below
	Power Quality	Reduced Momentary Outages	X →			included below
		Reduced Sags and Swells	X →			included below
		Storage		1	21	Appendix A
Environmental	Air Emissions	Electrification		21	21	Appendix A
		PEVs		5	123	Appendix A
		Enhanced Energy Efficiency*		1	4	Appendix A
		Storage		10	15	Appendix A
		Facilitate Renewables		10	172	Appendix A
		Reduced CO_2 Emissions	X →			included below
		Reduced SOx, NOx and PM-10 Emissions	X →			included below

Benefit Category	Benefit Sub-Category	Benefit	Included in Original Estimate?	Estimated Value 2010-2030 $Billion		Reference
				Low	High	
Security	Energy Security	Reduced Imported Oil Usage		–	–	not included
		Personal Security		–	–	not included
		National Security		–	–	not included
		Reduced Wide-Scale Blackouts	X →			included below
		Safety	X →			included below
Previous EPRI Estimates – All included in original estimate			X	730	917	
Not included in original estimate				564	1,111	
Total				1,294	2,028	

*Enhanced Energy Efficiency includes:
Continuous Commissioning of Large Commercial Buildings
Direct Feedback on Energy Usage
Energy Savings Corresponding to Peak Load Management
Energy Savings Corresponding to Enhanced M&V Capability

Appendix 2: Table 5-4 from Electric Power Research Institute *'Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a fully functioning Smart Grid'* , page 5-9 – 5-11: Sensor Needs

	Item	Cause	Result	Update Interval	Probability	Consequence	Sensing Technologies
1	System Tampering	Terrorism	Tower/line down	Real-time	Low	High	Vibration, Acoustic, E-Field, Optical
2	System Encroachment	Man-made	Safety hazard, Less reliable	3-12 mo	High	Med	Optical, Satellite, Proximity, Vibration, E-Field
3	System Encroachment	Vegetation	Flashover, Fire	3 mo	High	High	Optical, Satellite, LIDAR, Line-of-Sight, Proximity
4	System Encroachment	Avian Nesting, Waste	Flashover	6-12 mo	High	High	Optical, Vibration, Leakage Current, Proximity, E-Field
5	Shield Wire	Corrosion	Flashover, Outage	3-6 years	Med	High	Optical, IR Spectroscopy, Eddy Current, MSS
6	Shield Wire	Lightning	Flashover, Outage	1 year	Med	High	Optical, IR Spectroscopy, Eddy Current, MSS, Lightning Detection, Vibration
7	Insulator (Polymer)	Age, Material Failure	Outage	6 years	Med	High	Optical, Vibration, RFI, UV, IR
8	Insulator (Ceramic)	Age, Material Failure	Outage	12 years	Low	High	Optical, Vibration, RFI, UV, IR
9	Insulator	Contamination	Flashover	3 mo	Med	Med	Optical, RFI, UV, IR, Leakage Current
10	Insulator	Gun Shot	Outage	Real-time, 3 mo	Med	High	Optical, Vibration, RFI, UV, IR, Acoustic

	Item	Cause	Result	Update Interval	Probability	Consequence	Sensing Technologies
11	Phase Conductor	External strands broke	Line Down, Fire	1 year	Low	High	Optical, Vibration, RFI, UV, IR
12	Phase Conductor	Internal strands broke	Line Down, Fire	1 year	Low	High	E-MAT, MSS, Electromagnetic
13	Phase Conductor	Corrosion of steel core	Line Down, Fire	1 year	Low	High	E-MAT, MSS, Electromagnetic, IR Spectroscopy, Optical
14	Connector Splice	Workmanship, thermal cycling, age	Line Down, Fire	1 year	Med	High	Direct Contact Temperature, IR Temperature, Ohmmeter, RFI, E-MAT, MSS
15	Hardware	Age	Line Down, Fire	6 years	Low	High	Optical, IR Spectroscopy
16	Phase Spacer	Age, galloping event	Line Down, Fire	6 years	Low	Med	Optical, UV, RFI
17	Aerial Marker Ball	Vibration Damage, Age	Safety concerns	1 year	Low	Med	Optical, UV, RFI
18	Structure (Steel Lattice)	Corrosion	Reliability Concerns	10 years	Med	Med	Optical, IR Spectroscopy
19	Structure (Steel Lattice)	Bent, damaged members	Reliability Concerns	1 year	Med	Med	Optical, Strain, Position, Tilt
20	Structure (Steel Pole)	Corrosion, age	Reliability Concerns	10 years	Med	Med	Optical, IR Spectroscopy

	Item	Cause	Result	Update Interval	Probability	Consequence	Sensing Technologies
21	Structure (Steel Pole)	Internal Deterioration	Reliability Concerns	1 year	Med	Med	Optical, MSS, Ultrasonics
22	Foundation (Grillage)	Age, corrosion	Reliability Concerns	10 years	High	High	Excavation, MSS, Radar, GPR Imaging, Half Cell, Voltage Potential
23	Foundation (Anchor Bolt)	Age, corrosion	Reliability Concerns	10 years	Low	High	Optical, Ultrasonics, E-MAT, Vibration
24	Foundation (Preform)	Age, corrosion	Reliability Concerns	10 years	Med	High	Optical, Ultrasonics, E-MAT, Vibration
25	Foundation (Stub Angles)	Age. Corrosion	Reliability Concerns	10 years	Low	High	Optical, Ultrasonics, E-MAT, Vibration
26	Foundation (Direct Embedment)	Age, corrosion	Reliability Concerns	10 years	High	High	Excavation, MSS, Half Cell, Voltage Potential
27	Foundation (Anchor Rods, Screw-In)	Age, corrosion	Reliability Concerns	10 years	High	High	Excavation, MSS, Half Cell, Voltage Potential, Ultrasonics
28	Grounding	Age, corrosion, tampering	Reliability, Lightning, Safety concerns	6 years	Med	Med	AC impedance, DC resistance, Impulse
29	TLSA (Transmission Line Surge Arrestor)	Lightning Strikes, age	Reliability, Lightning Concerns	1 year	Med	Med	Optical, IR, Leakage Current, Lightning Strike Counter

Appendix 3: Tables 1, 2 and 3 from 'Hurricane Ike Impact Report', Texas Engineering Extension Service: Negative vale by sector in the 12 months following Hurricane Ike

TABLE 1: INDUSTRIAL SECTORS

Industrial Sectors	Total Avg. Loss	Quarterly Avg. Loss	Weekly Avg. Loss
Agricultural Support	$38,793,587	$9,698,396	$746,030
Utilities	$9,624,794,721	$2,406,198,680	$185,092,206
Construction	$3,080,566,408	$770,141,602	$59,241,661
Manufacturing	$93,580,886,674	$23,395,221,668	$1,799,632,436
Wholesale Trade	$40,119,203,939	$10,029,800,985	$771,523,152
Retail Trade	$6,696,308,711	$1,674,077,178	$128,775,168
Transportation/ Warehousing	$2,123,495,670	$530,873,918	$40,836,455
Mining/Oil/Gas	$3,099,595,502	$774,898,876	$59,607,606

TABLE 2: AGRICULTURAL SECTORS

Agriculture Sectors	Total Avg. Loss	Quarterly Avg. Loss	Weekly Avg. Loss
Corn	$311,931	$77,983	$5,999
Cotton	$6,836,967	$1,709,242	$131,480
Grain Sorghum	$5,178,324	$1,294,581	$99,583
Rice	$23,004,119	$5,751,030	$442,387
Soybeans	$1,196,979	$299,245	$23,019
Wheat	$935,334	$233,834	$17,987
Beef	$66,095,870	$16,523,968	$1,271,074
Goats	$1,231,737	$307,934	$23,687
Sheep	$207,508	$2,804	$3,991

TABLE 3: SERVICES SECTORS

Services Sectors	Total Avg. Loss/Gain	Quarterly Avg. Loss/Gain	Weekly Avg. Loss/Gain
Information	-$33,485,576	-$8,371,394	-$643,953
Finance/Insurance	$3,590,663,758	$897,665,939	$69,051,226
Real Estate	$2,097,143,973	$524,285,993	$40,329,692
Professional Service	$7,144,220,825	$1,786,055,206	$137,388,862
Management	-$1,655,531,873	-$413,882,968	-$31,837,151
Administration	$1,968,054,066	$492,013,517	$37,847,194
Education	$32,157,207	$8,039,302	$618,408
Health Services	$7,746,495	$1,936,624	$148,971
Entertainment	$72,993,853	$18,248,463	$1,403,728
Hotel/Food Services	$376,087,064	$94,021,766	$7,232,444
Other Services	$715,395,377	$178,848,844	$13,757,603
Public Administration	-$1,705,178,986	-$426,294,747	-$32,791,904

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