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Economic and Physical Linkages of the Information and Communication Technology (ICT) Service Industry to Key Industries of the Economy: An *Ad Hoc* Analysis

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January 2017

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Richland, Washington 99352

Executive Summary

This report examines the information and communications technology (ICT) services industry in response to a "quick-response" inquiry by the DOE Office of Energy Policy and Systems Analysis. The report answers several key questions:

- How has the reliance on ICT services evolved in recent years for key infrastructure services such as air travel, freight transport, electricity and natural gas distribution, financial services, and critical health care, and for the household sector?
- What ICT industry trends explain continued strong linkage to and reliance upon ICT?
- What is the ICT industry's reliance on grid-supplied power, uninterruptible power supplies, and back-up energy storage technologies?
- What are the observed direct effects of ICT disruptions induced by electrical system failures in recent history and how resilient are the components of the ICT industry?
- How has the use of digital communications evolved through the past 100 years?

Economic reliance in the ICT services industry has been estimated quantitatively in the following table. Expenditures on ICT service as a fraction of all production inputs indicate economic reliance.

ICT Key Sector	2008 ICT Expenditures	2014 ICT Expenditures	Annual Average Change in ICT Expenditures	Annual Average Percentage Change in ICT Expenditures	Annual Average Percentage Change in ICT Input Fraction[1]
	$MM (2014)	$MM (2014)	$MM (2014)	Percent	Percent
Electric power transmission and distribution	398	287	(111)	-4.66%	-9.85%
Natural gas distribution	231	651	420	30.26%	58.47%
Air transportation	2,108	2,044	(64)	-0.51%	-2.40%
Rail transportation	895	651	(244)	-4.55%	-4.95%
Water transportation	384	701	317	13.75%	9.11%
Truck transportation	3,252	2,330	(923)	-4.73%	-5.76%
Warehousing and storage	445	1,456	1,012	37.94%	18.95%
Banking and Investment Services	37,215	51,805	14,590	6.53%	6.74%
Management of companies and enterprises	28,925	30,160	1,235	0.71%	1.87%
Hospitals	6,628	12,281	5,653	14.21%	8.79%
Total of Key Industries	80,482	102,366	21,884	4.53%	3.00%
Household Sector	788,005	966,917	178,913	3.78%	3.41%
Key Industries plus Households	868,487	1,069,283	200,797	3.85%	3.21%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)
1) Relative change in the proportion of ICT services used as production inputs for these industries.

The table suggests a strong trend toward increasing supply chain linkages between ICT services and key infrastructure services as evidenced by the increase in such expenditures by over 27 percent in the 2008-2014 period. Household expenditures for ICT services have increased nearly 23 percent in the same period. Using interindustry expenditure data, it is evident that expenditures for ICT services are growing at a much greater rate than the economy as a whole. For example, US real GDP for the same period grew just 13.7 percent. Further, expenditures as a proportion of each industry's production inputs (input fractions) are showing growing importance relative to all other production inputs for these industries.

The report discusses several important findings including the following:

1. The ICT services industry has been and continues to grow steadily, significantly outpacing the economy as a whole. Over the 6-year period covered, industry expenditures on ICT technology grew by double the rate of growth in GDP as a whole (over 27% growth compared just under 14% growth in GDP).
2. Key infrastructure services (e.g. air travel, freight transport, electricity and natural gas distribution, financial services, and critical health care, among others) make over $100 billion in expenditures for these services – this is a major industry in its own right.
3. The key sectors are continuing to strengthen their supply chain linkages to the ICT services industry at the relative expense of other inputs to production.
4. Households purchase nearly 10 times more ICT services than the key infrastructure sectors purchase – primarily for wired and wireless communications services (e.g. phone service, cable and satellite TV, and internet services.
5. Network convergence is a two-edge sword. It is necessary to continue to harvest economic and performance efficiencies from key sectors. However, the connected system is more vulnerable to the unintended or uncontemplated consequences brought about by technology failure or human error in a specific domain of the system.
6. As a result of the growing interdependencies between ICT, electric generation, and distribution, the risk of cascading failures from unforeseen events such as natural disasters, human error, cyber-attacks, or cascading technical failures can create larger and larger negative impacts as network technologies become more tightly linked and interdependent with the key services highlighted in this study.
7. Even with ever-progressing network convergence, ICT Services are inherently resilient by design, as evidenced in the relatively light disruption and quick recovery of networked systems after Hurricane Katrina, for example. As such, they are able to survive catastrophic events, realizing less damage than other fixed infrastructure.
8. As the economic and physical importance of the ICT service industry increases, so does the need for reliable and resilient electric grid services. ICT services themselves represent a significant input to providing a more reliable grid.

This research effort is the result of a short-turnaround DOE request for information. It relies upon information and data found to be readily available from public access sources. Methods employed to develop the paper were necessarily limited in time and effort to meet the request. For example, the report includes direct quotes and graphics developed as original content for existing literature reviewed by PNNL, but which are reproduced here, with citations, in the name of expedience. Due to the nature of this research effort, other approaches including simulation and modeling might be warranted and likely would result in additional refinement of estimates and conclusions presented in this report.

1. Background

This paper examines the characteristics of information and communications technologies (ICT) and related services on key sectors of the economy having increasing reliance on ICT services. For the purposes of this paper, we define the ICT sector as a set of 6-digit NAICS industries which include important services reliant upon specific technologies to provide their services. Specifically, our definition encompasses critical services and technologies related to enterprise information and communication, continuation of service/disaster recovery, and data backup and restoration. Table 1 summarizes the classification of services we are defining as the ICT industry for this paper. This classification is not inconsistent with other very similar approaches in the literature.

Table 1. NAICS Sectors Included in the ICT Services Industry

NAICS Code	Industry	Key ICT Services
517110	Wired Telecommunications Carriers	• Broadband Internet service providers, wired (e.g. cable, DSL) • Local telephone carriers, wired • VoIP service providers, using own operated wired telecommunications infrastructure • Telecommunications carriers, wired • Multichannel multipoint distribution services (MMDS)
517210	Wireless Telecommunications Carriers (except Satellite)	• Cellular telephone services • Wireless Internet service providers, except satellite • Paging services, except satellite
517410	Satellite Telecommunications	• Satellite telecommunication carriers • Satellite telecommunication resellers
518210	Data Processing, Hosting, and Related Services	• Application hosting • Application service providers • Web hosting • Computer data storage services
541512	Computer Systems Design Services	• Computer systems integration design consulting services • Local area network (LAN) computer systems integration design services • Information management computer systems integration design services • Office automation computer systems integration design services
541513	Computer Facilities Management Services	• Facilities (i.e., clients' facilities) management and operation services, computer systems, or data processing
541519	Other Computer Related Services	• Computer disaster recovery services

Key questions answered in this report:

- How has the reliance on ICT services evolved in recent years for key infrastructure services such as air travel, freight transport, electricity and natural gas distribution, financial services, and critical health care?
- What ICT industry trends explain continued strong linkage to and reliance upon ICT?
- What is the ICT industry's reliance on grid-supplied power, uninterruptible power supplies, and back-up energy storage technologies?
- What are the observed direct effects of ICT disruptions induced by electrical system failures in recent history and how resilient are the components of the ICT industry?
- How has the use of digital communications evolved through the past 100 years?

This report focusses in two areas. First, it documents the economic reliance or dependence upon ICT services of key sectors of the larger economy subject to immediate significant disruption if electrical service is lost. For this report, those key sectors include air travel, freight transport, electricity and natural gas distribution, financial services, and critical health care. Other industries are also dependent on ICT services and vulnerable to significant disruption if electrical service is lost unexpectedly, but we have limited the scope of this effort to just those industries mentioned to be responsive to the DOE request for information. Second, it explains this reliance on the ICT service industry in terms of size and importance of key technologies, such as data centers, uninterruptible power supply, and backup energy storage. It presents important trends identified as contributors to the evolving economic reliance on ICT services.

1.1 Evolution of ICT Technologies

ICT has come a long way since human beings started speaking and writing. From the earliest forms of speech, the elementary use of pictures and symbols we have grown, matured, and evolved into a place where today advanced communications technologies that enable instantaneous global exchanges of information are absolutely fundamental to not only the health and economic well-being of nations on the planet, but is now equally essential to individual citizens. The global, national, regional, and community infrastructures we depend on including; electricity, water, fuel, food, communications, and transportation all heavily depend on reliable ICT.

Figures 1 and 2 (on the next page) depict the supply chain relationships for key components of the ICT services sector[1]. Supply chains refer to the economic and physical linkages that one industry has with its supplying industries or production inputs. For example, telecommunications providers are linked through their purchases of inputs needed to operate the communication transmission system, related data centers, and the materials and labor needed to keep such facilities in operation. Such inputs include the purchase of electricity and cooling water, fuel for backup power generation, technical software development and

1 https://sftool.gov/Content/attachments/GSA%20Climate%20Risks%20Study%20for%20Telecommunications%20and%20Data%20Center%20Services%20-%20FINAL%20October%202014.pdf

maintenance, and monitoring services by expert technical staff. The supply chain for data centers includes maintenance and operations of individual server farm site buildings, including facility cooling technologies, backup power generation equipment and uninterruptible power supplies, specialized software development and maintenance, in addition to infrastructure requirements like electricity, water, and fuel for backup power generation.

Figure 1. Supply Chain for the Telecommunications Sector (Source: GSA, 2014)

Figure 2. Supply Chain for the Data Center Sector (Source: GSA, 2014)

1.2 Linkage of ICT Services and Electricity

As ICT services have matured and become more ubiquitous throughout the economy, and as economic linkages to these services have grown stronger, the grid services needed to enable the provision of ICT services have received increased attention. Reliable and resilient electricity service is essential to enabling the provision of ICT services. As all significant commerce is carried out on networked systems, these enterprises rely upon data centers for archival record storage, real-time database processing operations, and electronic bandwidth to carry out commerce online. Those services need to have contingencies for potential disruptions in the electrical supply, whether momentary or prolonged. ICT services deploy back-up power supply generators, and electricity storage technologies, in addition to uninterruptible power supply (UPS) technologies to mitigate outages or recover from outages induced by other external events.

This report highlights these linkages between the ICT sector and the electricity sector. Reliance is not just the economic reliance alluded to above, but the physical reliance implied by increasing system convergence. As economic supply chains demonstrate the increased use of ICT services by key industries and the household sector, those industries become more strongly linked physically. Economic metrics allow us to characterize those linkages quantitatively, but those physical linkages also are identified and demonstrated when disruptions occur.

As discussed below, outages of ICT services from non-grid related issues are common but do not often impact grid operations. Data center outages have the potential to cause grid failures and these are generally caused by equipment failures within the data centers. Cyber attacks are one source for non-equipment failures of current concern. Suspected cyber attacks have been happening over the last 15 years in the US, even though there are only 15 listed in the DOE Electric Disturbance Events Annual Summaries[2]. The largest known cyber attack impacting the electrical grid occurred in late 2015 in the Ukraine[3]. Another common potential disruption for the power grid is the loss of communications capabilities due to the disruption of fiber-optic systems[4].

Europe with its dense infrastructure and interconnected complex energy systems has started to consider the criticality of intertwined network infrastructures to vulnerability and risk. In a recent article from the European Journal for Security Research[5], the author presents this insight:

> *"While the re-conceptualization of the electric power grid is fast-occurring to allow for the integration of large shares of electricity produced by harvesting solar and wind energies at the most suitable sites (e.g. desert solar and offshore wind farms), a "smarter" system is sought with decentralized generation, smart metering, new devices for increased controllability, self-healing etc., which will convert the existing power grid from a static infrastructure to be operated as designed into a flexible, adaptive infrastructure operated proactively through three foundational layers: power and energy, communication, IT/computer. What emerges is the typical construct of system of systems (SoS), in which the systems forming the collaborative set of the SoS fulfill their purposes and are managed for their own purposes and the purposes of the whole SoS (Eusgeld et al. 2011; Zio and Sansavini 2011). This may lead to new and unexpected hazards and vulnerabilities. For example, the*

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[2] https://www.oe.netl.doe.gov/OE417_annual_summary.aspx
[3] https://www.wired.com/2016/03/inside-cunning-unprecedented-hack-ukraines-power-grid/
[4] http://www.wsj.com/articles/SB10001424052702304851104579359141941621778
[5] http://link.springer.com/article/10.1007/s41125-016-0004-2

growing role of ICT in the energy infrastructure requires that cyber-security be considered in the development of smart grids from the outset (Zio and Sansavini 2013). Indeed, recent incidents have shown that ICT systems can be vulnerable to cyber-attacks and that such attacks can lead to disruption of physical systems and networks.

On top of the technological challenges related to the evolution of such systems (e.g. creation of distribution management through using distributed intelligence and sensing, integration of renewable resources, etc.), a number of other issues are daunting the electric power grid systems and increasing the stress of the environments in which these are to be operated:

- *the deregulated energy market which has resulted in the systems being operated closer to their capacity and limits, i.e., with reduced safety margins, and consequently in the need for new and balanced business strategies;*
- *the prospected demand for electricity in the next 25–50 years, which results in the need to technically respond by increased capacity and efficiency;*
- *the sensed increase in the exposure to malevolent attacks that are no longer only hypothetical, which calls for effective protection to a different type of hazard/threat, much more difficult to predict than random failures.*

In these scenarios of increased stress onto the electric power grids, concerns are naturally arising on the vulnerabilities and risks associated to their future development and operation."

2. Reliance on ICT by Key Industries

Key industry sectors rely upon ICT services and this reliance has been increasing steadily and markedly in recent years. Table 2 summarizes this reliance in economic terms. The table reports estimated expenditures by each key industry for ICT-related services in 2008 and 2014, based on the IMPLAN[6] (2010, 2016) interindustry database. That source also provides several other economic metrics including industry output, the input fractions of each input to production, and others. Economic reliance is determined by examining the input fractions of the supplier industries contributing to the output of the purchasing industry. In this case, we are analyzing the purchasing of ICT services for the provision of air transportation, banking and finance, hospitals, etc. Seeing how these input fractions are changing over time provides some evidence of increasing or decreasing reliance on ICT services by these key industries.

Although the IMPLAN data are more disaggregated than most publicly available data sources, they are still too aggregated to resolve to very finely specified services like disaster recovery, offsite data storage and backup, or data center facilities, for example. Thus, interpretation of the changes between 2008 and 2014 require informed judgment and caution. In addition, given the time limitations of this study, we used data products that were readily available to us from previous related work (2008 and 2014 vintages). The comparison of these years in absolute constant dollar terms may be affected by general economic conditions in 2008 at the onset of a significant recession. However, the relative comparison of input fractions or proportions should not be overly affected by the years selected to analyze.

With these considerations in mind, there are a few observations to discuss. In real terms, these key industry sectors have increased their annual purchases of ICT services by over $21 billion since 2008, growing by an average of more than 3 percent annually. Over half of this growth has occurred in the financial services sector, which is attributable to that sector's size, relative to the other sectors analyzed. In aggregate, expenditures for ICT services by these key industries have increased from over $80 billion in 2008 to well over $100 billion as of 2014.

The annual growth rates vary widely between industries, which may suggest some (e.g. natural gas distribution, water transportation, warehousing, and hospitals) are investing in ICT services at a greater pace than the other industries. There are many potential reasons for why these variation exist including*: reducing costs, providing greater customer service, and expanding revenue channels* (Researchmoz Global Pvt Ltd , 2016).

The change in input fractions between 2008 and 2014 gives an indication of the change in the use of ICT services relative all other inputs to production in the industries analyzed. In other

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[6] IMPLAN® (IMpact analysis for PLANning),[6] a widely accepted economic database. IMPLAN provides a means for examining the relationships within an economy, both between industries and between industries and final consumers. The IMPLAN model captures all the monetary market transactions between industries and final consumers for an annual snapshot. This allows for examination of very detailed representations of the nation's industrial structure and to trace how changes in one or more sectors of an economy affects other sectors in the nation. Each economic activity is represented as both a purchaser of industrial inputs and the seller of its output. These linkages, called inter-industry transactions, represent the dollar flows between industries necessary to produce their goods and services. The national data files for 2008 and 2014 were used in this analysis with 2008 data converted to 2014 constant dollars.

words, the input fraction is the proportion of ICT expenditures relative to the industry's total output. In many cases, the industries studied are becoming significantly more reliant on ICT services, though some have shown decreased reliance between 2008 and 2014. This reliance, indicated by changing input proportions for ICT services, is growing on average by over 3 percent in real terms annually across all industries studied. Section 3 describes the characteristics of the ICT services industry and examines the trends that account for the increasing reliance observed over the past 8 years.

Table 2. Key Industry Reliance on ICT Services (2008 and 2014)*. Reliance is indicated by the magnitude of expenditures made for ICT services as inputs to the production in other key industries and by the increase in these expenditures as a proportion of all production inputs (input fraction). Additional detail for subcomponents of ICT services appears in the Appendix.

ICT Key Sector	2008 ICT Expenditures	2014 ICT Expenditures	2008 Output[1]	2014 Output[1]	2008 ICT Input Fraction[2]	2014 ICT Input Fraction[2]	Change in Annual ICT Expenditures	Annual Average Percentage Change in ICT Expenditures	Annual Average Percentage Change in ICT Input Fraction[3]
	$MM (2014)	$MM (2014)	$MM (2014)	$MM (2014)	Share	Share	$MM (2014)	Percent	Percent
Electric power transmission and distribution	398	287	196,296	345,601	0.002027	0.000829	(111)	-4.66%	-9.85%
Natural gas distribution	231	651	140,124	87,523	0.001651	0.007443	420	30.26%	58.47%
Air transportation	2,108	2,044	160,379	181,723	0.013145	0.011249	(64)	-0.51%	-2.40%
Rail transportation	895	651	77,009	79,666	0.011619	0.008166	(244)	-4.55%	-4.95%
Water transportation	384	701	47,011	55,485	0.008168	0.012630	317	13.75%	9.11%
Truck transportation	3,252	2,330	300,877	329,264	0.010810	0.007075	(923)	-4.73%	-5.76%
Warehousing and storage	445	1,456	63,788	97,791	0.006969	0.014894	1,012	37.94%	18.95%
Banking and Investment Services	37,215	51,805	1,306,790	1,295,503	0.028478	0.039988	14,590	6.53%	6.74%
Management of companies and enterprises	28,925	30,160	588,486	551,727	0.049151	0.054665	1,235	0.71%	1.87%
Hospitals	6,628	12,281	599,867	727,550	0.011050	0.016880	5,653	14.21%	8.79%
Total of Key Industries	80,482	102,366	3,480,627	3,751,836	0.023123	0.027284	21,884	4.53%	3.00%
Household Sector	788,005	966,917	11,727,039	11,948,056	0.067196	0.080927	178,913	3.78%	3.41%
Key Industries plus Households	868,487	1,069,283	15,207,667	15,699,892	0.057108	0.068108	220,496	3.85%	3.21%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)

1 Total production including the aggregate cost of all inputs plus value added (labor, taxes, owners' investment, etc.)

2 Purchased inputs of ICT services as a fraction of total output.

3 Relative change in the proportion of ICT services used as production inputs for these industries.

* Data for 2008 and 2014 were readily available for this study. Additional data could not be acquired and analyzed in the time allotted.

3. ICT Services Industry Data and Trends

Services provided by information and communication technologies are now critical to most enterprises in the economy. As the technologies used by ICT services industry have matured over time, dependence on them to make business operations increasingly efficient has grown significantly. This report focuses on trends observed for data centers, uninterruptible power supplies, and back-up electricity storage. Current market research suggests that strong growth in the deployment of these services and the related technologies will continue to be strong for the foreseeable future. The trends are driven by falling costs of the underlying technologies. As adoption grows, more suppliers enter the market – driving down costs.

3.1 Data Center Market

Over the last decade, there has been a steady shift from company operated data centers to cloud computing. A recent survey[7] of senior IT executives confirmed that at least half of all work processes will shift to the cloud by 2020. This shift is driven by improved efficiency and cost effectiveness of cloud-based systems compared to company-owned facilities, in addition to the need for increased reliability and security of the stored data. The major players in this area are Amazon Web Services, Google, IBM, and Microsoft. Data center growth is shown by the growth in cloud-based systems. Figure 3 from Cisco[8] illustrates projections of that growth for 2014 to 2019.

Figure 3. 2014-2019 Expected Growth in Cloud Services Data Requirements (25% Compounded Annual Growth Rate (CAGR))

As data center use grows either for company specific use or cloud use to a wide range of end-users, the consequent requirements for additional uninterruptible power supply and backup generators will grow in parallel, because of the need to allow reliable continuous operation in the

[7] http://www.enterprisetech.com/2016/06/22/datacenter-survey-confirms-steady-cloud-shift/

[8] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/global-cloud-index-gci/Cloud_Index_White_Paper.pdf

face of short-term, less than 24 hour, grid outages. The focus by data center operators and utilities supplying power to them has been on efficient energy use, which includes uninterruptible power supply efficiency to meet Energy Star standards. Utilities such as PG&E in California have recommendations for maximizing energy efficiency and as well as uninterruptible power supply efficiency[9].

Data center backup systems planning[10] includes the proper configuration of generator units and uninterruptible power supply (UPS) systems. In a generation system, every available generator unit can be programmed to start automatically during a loss of utility power. As long as sufficient fuel is available, the generators power the entire data center load until the utility power source is restored.

When regular power is restored, the generators transfer the load back to the utility and stop operating. The transition to and from the backup-generator power is seamless, when configured properly. The most effective designs will incorporate the necessary generators to supply power, as well as backup generators, should any one unit fail.

Redundancy should also be built into the UPS system so that one failing module won't affect the overall capacity of the system. Both generator and UPS systems can be configured for automatic and manual power transfer. Automatic transfer is critical during unexpected outages. Manual transfers are used for scheduled maintenance and testing of data center equipment and procedures without interfering with normal operations.

3.2 End-Use Electric Storage Market

The emergence of behind-the-meter energy storage is apparent in market research reported by Cleantechnica[11], covering the 2015 US Energy Storage Summit, where GTM Research Senior Vice President Shayle Kann predicted in his keynote speech that annual energy storage installations will grow from 51 megawatt hours (MWh) in 2013 to 3,659 MWh by 2020 on the strength of improving economics and policy developments. Figure 4 illustrates significant increases in end-user installation of energy storage technologies through 2020.

The use of energy storage for power system reliability in commercial buildings or data centers either for basic infrastructure operations and data center power reliability is indicated in the nonresidential bars in Figure 4 below. One concept that has validity is the use of both energy storage and backup generation being used in demand response programs to use in place infrastructure components to generate revenues from the supplying utility[12].

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[9] http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/DataCenters_BestPractices.pdf

[10] http://www.datacenterjournal.com/reliability-redundancy-understanding-high-availability-data-center/

[11] https://cleantechnica.com/2015/12/09/falling-costs-rising-applications-will-boost-us-energy-storage-market/

[12] http://www.datacenterdynamics.com/content-tracks/power-cooling/cutting-data-center-energy-demand-for-a-profit/96307.fullarticle

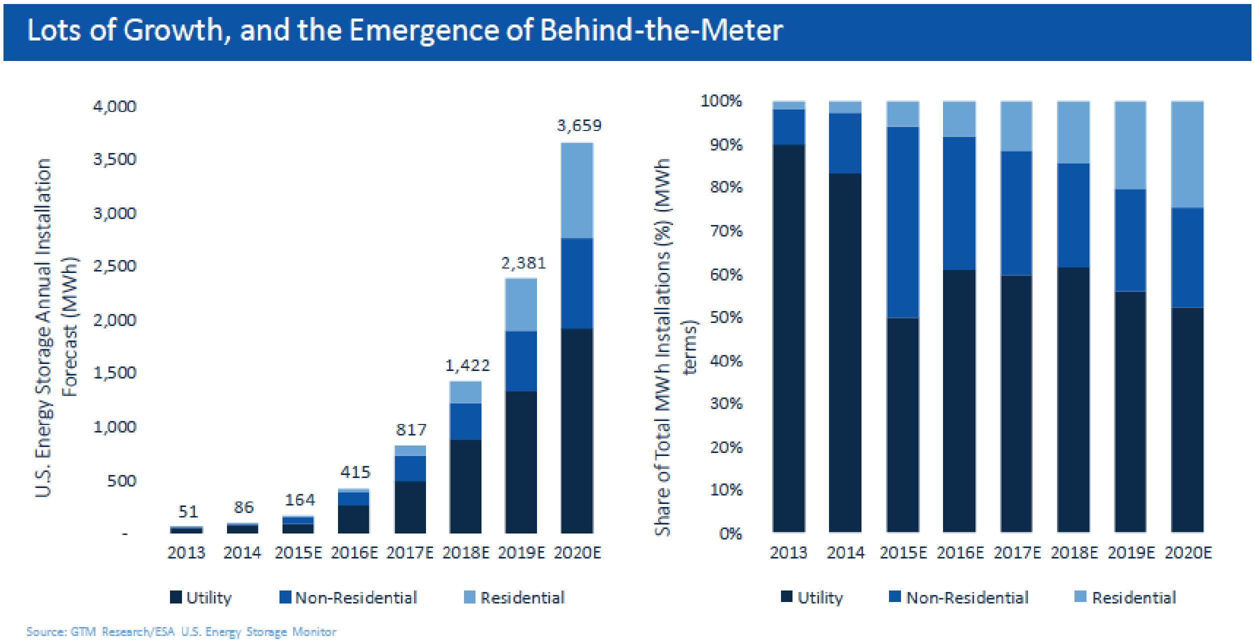

Figure 4. 2013-2020 Trends in End-Use Energy Storage Market Adoption (Source: Cleantechnica, 2015)[13] The figure suggests that electricity storage as a component of commercial and residential sector back-up and supplemental power resources is growing and gaining market share relative to utility scale electricity storage.

3.3 Uninterruptible Power Supply Market

Trends in this market follow trends in the data center market, as these technologies are critical to the operation of data centers. Recent market research by Grand View Research[14] suggests the trends indicated in Figure 5.

As implementation of cloud computing continues to grow, along with the need for sensitive and ubiquitous data, data center UPS installations are projected to follow that trend. Increased adoption of mobile computing services, online services, and remote access services also continue to bolster the industry. Other factors boosting the data center UPS market growth are increased adoption of Software as a Service (SaaS), high-performance computing, online gaming, and online media streaming. The use of portable UPS systems has gained prominence, which is further expected to boost data center UPS market growth. US segmentation of the data from this source is not publicly available. The clear trend in increased deployment of small data centers suggests that smaller and smaller enterprises are becoming more and more reliant upon enterprise data back-up solutions.

[13] https://cleantechnica.com/2015/12/09/falling-costs-rising-applications-will-boost-us-energy-storage-market/
[14] http://www.grandviewresearch.com/industry-analysis/data-center-ups-market

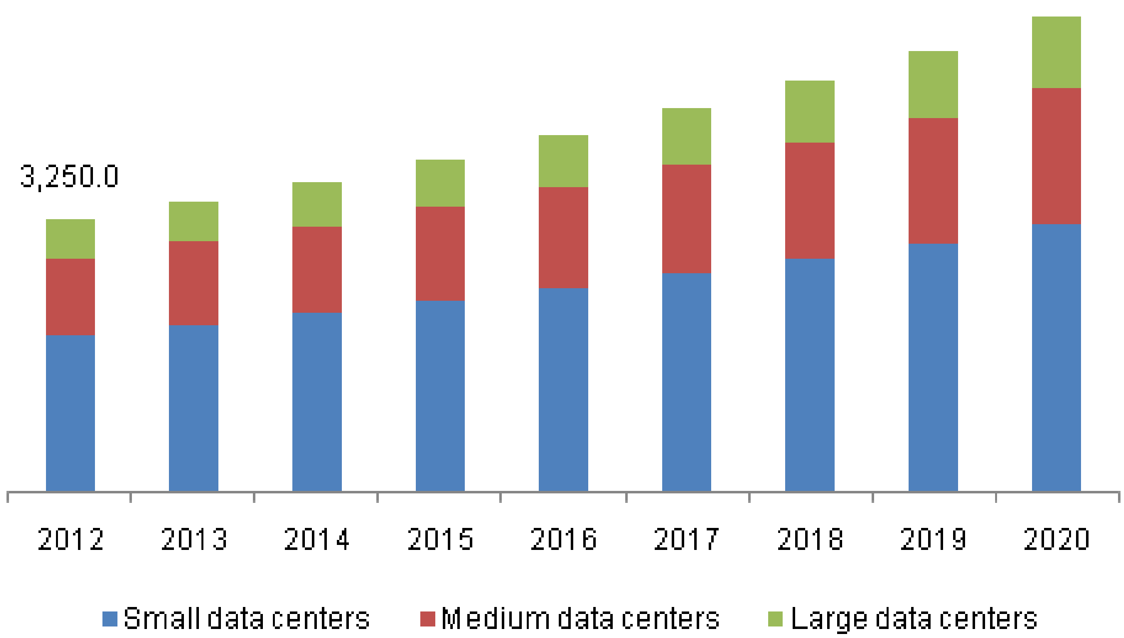

Figure 5. 2012 – 2020 Global data center UPS market by product, ($MM) (Source: Grand View Research, 2014). This chart is from an abstract of a commercially available industry report suggesting that while the UPS market segments for medium and large data centers are projected to grow slightly through 2020, substantial growth is expected in the small data center market for UPS equipment. This indicates that smaller and smaller enterprises are requiring data center services and becoming reliant upon them.

4. ICT Services and Grid Power

Automation in the electric grid system began with the need to limit short circuits by protecting equipment with fuses and electromechanical relays. At the distribution level prior to the 1940s, outage repair was based on replacing blown fuses and repairing downed lines with manual labor. The initial use of the automated distribution "re-closer" in the 1940s, which relied on basic sensors and timers, began the march to more reliability, lower labor costs, and faster outage resolution.

Supervisory Control and Data Acquisition (SCADA) systems based on sensors and digital communication networks came into use in the late 1970s allowing both the display of grid information in control centers and remote operation of circuit breakers and other devices in substations that were previously manned. As digital relays were developed using microprocessors, faster control speeds required improved communication systems speeds. This has been true at both the transmission and distribution level.

Communications systems for grid control evolved from powerline carrier (very slow data rates) to analog microwave channels, then digital microwave channels and onto fiber-optic cables either buried in right-of-way or attached to ground or conductor wires. The original microwave channels were utility owned and operated. When the shift to fiber optics happened, utilities began sharing expenses and right-of-way with commercial communications companies to install fiber optics. Particularly at the distribution level, communications companies would install fiber and utilities would then take advantage of in-place infrastructure for high-speed communications to improve grid automation. This evolution of power and communications has grown both physically in the same right-of-way as well as been intermixed from communications and control standpoint. This has become the basis for the smart grid concept, which the DOE Office of Electricity Delivery and Energy Reliability defines as "a grid that uses digital technology to improve reliability, resiliency, flexibility, and efficiency (both economic and energy) of the electric delivery system".[15]

The reality of current day and projected future grid interactions with end-use power and ICT are well-defined in how to enable the benefits of the power grid in coordination with communications in a "Buildings to Grid Technical Opportunities" perspective paper[16]:

> *ICT is used to refer to the convergence of communications, which represents the integration of data, voice, and information exchange and associated technologies. Throughout this section, ICT is used synonymously with the data exchange and communication infrastructures, including hardware, software, and underlying theory and principles, but it does not include the application software that resides on top of the infrastructure (e.g., analysis and visualization software tools). It encompasses the transmission, exchange, storage, retrieval, and management of data in support of interactions among components of the grid, buildings, renewable generation, and storage installed on or in buildings, and neighborhoods and communities.*
>
> *Broadly speaking, highly interactive, distributed control requires ICT in three different domains—smart electric grid, building automation, and the interface between the two. Because different companies provide technology to different users/decision-makers and different standards already exist or are being developed for the smart*

[15] http://energy.gov/oe/services/technology-development/smart-grid

[16] http://energy.gov/sites/prod/files/2014/03/f14/B2G_Tech_Opps--Info_Comm_Tech_Perspective.pdf

grid and for buildings, it is quite possible that smart grid and building automation may not converge, but instead will remain separate. Furthermore, the needs in each of these sectors differ. For example, the priorities in buildings are to provide comfort and other amenities to owners and occupants and to minimize occupants' complaints, while for the electric power grid, keeping the grid operating reliably is of paramount importance. Therefore, the interface between ICT systems represents a critical third ICT 'domain' that straddles buildings and the grid.

The Smart Grid is essentially an integration of the power infrastructure with an information infrastructure, combining the maturity of the electric grid with the efficiency, connectivity, and cost gains brought by ICT. A transaction-based system will require exchanges of value among participants both on the grid side and the end-user side. It will be a network of networks comprising many systems and subsystems with various ownership and management boundaries interconnected to provide end-to-end services between and among stakeholders, as well as between and among intelligent devices representing stakeholders. ICT is essential for monitoring and managing distributed energy resources, including storage, automated Demand Response, and the coordination and control required for operational stability of electric grid.

4.1 Effects of Power Outages on ICT

Electricity is essential to providing ICT services which impact almost all Americans daily lives either for communications, entertainment or to transact incoming or outgoing business operations. The reliability of power in the form of grid power, uninterruptible power supplies, energy storage or backup generation to keep society functioning is essential.

The technologies that form the backbone of ICT services depend upon reliable electric service to function. Routers depend on communications circuits, such as leased lines, local area networks, microwave, fiber optic, and satellite links, to connect to neighboring routers and networks. Most of these links are operated by communications common carriers that are usually not the same organizations that run the routers. These links may fail or go out of service periodically because of technical problems, cable cuts, or other issues beyond the control of router operators. An outage in a communications carrier's core network may not affect Internet routing very much, as the carrier would most likely have other routes available to which the traffic could be switched. An outage in the "last mile" of a circuit serving a router facility may cause a connectivity problem, because there may be no alternate path to the Internet until the circuit is fixed (DHS, 2011)[17].

Whenever there are large grid outages, communications systems can be disrupted because power lines go down, emergency generators go on at telephone switch offices, cellular sites, internet switching centers as well as business data centers large and small. When the power cannot be restored in eight hours or less, generators at cellular sites run out of fuel and stop working. This causes a disruption to emergency services that rely on mobile communication systems based on cellular technology as well as emergency services from ambulance to police.

[17] https://www.dhs.gov/xlibrary/assets/itsrm-for-internet-routing-report.pdf

If the power is out for more than 24 hours, disruptions to central telephone office switches, hospitals and other emergency services are often disrupted because fuel supplies for these services are generally only good for 24 hours of run time. When there are downed power poles, trees or flooding, the ability to deliver fuel to keep these generators running or restart them can cause tremendous suffering and threaten lives. Other additional community services such as water, sewer and emergency services are put at risk.

4.1.1 Electric Reliability and Resilience

Outage impacts are typically measured based on industry-standard metrics such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI)[18]. Figures 6 and 7 illustrate the recent commercial sector trends in these metrics. Trends suggest general improvement (e.g., duration and frequency of outages are declining). However, these metrics do not account for the accompanying economic impacts of the associated outages, and there is currently no metric that provides such information in a standardized way. Harmonization of SAIDI data was not done until the 1990s and began in the 1980s because of the advent of digital devices (clocks) which would "blink" when momentary power outages cause them to reset.

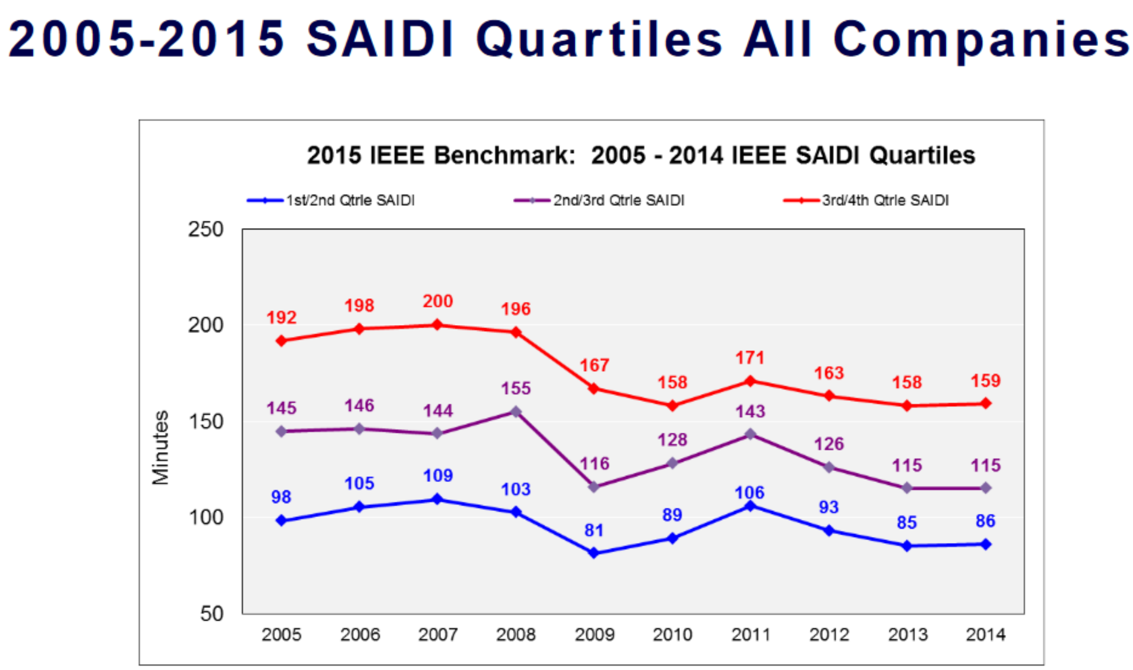

Figure 6. Recent Trends in Electric System Outage Average Duration (Source: IEEE, 2016). This suggests a decreasing duration (minutes) of distribution level outages over the last decade

[18] http://grouper.ieee.org/groups/td/dist/sd/doc/2015-09-Benchmarking-Results-2014.pdf

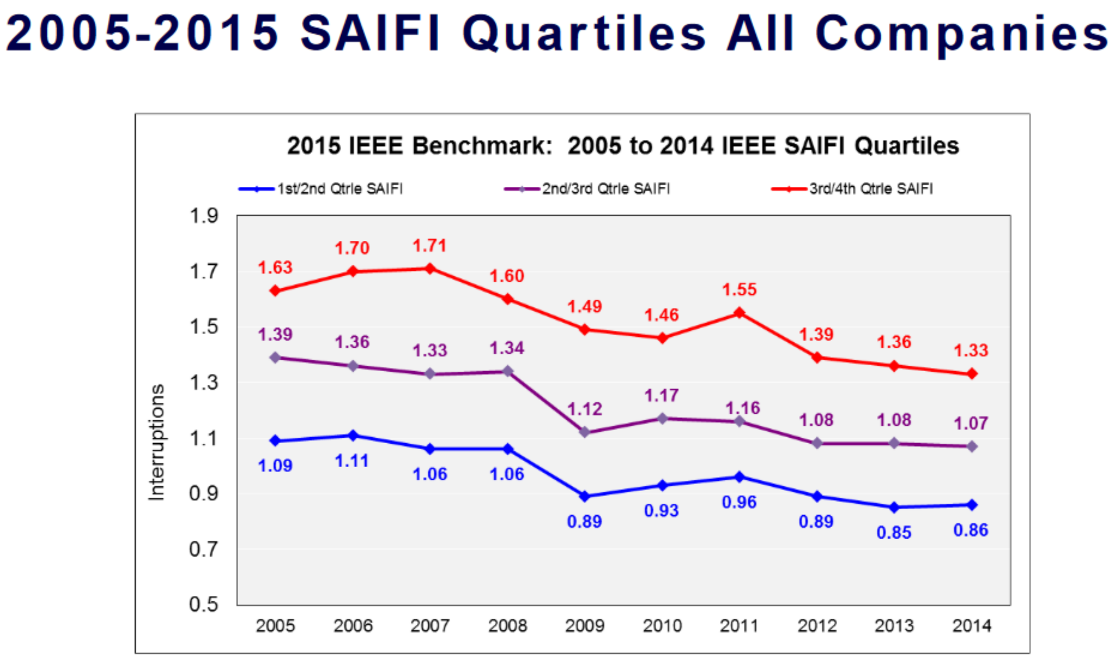

Figure 7. Recent Trends in Electric System Outage Average Frequency (Source: IEEE, 2016) This suggests a decreasing frequency of distribution level outages over the last decade

Recent work by Lawrence Berkley National Laboratory (LBNL)[19] attempted to identify statistical evidence for increasing or decreasing reliability of the US electrical system. They studied data collected from 195 utilities on frequency and duration of outages over the 2000-2012 period. They concluded that no trend exists for increasing frequency of outages whether the outages are weather-related or not. *They did identify statistically significant trends for increasing duration of outages over that period, both for weather related and non-weather related outages over that period.* The conclusions regarding outage duration are consistent with the incidence of more frequent severe disasters, which tend to cause outages of longer duration. The LBNL conclusions would seem to differ somewhat from a visual inspection of Figures 6 and 7, but their analysis covers a longer time series and makes several important adjustments to the reported utility data. ***Thus, the best data would suggest that frequency of outages is essentially flat, but that duration (and associated economic impact) is increasing***.

Resilience is an important concept that builds on reliability and for which widely accepted metrics have yet to be developed or reported. It is the notion of how well can the system recover from, adapt to, or avoid external (e.g. outage-causing) events. Data centers, cellular data equipment, and Internet Service Providers (ISPs) are all dependent upon commercial power from local utilities for operation. Each of these has a limited capability/requirement for backup power generation, generally in the 8 to 24 hour range, based on batteries – UPS – energy storage, fuel cells, or generator sets. Disasters such major storms, hurricanes, tornadoes, earthquakes or wildfires affect the reliability of the electricity grid, which in turn affects the reliability of networked communications. Figure 8[20] illustrates the effects of Hurricane Katrina on the networked infrastructure as the storm made landfall in August of 2005. It also illustrates a view of the resilience of the networked systems in the affected states, in terms of how much time restoration required.

[19] http://eetd.lbl.gov/sites/all/files/lbnl-188741.pdf

[20] http://research.dyn.com/content/uploads/2013/05/Renesys-Katrina-Report-9sep2005.pdf

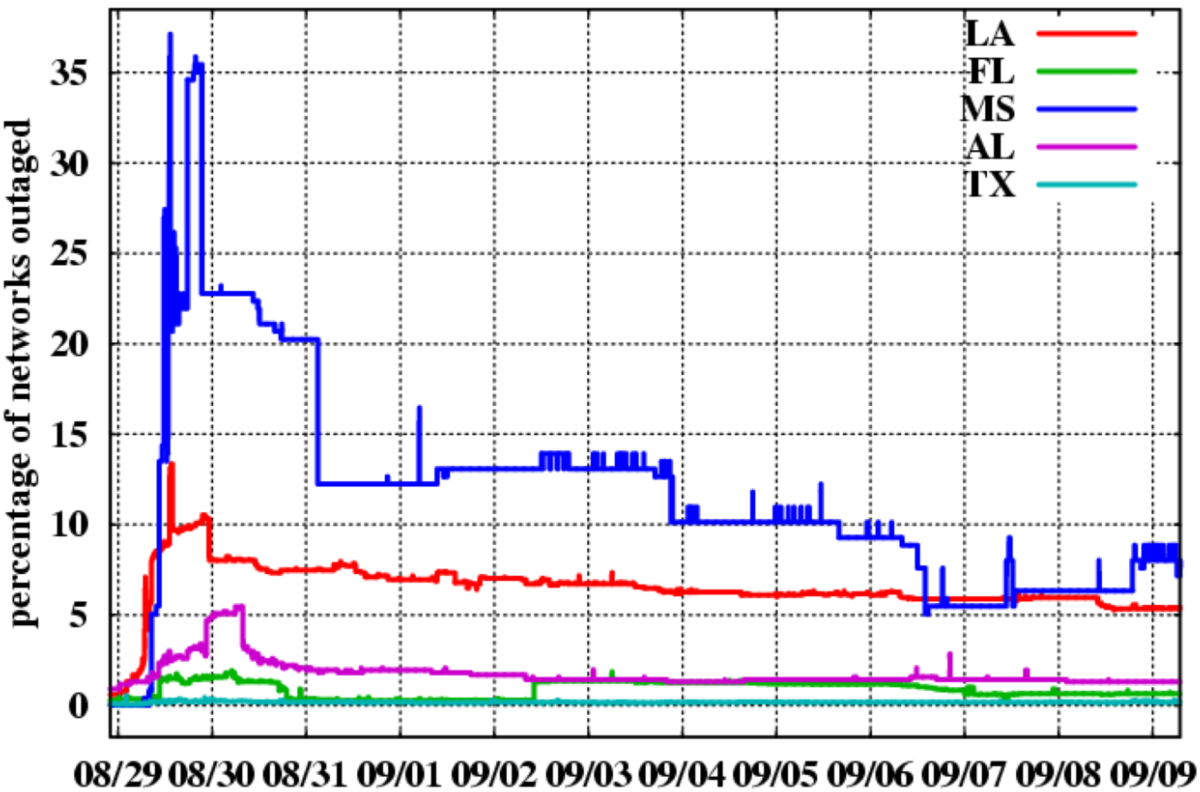

Figure 8. Communications Network Outages Induced by Hurricane Katrina (Source: Renesys, 2005). This figure illustrates the nature of network service restoration. The most acute and widespread outages are restored to service within hours of the outage triggering. Service restoration continues in parallel with electrical service restoration, with over half of all affected networks restored within 2 days. The number of networks experiencing an outage is cut in half again within a week. One to several weeks may be required to restore services to all affected electricity and network customers.

Even with the well-documented severity of hurricane Katrina, network outages generally stayed below 10 percent, except in Mississippi, where they stayed below 25 percent, except for a peak outage period of about 35 percent. However, the severity of hurricane Katrina contributed to the long duration of network outages across the affected path, reflected by the slow restoration of network services due to other infrastructure damage.

Disruptions of data center activities in many cases stem from failure in backup systems that typically only trip in cases of grid instability.[21] Figure 9 illustrates the root causes of data center outages. Figure 10 illustrates the average cost impacts across a study of 63 data centers. UPS system failure, weather related events, and generator failure account for over 40% of unplanned data center outages thus far in 2016. Power failure or other electrical issues would be the typical reason for these systems to engage in the first place.

[21] http://www.emersonnetworkpower.com/en-US/Resources/Market/Data-Center/Latest-Thinking/Ponemon/Documents/2016-Cost-of-Data-Center-Outages-FINAL-2.pdf

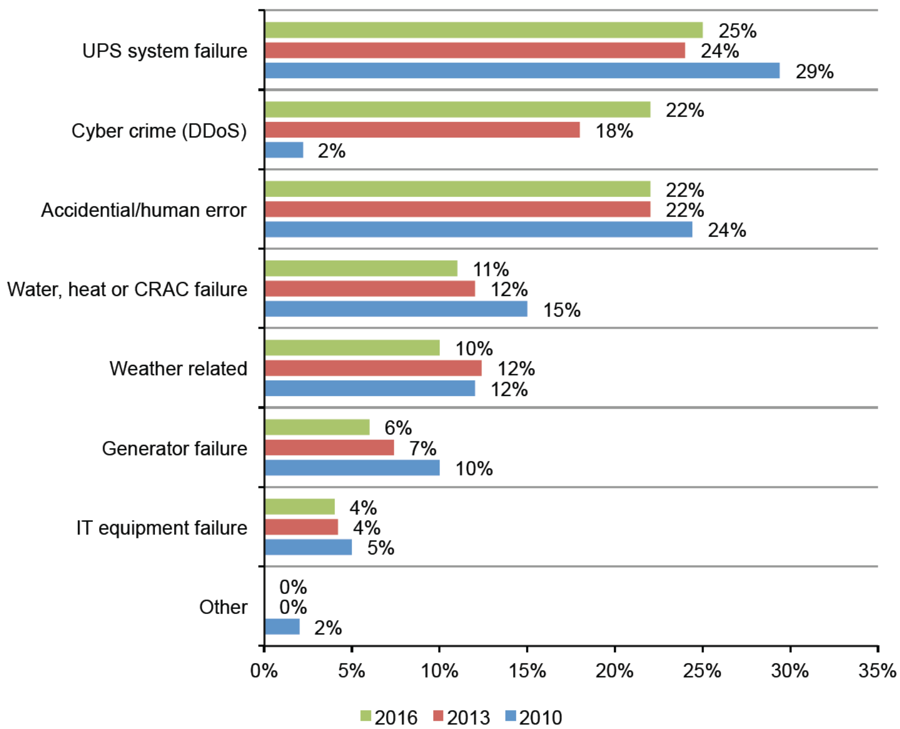

Figure 9. Root Causes of Unplanned Data Center Outages (% of cases) (Source: Ponemon Institute LLC, 2016)[22]

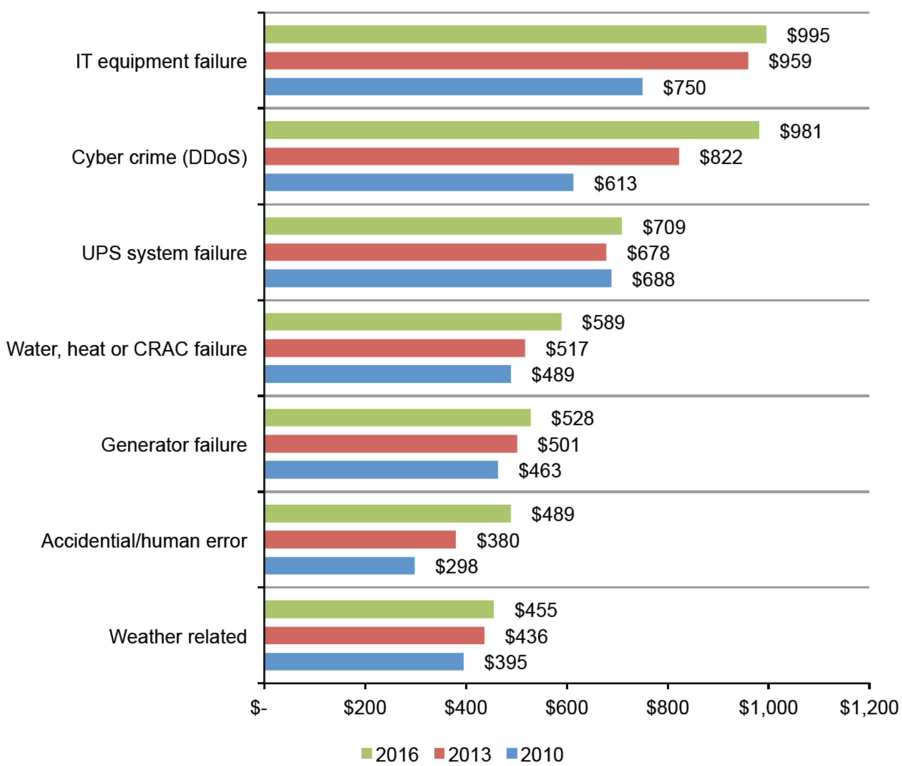

Figure 10. Average Cost by Root Cause of Unplanned Data Center Outages ($000) (Source: Ponemon Institute LLC, 2016)[18]

[22] http://www.emersonnetworkpower.com/en-US/Resources/Market/Data-Center/Latest-Thinking/Ponemon/Documents/2016-Cost-of-Data-Center-Outages-FINAL-2.pdf

ICT disruptions of long-term nature are rare due to the reliability of the Internet, because of rerouting data packets, which currently carries the majority of data and voice communications[23]. A report on the impacts of the 2003 blackout on the Internet[24] had the following to say:

> “The very largest provider networks (the Internet backbones) were reportedly unaffected by the blackout, but thousands of corporate and other institutional networks and millions of individual Internet users were offline for hours or days. Banks, investment funds, business services, manufacturers, hospitals, internet service providers, and federal and state government units were among the affected organizations.”

Figure 11 illustrates recent trends in the number of billion-dollar disasters. The economic damage from these storms is correlated with the severity of lost services, such as electricity service. This also supports the LBNL finding above that there is an increasing trend on outage duration over the 2000-2012 period.

Since 1980, the United States has sustained 144 weather disasters whose damage cost reached or exceeded $1 billion. The total cost of these 144 events exceeds $1 trillion (U.S. Department of Commerce 2013). Moreover, seven of the ten costliest storms in U.S. history occurred between 2004 and 2012 (U.S. DOC 2012). These “billion dollar storms” have rendered a devastating toll on the U.S. economy and the lives of millions of Americans.

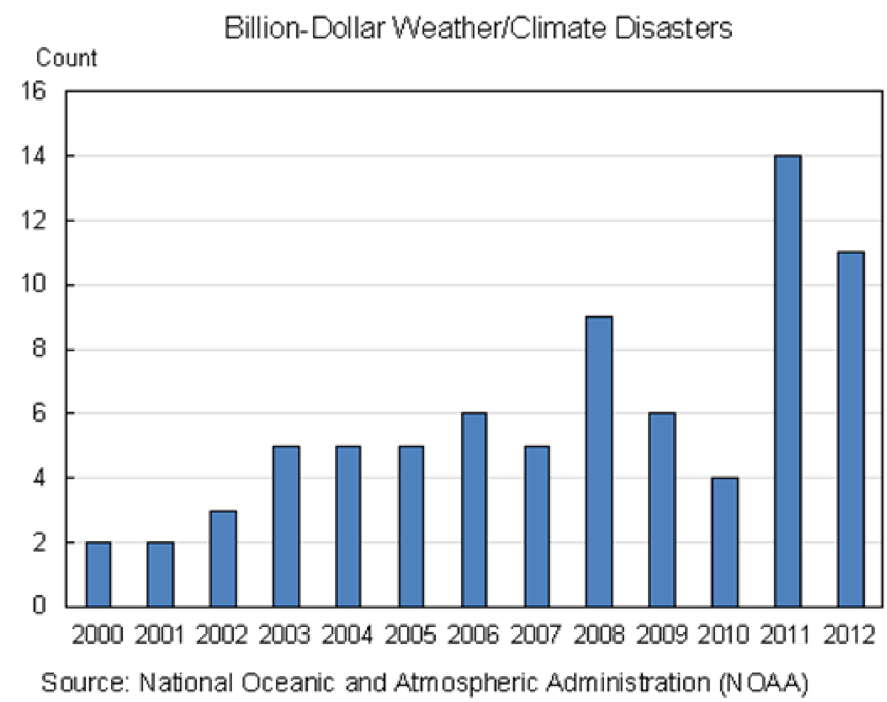

Figure 11. Billion-Dollar Disasters in the United States, 2000-2012

[23] Personal conversation with Andjelka Kelic and Kevin Stamber, Sandia Lab, National Infrastructure Simulation and Analysis Center, 17 Aug 2016

[24] http://research.dyn.com/content/uploads/2013/05/Renesys_BlackoutReport.pdf

In 2016 (as of July), there have been 8 weather related disaster events with losses exceeding $1 billion each across the United States[25]. These events included 2 flooding events and 6 severe storm events. Overall, these events resulted in the deaths of 30 people and had significant economic effects on the areas impacted. Figure 12 illustrates the root causes of business interruption[26] from natural disasters. Over 70% of business disruption from natural disasters is due to power outages.

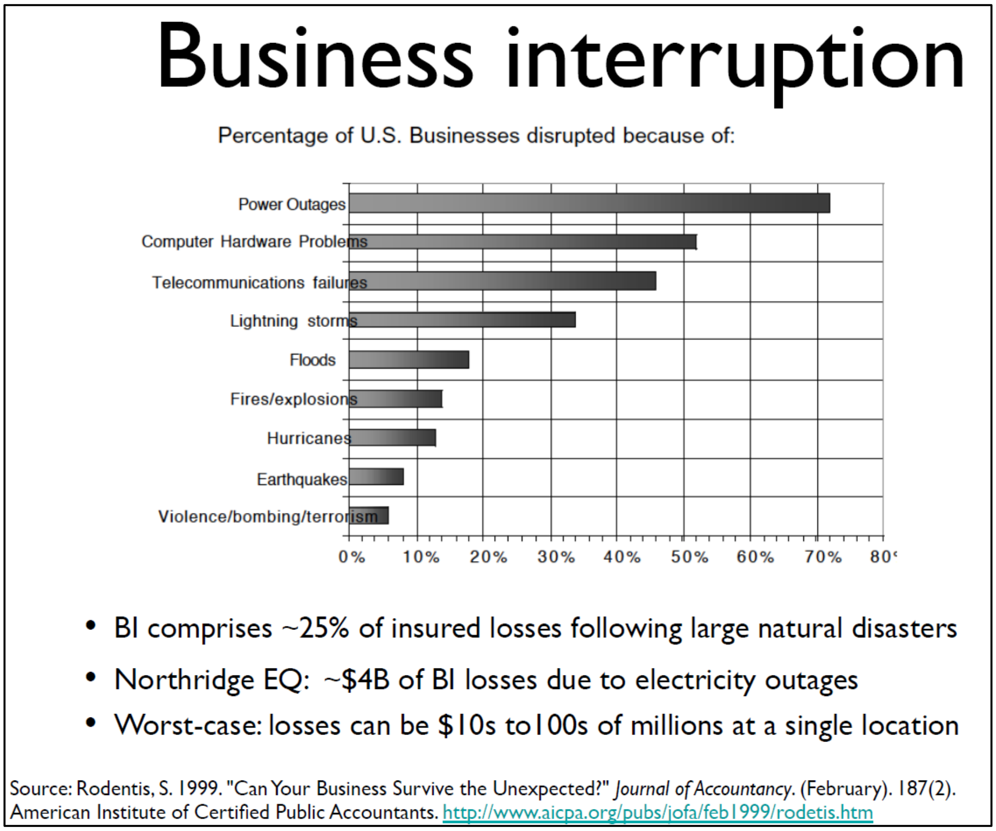

Figure 12. Characteristics of Business Interruption Induced by Natural Disasters.

4.1.2 Case Study: "Deadly Downtime: The Worst Network Outages Of 2013"[27]

This listing of Internet failures includes Amazon's major 2013 Eastern region failure, the failure in 17 states by Xerox's electronic benefit system for food stamps, short complete outages of Google, and a number of other software and hardware failures. These failures make the point that "The more we rely on technology, the more devastating it is when there's a network or systems failure." "More serious outages cause business disruptions, which can result in reduced productivity, damage to reputation, breaches in security, and lost revenue. According to network services company MegaPath, the average cost of downtime equates to $212,200 per hour -- a figure that can skyrocket for web- and network-based businesses. In August, the

[25] https://www.ncdc.noaa.gov/billions/overview

[26] http://evanmills.lbl.gov/presentations/Mills-Grid-Disruptions-NCDC-3May2012.pdf

[27] http://www.networkcomputing.com/infrastructure/deadly-downtime-worst-network-outages-2013/828373499

Amazon.com website went down for a period of 30 to 40 minutes, costing the company between $3 and $4 million."

5. ICT Outages and Service Impacts to Key Industries

Most ICT service disruptions are not grid-related, as illustrated previously. Failure of key ICT equipment such as network servers and routers, uninterruptible power supplies, and back-up power technologies are the greatest cause of ICT service disruption. This section characterizes these areas of potential risk to industries that are heavily reliant upon them.

5.1 Wireless and Wired Communications

As wireless communications technology has improved and proliferated, more and more enterprises have migrated and continue migrating away from wired phone lines for communications. This is calling into question the nation's dependence on somewhat less reliable wires technologies. For example, there is a regulatory movement underway to force wireless providers to offer some form of back-up power to their customers' wireless services to mitigate the outage times encountered in any one year. Importance of cellular communication systems during a grid outage cannot be overestimated because of the reliance of emergency services use of cellular voice and data (ICT services) during disasters.

FCC backup telecommunication power requirement[28]: requires that providers should maintain emergency backup power for a minimum of 24 hours for assets inside central offices and eight hours for cell sites. FCC's industry-based advisory group, the Communication Security, Reliability and Interoperability Council working group 9 subcommittee for backup power cell sites, recommends details for backup power requirements in their 2014 document[29]. This industry working group has recommended that the details of their document be shared with NIST which has prepared a Community Disaster Resilience Framework[30], which, in turn, includes both energy and communications sections, in addition to a wide range of other issues covered.

Industry stakeholders argue the need for backup power rules for phone lines[31]: "As consumers transition from legacy copper loops to new technologies, it is important they continue to have reasonable CPE [customer premises equipment] backup power alternatives to support minimally essential residential communications, particularly access to emergency communications, during power outages," the FCC said.

The commission tentatively proposed requiring that service providers "assume responsibility for provisioning backup power that is capable of powering their customers' CPE during the first

[28] http://njslom.org/FCC-07-177A1.pdf section 4 Page 2
[29] https://transition.fcc.gov/pshs/advisory/csric4/CSRIC_WG%209_Backup_Power_Reccomendations%20_11-24-2014.pdf
[30] youhttp://www.nist.gov/el/resilience/upload/Community-Resilience-Planning-Guide-Volume-2.pdf
[31] http://arstechnica.com/business/2015/02/internet-providers-lobby-against-backup-power-rules-for-phone-lines/

eight hours of an outage." However, the FCC said it would consider a 24-hour requirement and noted that Verizon already offers a 24-hour backup device. [32]

Not surprisingly, voice providers don't want to face any new requirements. They argue that consumers have willingly switched from copper landlines to VoIP service despite carriers being required to inform customers of the power limitations. Customers are also increasingly using cellular service instead of landlines to make voice calls, they note. [33]

> *"Mandating that providers of VoIP service provide all customers with battery backup capability would impose an unnecessary and wasteful 'battery tax' on consumers," the National Cable & Telecommunications Association (NCTA) argued in a filing last week. "The better approach is for the Commission to work with VoIP providers on identifying network best practices and assisting with consumer education to ensure that all customers have the information they need to determine how best to stay connected when the power goes out."*

What we learned from New York Stock Exchange, United Airlines Tech outages – Wall Street Journal 9 July 2015 - Quotes[34]

The Wall Street Journal covered major technology outages in July 2015. The article pointed out the strengths of the plain old telephone system (POTS) when it was run by the Bell telephone system under regulation and compares it to the current Internet-based communications which is prone to failure because of low cost components and a lack of maintenance. The quotes below emphasize these points.

> *"Say what you will about Plain Old Telephone Service (POTS), but it worked. The functionality of POTS, as it was known, was limited to making calls, and they were expensive. But many traditional phone companies offered 99.999% reliability, which allowed for about five minutes of downtime a year.*
>
> *"Today's networks are far less expensive, infinitely more capable than, and nowhere near as reliable as the wired-to-the-wall phone, as a spate of network outages on Wednesday demonstrated. The New York Stock Exchange (NYSE) halted trading, citing a technical problem. United Airlines was grounded because of an IT issue. The NYSE outage lasted about four hours, or nearly 50 years of allowable downtime using the "five nines" standard.*
>
> *"In the age of artificial intelligence, smartphones, cloud computing and robotic cars, how can this be?*
>
> *"To some extent, contemporary networks suffer from inattention. The old phone system worked so well because regulators in certain countries like the U.S. said it had to, and enough money was set aside to fund an army of technicians and engineers to oversee it. That generally isn't the case with modern, digital networks and IT infrastructure, and companies often neglect this nuts-and-bolts technology."*

[32] http://arstechnica.com/business/2015/02/internet-providers-lobby-against-backup-power-rules-for-phone-lines/
[33] http://arstechnica.com/business/2015/02/internet-providers-lobby-against-backup-power-rules-for-phone-lines/
[34] http://www.wsj.com/articles/spate-of-tech-outages-yesterday-signal-an-era-has-ended-1436464561

The problems extend beyond power supply reliability:

"That process seemed to break down at the NYSE, which issued a statement Thursday saying that customer gateways weren't properly configured for a software release, leading to communication problems with a trading unit.

In a fragmented market like finance, if one exchange or network goes down, another is supposed to pick up the slack. No single network bears the world on its back anymore, so the pressure to be perfect isn't as high. "When I was there, if you had interruption for a second, it feels like an hour. It's an eternity," said former NYSE Euronext CIO Steve Rubinow, now CTO at data-marketing firm Catalina.

Underneath it all, the economics of falling prices carry a trade-off. Consumers get more for their money in the mobile, digital era, but that often leaves margin-stretched companies with fewer resources to invest in robustness and maintenance. Reliability is as much a function of business and risk management as it is about tech.

"I don't know if people are sweating that detail as much as they used to," said Mr. Bayer, previously CIO of the Securities and Exchange Commission."

5.2 Internet Service

A recent PNNL study[35] concluded that the recent trends in the utility industry suggest an even tighter coupling of interdependence between electric and ICT infrastructure networks in coming years. While cyber vulnerability must remain a focus of federal research, development, and information-sharing efforts with industry, the convergence of these networks also holds substantial promise as a platform for energy innovation, leading to potential new value streams and enhanced system resilience.

5.3 Electricity and Gas Distribution Services

The PNNL study[36] also suggests that the convergence of electricity and ICT networks holds promise as a key element of a platform for energy innovation, leading to potential new value streams and enhanced system resilience. The pace at which this convergence (see Figure 13[37]) occurs and new services and operational methods emerge, will depend on a number of factors, including regulatory structures that set the framework within which utilities and grid operators prioritize infrastructure investment decisions. As convergence increases, the risk increases that unintended consequences of failure in one domain of the converging system will affect all the others, similar to the web convergence example above.

One example of the convergence of the electric system and natural gas supply for electrical generation was the polar vortex event of 2013. The North American Electric Reliability Corporation reported on this near miss which even though only 300 MW of load was dropped, was categorized as a category five event that could have caused the loss of more than 10,000

[35] http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24643.pdf
[36] http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24643.pdf
[37] http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24152.pdf

MW of generation[38]. This report contained recommendations on how to improve the reliability situation and the PJM market changes to their bidding rules to decrease the likelihood of problems in the future. Some of the key recommendations included[32]:

- Examine and review the natural gas supply issues encountered during the event. Industry should also work with gas suppliers, markets, and regulators to quickly identify issues with natural gas supply and transportation so that appropriate actions can be developed and implemented to allow generators to be able to secure firm supply and transportation at a reasonable rate.

- Continue to improve operations management awareness of the fuel status of all generators, including improved awareness of pipeline system conditions. This might include a daily fuel inventory solicitation process, ability to dispatch plants early in anticipation of extreme winter weather, and increased communication channels with electric and gas industries during extreme events.

- Industry should review internal processes to ensure they are ready to take proactive actions to secure the waivers (market, environmental, fuel, etc.) from the appropriate entities. For example, PJM requested waivers of certain provisions of PJM's governing documents that would permit them to share certain nonpublic information with natural gas pipeline operators during the forecasted extreme weather conditions. The Federal Energy Regulatory Commission responded promptly to PJM's filing, which enabled those communications to commence quickly.

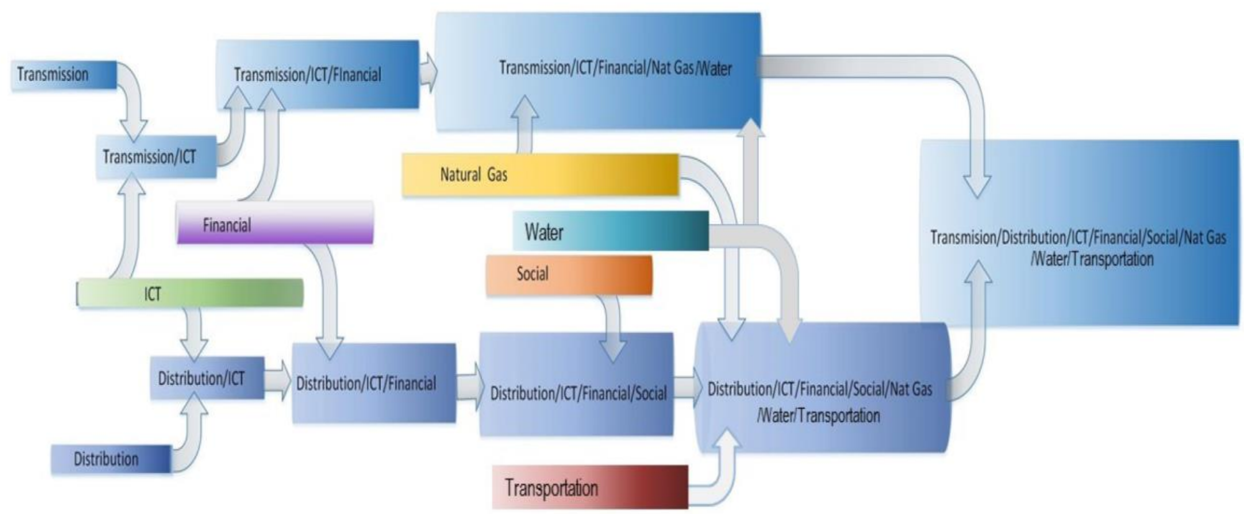

Figure 13. Network Convergence in the Electricity and Gas Industries (Source: PNNL-24152[39]). Convergence refers to the tightening of intersectoral linkages made possible by ever-improving ICT services. These tight linkages require ever more reliable and resilient power infrastructure to ensure against cascading failure from disruption in one sector tripping additional disruption in connected sectors.

38 http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf executive summary page iii

39 http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24152.pdf

5.4 Cloud Data Services

Cloud-scale data centers handle the data storage and back-up services for potentially thousands of enterprises. Many cloud service data centers today may be identified as mega data centers, having on the order of tens of thousands or more servers, drawing tens of MW of power at peak. Massive data analysis applications (e.g., computing the web search index) are a natural fit for a mega data center, where some problems require huge amounts of fast random access memory, others require massive numbers of central processing unit cycles, and still others require massive disk Input/Output band-width.

5.4.1 Case Study: Telia Outage[40]

June 2016: Global Telia Outage Disrupts Popular Internet Services: This is an example of a global network provider failing to perform and not even admitting the situation to its customers. The scope of this performance failure was global and unacknowledged, even though many customers were affected:

> *"Glitchy internet performance" on Monday, June 16, 2016, "reportedly affected a whole range of popular sites and services – from Amazon's infrastructure cloud to Reddit and Facebook's WhatsApp – and has been blamed on problems with Telia Carrier, the backbone network operator arm of the Swedish telco TeliaSonera."*
>
> *"It's unclear what caused Telia's global backbone to lose data packets traveling between five continents (North America, South America, Africa, Europe, and Asia). Some news reports have tied the outage to an error made by a Telia engineer without indicating the source of the information."*
>
> *"Packet loss on Telia's backbone has been documented in detail by one of its major customers, CloudFlare, which operates a global content delivery network (CDN). This was a second major Telia outage CloudFlare had experienced in four days, and the CDN provider's CEO took to social networks to vent his frustration over what he said was a 60-day period of subpar reliability."*
>
> *"Telia is one of the biggest global backbone operators. Its mesh of interconnected metro networks and PoPs is hosted in many data centers around the world, operated by a variety of data center providers, including Equinix, Digital Realty Trust and its subsidiary Telx, CyrusOne, Interxion."*

Such cases point out emerging realities of the impact of network failures on global commerce. Network and data center outages are the unavoidable for everybody who does business on the internet. All systems go down at some point in time, and while most customers recognize this as reality, service providers during outages are judged based on the speed of recovery and transparency.

[40] http://www.datacenterknowledge.com/archives/2016/06/21/global-telia-outage-disrupts-popular-internet-services/

6. ICT System Risk

A risk of principal concern identified in a Department of Homeland Security (DHS) baseline assessment[41] for the Internet Routing function is that a natural disaster or a manmade incident could destroy or disable a data center or telecommunications facility that houses a number of routers. A natural disaster may also damage or disable power and communications lines at or near the router facility, which could leave the routers intact, but leave them without a way to communicate with the Internet. The majority of internet and other communications outages involve isolated equipment failures, communications circuit outages, or faulty routing announcements. In the event of a natural disaster or a terrorist attack, restoring Internet routing operations may be hampered by problems accessing the routing facility, physical damage to communications lines, or getting replacement hardware, software, or routing updates.

The routers that provide an organization with connectivity to the Internet may be housed in a data center or in a telecommunications facility. Locating critical communications equipment such as routers and web servers in a number of geographically dispersed locations, and establishing processes and procedures for other locations to act as fail-over and backup operations sites, are well-established principles in data communications and telecommunications operations. These practices are fundamental elements of the resilience of the IT Sector.

The major Internet Exchange Points (IXPs), major hubs for routing Internet traffic that concentrate Internet routing and communications facilities for ISPs and carriers, can be particularly vulnerable to natural disasters, and electric power and communication outages. An IXP may have a number of local Internet Service Providers (ISPs) or Internet backbone carriers co-located to exchange Internet traffic. An IXP puts routers from a number of local, regional, and backbone carriers in the same building, where they can exchange traffic directly, instead of being in separate locations connected by high-speed communications lines.

Within the IXP, the routers can send traffic to other carriers or ISPs over high-speed local area network or direct links, avoiding the expense and potential delay of routing traffic through other parts of the Internet. The IXPs are frequently located in or near big cities, where they concentrate traffic originating from local ISPs across high-speed links to other parts of the Internet. IXPs in Europe, for example, may send traffic destined for web sites in North America directly across the Atlantic to another IXP on the East Coast, where it is re-directed to other IXPs or ISPs for delivery to its destinations.

IXP operators take many of the same precautions as data center operators to reduce their vulnerabilities. They usually have emergency power supplies and communications redundancy and diversity, and take other measures to ensure continuous operations.

The likelihood of an incident that would destroy or impair the operation of a major routing center may be fairly low, but the concentration of routing facilities in relatively few major routing centers does increase their vulnerability, as discussed in the next section.

[41] https://www.dhs.gov/xlibrary/assets/itsrm-for-internet-routing-report.pdf

6.1 ICT Disaster Recovery

The ICT networked systems and services are inherently resilient by design. The systems are designed to take advantage of the properties of networks to re-route communications around trouble spots. Service providers and carriers can recover from internet outages more quickly and with fewer problems if they have comprehensive recovery plans in place. Most reputable organizations have recovery plans, but the risk is whether those plans incorporate recovery processes for recent software updates or changes that have been made in the network or its services, such as new communications pathway recovery options. Another risk to recovery planning is the extent to which recovery plans have been tested. Testing uncovers deficiencies in plans, processes, and procedures, but running full-scale tests of those plans takes time, money, and resources that some organizations may not be willing or able to commit.[42]

In our interconnected, networked world, Internet access is indispensable. Alternative power source options during Very Large Scale Events are essential. Vital facilities such as cell towers and critical data centers need to have power restored before their backup generators run out of fuel, or further restoration and emergency services efforts will be compromised. Recommendation: Electric utilities, infrastructure providers, and local communities need to work more closely together to define and update critical customer and infrastructure demands to minimize societal impacts.[43]

[42] https://www.dhs.gov/xlibrary/assets/itsrm-for-internet-routing-report.pdf

[43] https://www.naseo.org/Data/Sites/1/documents/committees/energysecurity/documents/gridwise-superstorm-sandy-workshop-report.pdf

7. Discussion and Conclusions

This report illustrates several important considerations for understanding and analyzing the ICT services industry.

1. The ICT services industry has been and continues to grow steadily, significantly outpacing the economy as a whole.

2. Key infrastructure services (e.g. air travel, freight transport, electricity and natural gas distribution, financial services, and critical health care, among others) make substantial expenditures for these services – this is a major industry in its own right.

3. The key sectors are continuing to strengthen their supply chain linkages to the ICT services industry at the relative expense of other inputs to production.

4. Households purchase nearly 10 times the ICT services that the key infrastructure services purchase – primarily for wired and wireless communication services (e.g. phone service, cable and satellite TV, and internet services.

5. As the economic and physical importance of the ICT service industry increases, so does the need for reliable and resilient electric grid services.

6. Network convergence is a two-edge sword. It is necessary to continue to harvest economic and performance efficiencies from individual industries. However, the connected system is more vulnerable to the unintended or uncontemplated consequences brought about by technology failure or human error in a specific domain of the system.

7. Unforeseen events such as natural disasters, human error, or cascading technical failures will wreak larger and larger negative impacts as network technologies become more tightly linked and interdependent with the key services highlighted in this study.

8. Even with ever-progressing network convergence, ICT Services are inherently resilient by design. As such, they are able to survive catastrophic events, realizing less damage than other fixed infrastructure.

Appendix A
ICT Economic Reliance Subsector Detail

Table A1. Key Industry Reliance on ICT Services (2008 and 2014)* by Service: Other computer related services, including facilities management services.

Other computer related services, including facilities management services	2008 Expenditures	2014 Expenditures	2008 Output[1]	2014 Output[1]	2008 Input Fraction[2]	2014 Input Fraction[2]	Change in Annual Expenditures	Annual Average Percentage Change in Expenditures	Annual Average Percentage Change in Input Fraction[3]
	$MM (2014)	$MM (2014)	$MM (2014)	$MM (2014)	Share	Share	$MM (2014)	Percent	Percent
Electric power transmission and distribution	96	49	196,296	345,601	0.000487	0.000141	(47)	-8.18%	-11.85%
Natural gas distribution	136	335	140,124	87,523	0.000971	0.003827	199	24.36%	49.02%
Air transportation	89	271	160,379	181,723	0.000558	0.001492	182	33.84%	27.91%
Rail transportation	325	162	77,009	79,666	0.004223	0.002034	(163)	-8.36%	-8.64%
Water transportation	35	9	47,011	55,485	0.000748	0.000163	(26)	-12.39%	-13.05%
Truck transportation	654	92	300,877	329,264	0.002174	0.000278	(562)	-14.33%	-14.53%
Warehousing and storage	103	176	63,788	97,791	0.001607	0.001798	73	11.92%	1.98%
Banking and Investment Services	6,326	5,014	1,306,790	1,295,503	0.004841	0.003870	(1,312)	-3.46%	-3.34%
Management of companies and enterprises	6,800	6,452	588,486	551,727	0.011556	0.011694	(349)	-0.85%	0.20%
Hospitals	1,326	2,505	599,867	727,550	0.002211	0.003442	1,178	14.81%	9.28%
Total	15,891	15,064	3,480,627	3,751,836	0.004565	0.004015	(827)	-0.87%	-2.01%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)
1 Total production including the aggregate cost of all inputs plus value added (labor, taxes, owners' investment, etc.)
2 Purchased inputs of ICT services as a fraction of total output.
3 Relative change in the proportion of ICT services used as production inputs for these industries.
* Data for 2008 and 2014 were readily available for this study. Additional data could not be acquired and analyzed in the time allotted.

Table A2. Key Industry Reliance on ICT Services (2008 and 2014)* by Service: Computer systems design services.

Computer systems design services Key Sector	2008 ICT Expenditures	2014 ICT Expenditures	2008 Output[1]	2014 Output[1]	2008 Input Fraction[2]	2014 Input Fraction[2]	Change in Annual Expenditures	Annual Average Percentage Change in Expenditures	Annual Average Percentage Change in Input Fraction[3]
	$MM (2014)	$MM (2014)	$MM (2014)	$MM (2014)	Share	Share	$MM (2014)	Percent	Percent
Electric power transmission and distribution	27	27	196,296	345,601	0.000136	0.000079	1	0.39%	-6.98%
Natural gas distribution	28	148	140,124	87,523	0.000203	0.001690	120	70.19%	122.39%
Air transportation	46	275	160,379	181,723	0.000285	0.001511	229	83.52%	71.76%
Rail transportation	454	462	77,009	79,666	0.005892	0.005802	8	0.31%	-0.25%
Water transportation	21	9	47,011	55,485	0.000437	0.000164	(11)	-9.29%	-10.42%
Truck transportation	149	99	300,877	329,264	0.000495	0.000301	(50)	-5.57%	-6.52%
Warehousing and storage	40	128	63,788	97,791	0.000635	0.001306	87	35.90%	17.62%
Banking and Investment Services	3,282	4,755	1,306,790	1,295,503	0.002512	0.003670	1,473	7.48%	7.69%
Management of companies and enterprises	4,210	9,428	588,486	551,727	0.007153	0.017088	5,219	20.66%	23.15%
Hospitals	625	2,692	599,867	727,550	0.001041	0.003701	2,068	55.17%	42.56%
Total	8,881	18,023	3,480,627	3,751,836	0.002551	0.004804	9,142	17.16%	14.71%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)
1 Total production including the aggregate cost of all inputs plus value added (labor, taxes, owners' investment, etc.)
2 Purchased inputs of ICT services as a fraction of total output.
3 Relative change in the proportion of ICT services used as production inputs for these industries.
* Data for 2008 and 2014 were readily available for this study. Additional data could not be acquired and analyzed in the time allotted.

Table A3. Key Industry Reliance on ICT Services (2008 and 2014)* by Service: Computer systems design services.

Data processing, hosting, and related services Key Sector	2008 ICT Expenditures	2014 ICT Expenditures	2008 Output[1]	2014 Output[1]	2008 Input Fraction[2]	2014 Input Fraction[2]	Change in Annual Expenditures	Annual Average Percentage Change in Expenditures	Annual Average Percentage Change in Input Fraction[3]
	$MM (2014)	$MM (2014)	$MM (2014)	$MM (2014)	Share	Share	$MM (2014)	Percent	Percent
Electric power transmission and distribution	12	166	196,296	345,601	0.000059	0.000481	155	223.13%	119.53%
Natural gas distribution	14	53	140,124	87,523	0.000096	0.000600	39	48.08%	86.98%
Air transportation	33	675	160,379	181,723	0.000204	0.003716	643	328.16%	287.66%
Rail transportation	17	-	77,009	79,666	0.000217	0.000000	(17)	-16.67%	-16.67%
Water transportation	30	-	47,011	55,485	0.000637	0.000000	(30)	-16.67%	-16.67%
Truck transportation	109	31	300,877	329,264	0.000361	0.000094	(77)	-11.89%	-12.31%
Warehousing and storage	24	38	63,788	97,791	0.000380	0.000391	14	9.64%	0.49%
Banking and Investment Services	1,165	27,515	1,306,790	1,295,503	0.000891	0.021239	26,350	377.02%	380.45%
Management of companies and enterprises	1,175	6,301	588,486	551,727	0.001997	0.011420	5,126	72.70%	78.65%
Hospitals	236	2,067	599,867	727,550	0.000393	0.002841	1,831	129.57%	103.90%
Total of Key Industries	2,813	36,846	3,480,627	3,751,836	0.000808	0.009821	34,033	201.67%	185.89%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)
1 Total production including the aggregate cost of all inputs plus value added (labor, taxes, owners' investment, etc.)
2 Purchased inputs of ICT services as a fraction of total output.
3 Relative change in the proportion of ICT services used as production inputs for these industries.
* Data for 2008 and 2014 were readily available for this study. Additional data could not be acquired and analyzed in the time allotted.

Table A4. Key Industry Reliance on ICT Services (2008 and 2014)* by Service: Satellite, telecommunications resellers, and all other telecommunications.

Satellite, telecommunications resellers, and all other telecommunications	2008 ICT Expenditures	2014 ICT Expenditures	2008 Output[1]	2014 Output[1]	2008 Input Fraction[2]	2014 Input Fraction[2]	Change in Annual Expenditures	Annual Average Percentage Change in Expenditures	Annual Average Percentage Change in Input Fraction[3]
	$MM (2014)	$MM (2014)	$MM (2014)	$MM (2014)	Share	Share	$MM (2014)	Percent	Percent
Electric power transmission and distribution	15	2	196,296	345,601	0.000079	0.000004	(14)	-15.04%	-15.74%
Natural gas distribution	3	7	140,124	87,523	0.000022	0.000082	4	21.74%	44.83%
Air transportation	114	43	160,379	181,723	0.000709	0.000239	(70)	-10.31%	-11.06%
Rail transportation	6	15	77,009	79,666	0.000075	0.000187	9	26.06%	24.64%
Water transportation	17	15	47,011	55,485	0.000372	0.000269	(3)	-2.45%	-4.62%
Truck transportation	137	58	300,877	329,264	0.000456	0.000178	(79)	-9.56%	-10.17%
Warehousing and storage	16	29	63,788	97,791	0.000255	0.000299	13	13.31%	2.88%
Banking and Investment Services	1,549	363	1,306,790	1,295,503	0.001185	0.000280	(1,186)	-12.76%	-12.73%
Management of companies and enterprises	981	181	588,486	551,727	0.001666	0.000329	(799)	-13.59%	-13.38%
Hospitals	260	128	599,867	727,550	0.000434	0.000176	(132)	-8.47%	-9.91%
Total of Key Industries	3,099	842	3,480,627	3,751,836	0.000890	0.000224	(2,257)	-12.14%	-12.47%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)
1 Total production including the aggregate cost of all inputs plus value added (labor, taxes, owners' investment, etc.)
2 Purchased inputs of ICT services as a fraction of total output.
3 Relative change in the proportion of ICT services used as production inputs for these industries.
* Data for 2008 and 2014 were readily available for this study. Additional data could not be acquired and analyzed in the time allotted.

Table A5. Key Industry Reliance on ICT Services (2008 and 2014)* by Service: Wireless telecommunications (except satellite).

Wireless telecommunications (except satellite)	2008 ICT Expenditures	2014 ICT Expenditures	2008 Output[1]	2014 Output[1]	2008 Input Fraction[2]	2014 Input Fraction[2]	Change in Annual Expenditures	Annual Average Percentage Change in Expenditures	Annual Average Percentage Change in Input Fraction[3]
	$MM (2014)	$MM (2014)	$MM (2014)	$MM (2014)	Share	Share	$MM (2014)	Percent	Percent
Electric power transmission and distribution	94	32	196,296	345,601	0.000481	0.000093	(62)	-11.00%	-13.45%
Natural gas distribution	19	69	140,124	87,523	0.000136	0.000792	50	43.90%	80.30%
Air transportation	693	310	160,379	181,723	0.004323	0.001708	(383)	-9.21%	-10.08%
Rail transportation	35	10	77,009	79,666	0.000460	0.000130	(25)	-11.78%	-11.95%
Water transportation	107	336	47,011	55,485	0.002267	0.006056	229	35.88%	27.85%
Truck transportation	836	1,161	300,877	329,264	0.002780	0.003527	325	6.48%	4.48%
Warehousing and storage	99	560	63,788	97,791	0.001553	0.005724	461	77.51%	44.76%
Banking and Investment Services	9,448	6,921	1,306,790	1,295,503	0.007230	0.005343	(2,526)	-4.46%	-4.35%
Management of companies and enterprises	5,981	4,006	588,486	551,727	0.010163	0.007261	(1,975)	-5.50%	-4.76%
Hospitals	1,587	2,089	599,867	727,550	0.002646	0.002872	502	5.28%	1.42%
Total of Key Industries	18,900	15,496	3,480,627	3,751,836	0.005430	0.004130	(3,404)	-3.00%	-3.99%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)

1 Total production including the aggregate cost of all inputs plus value added (labor, taxes, owners' investment, etc.)

2 Purchased inputs of ICT services as a fraction of total output.

3 Relative change in the proportion of ICT services used as production inputs for these industries.

* Data for 2008 and 2014 were readily available for this study. Additional data could not be acquired and analyzed in the time allotted.

Table A6. Key Industry Reliance on ICT Services (2008 and 2014)* by Service: Wired telecommunications.

Wired telecommunications	2008 ICT Expenditures	2014 ICT Expenditures	2008 Output[1]	2014 Output[1]	2008 Input Fraction[2]	2014 Input Fraction[2]	Change in Annual Expenditures	Annual Average Percentage Change in Expenditures	Annual Average Percentage Change in Input Fraction[3]
	$MM (2014)	$MM (2014)	$MM (2014)	$MM (2014)	Share	Share	$MM (2014)	Percent	Percent
Electric power transmission and distribution	154	11	196,296	345,601	0.000786	0.000032	(143)	-15.49%	-16.00%
Natural gas distribution	31	40	140,124	87,523	0.000223	0.000452	8	4.47%	17.17%
Air transportation	1,134	470	160,379	181,723	0.007068	0.002584	(664)	-9.76%	-10.57%
Rail transportation	58	1	77,009	79,666	0.000752	0.000013	(57)	-16.38%	-16.39%
Water transportation	174	332	47,011	55,485	0.003707	0.005979	157	15.06%	10.22%
Truck transportation	1,367	888	300,877	329,264	0.004545	0.002696	(480)	-5.85%	-6.78%
Warehousing and storage	162	526	63,788	97,791	0.002539	0.005375	364	37.43%	18.62%
Banking and Investment Services	15,446	7,237	1,306,790	1,295,503	0.011820	0.005586	(8,209)	-8.86%	-8.79%
Management of companies and enterprises	9,778	3,792	588,486	551,727	0.016616	0.006873	(5,986)	-10.20%	-9.77%
Hospitals	2,595	2,800	599,867	727,550	0.004325	0.003849	206	1.32%	-1.84%
Total of Key Industries	30,899	16,096	3,480,627	3,751,836	0.008878	0.004290	(14,804)	-7.98%	-8.61%

Source: Derived from IMPLAN Database (IMPLAN 2010, 2016)

1 Total production including the aggregate cost of all inputs plus value added (labor, taxes, owners' investment, etc.)

2 Purchased inputs of ICT services as a fraction of total output.

3 Relative change in the proportion of ICT services used as production inputs for these industries.

* Data for 2008 and 2014 were readily available for this study. Additional data could not be acquired and analyzed in the time allotted

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